WORLD RESOURCES INSTITUTE

WORKING PAPER

TOWARD CREDIBLE TRANSPORT CARBON DIOXIDE EMISSIONS ACCOUNTING IN CHINA

LULU XUE AND DAIZONG LIU

EXECUTIVE SUMMARY

Highlights

- If China is to achieve its targets of reaching peak carbon dioxide (CO_2) emissions before 2030 and carbon neutrality before 2060, official transport emissions inventories and emissions-reduction targets will be necessary—at all levels of government from a base year—to monitor decarbonization progress and hold the government to account.
- This paper examines existing accounting methods and statistical data used by China's national and subnational governments. By comparing transport emissions estimates using different accounting methods, this study reveals that current top-down and bottom-up accounting methods are uncertain and do not correctly align responsibility for producing emissions with responsibility to mitigate them, especially when used to quantify subnational transport emissions.
- The top-down accounting method is appropriate for developing national transport emissions inventories, but transport fuel consumption statistics in China are incomplete.
- Whenever necessary, a bottom-up accounting method, using reliable data inputs, should be used in concert with the top-down method to derive emissions breakdowns and inform transport climate action planning.
- Emissions from aviation, railways, and water navigation should be allocated to the responsible corporations.

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Suggested Citation: Xue, Lulu, and Daizong Liu. 2022. "Toward Credible Transport Carbon Dioxide Emissions Accounting in China" Working Paper. World Resources Institute, Beijing. Available online at https://doi.org/10.46830/wriwp.22.00015en.

Context

China is developing a policy package to reach its targets of peaking carbon dioxide (CO_2) emissions before 2030 and reaching carbon neutrality before 2060. However, at present, transport sector–wide emissions-reduction targets have not been set and official subnational transport emissions inventories are not required, which will make it difficult for different levels of government to understand the magnitude of transport emissions, identify major emissions sources, monitor decarbonization progress over time, and hold these governments to account.

About This Paper

To help unify the transport emissions accounting methodologies for China's national and subnational governments and improve statistical data collection for credible transport emissions reporting, this study reviews the accounting methods and statistical data used globally and in China through a literature review and stakeholder interviews. It then employs six criteria, including data availability, estimation uncertainty, and policy relevance,[1] among others, to evaluate existing emissions accounting/allocation methods in China.

Research Findings

Although China conforms to the IPCC (1997) and IPCC (2006) guidelines for national transport inventories, this study's evaluation reveals the following:

- **Incomplete data are the primary obstacle for applying different transport emissions accounting methods in China.** Even using the top-down method, energy balances are either absent in many cities or infrequently updated.

- **There are no guidelines for how to choose which bottom-up method to use or validate the results.**

- **The top-down and bottom-up methods result in uncertain estimates when used to quantify transport emissions at the subnational level** (including provinces and cities) due to incomplete statistics on transport fuel consumption, limited data quality of bottom-up inputs like vehicle kilometers travelled, and other factors.

- **The top-down and bottom-up accounting methods misalign emissions mitigation responsibilities:** A few regions, such as Beijing, are responsible for disproportionately large shares of aviation and water navigation emissions that don't correspond with their mitigation responsibilities.

This study recommends the following:

- **Official transport emissions inventories should be required for subnational governments and be annually updated from a base year.**

- **The China-specific issue of incomplete transport fuel consumption statistics should be fixed.** Comprehensive fuel sale statistics should be collected and verified with a quality assurance and quality control (QA/QC) procedure. The tabular structure of energy balances should be refined to subsectors and be consistent with the Enhanced Transparency Framework's common reporting tables, which will become effective in 2024 (UNFCCC 2019). The frequency of fuel sales data collection should be increased, and enforcement of the regulations regarding illegal fuel stations, refineries, and fuel blenders should be tightened (MOFCOM 2020).

- **Whenever necessary, a bottom-up method with reliable inputs should be used to derive emissions breakdowns and inform transport climate action planning.** To this end, different levels of government need to periodically collect statistics such as vehicle kilometers travelled.

- **Emissions from aviation, railways, and water navigation should be allocated to the responsible corporations** because these businesses (especially state-owned enterprises) have more discretion and resources to mitigate their emissions than do subnational governments.

- **Administrative safeguards should be put in place** by updating relevant emissions accounting guidelines, developing data platforms, building capacities on data collection and inventory development, and establishing dedicated offices or personnel responsible for inventory development and validation.

1. TRANSPORT EMISSIONS IN CHINA: BACKGROUND

China's transport greenhouse gas (GHG) emissions have experienced rapid increases—2014 transport GHG emissions grew by 148 percent from the 2001 level (NDRC 2004; MEE 2018a). According to Climate Watch (2020), in 2018, China's transport GHG emissions accounted for 11.1 percent of the world's transport GHG emissions, following only the United States (21.3 percent) and the European Union plus the United Kingdom (UK) (11.2 percent).

Growth in transport CO_2 emissions in Chinese provinces and cities is also notable. For example, transport CO_2 emissions in Beijing and Shenzhen increased over 300 percent from 2001 to 2014, becoming the largest source of emissions in the cities (CEADS n.d.).

To ensure China can meet its target of peaking CO_2 emissions before 2030, both the national and subnational governments are developing sectoral emission-peaking action plans. However, in these plans, the decarbonization targets are in the form of emissions intensity reductions for specific subsegments; a transport sector–wide target (either in absolute or relative terms) is absent (Table 1). Because of a lack of relevant statistics, subnational governments have difficulty setting their emissions-reduction targets following national practice. Further, subnational governments are also not yet required to report transport emissions inventories to track their decarbonization progress against these targets (Pers. Comm. 2022a).

In fact, robust transport emissions inventories are crucial for all levels of government to be able to evaluate the current magnitude of transport emissions, identify major emissions sources, establish sectoral emissions-reduction targets, and monitor decarbonization progress over time. They will also help the national government benchmark subnational governments' performances and hold them accountable. Consistent transport emissions inventories are also needed to improve the overall national inventory so China can meet the new United Nations Framework Convention on Climate Change (UNFCCC) reporting

Table 1 | **Transport Emissions-Reduction Targets in National and Regional Carbon-Peaking Action Plans**

	ABSOLUTE EMISSIONS REDUCTION	EMISSIONS INTENSITY REDUCTION	EMISSIONS REDUCTION BELOW A BASELINE	PEAKING YEAR
National level[a]				
Carbon emissions intensity of ***operating vehicles*** reduced by 9.5% in 2030 compared with 2020		✓		
Energy consumption of ***national railways*** per unit of converted turnover reduced by 10% in 2030 compared with 2020		✓		
Oil consumption by ***land transport*** peaks by 2030				✓
Subnational level[b]				
Jiangxi Province:[c] Carbon emissions intensity of operating vehicles reduced by 10% in 2030 compared with 2020		✓		
Shanghai:[d] Carbon emissions intensity of ***operating vehicles*** reduced by 9.5% in 2030 compared with 2020		✓		

Notes: Targets are adapted from UNFCCC (2019).
[a] NDRC 2021.
[b] The examples listed here are for illustrative purposes.
[c] PGoJP 2022.
[d] SMPG 2022.

requirement under the Paris Agreement—the Enhanced Transparency Framework (ETF). ETF requires, starting in 2024, that all parties shall report a consistent annual national inventory of anthropogenic GHG emissions and removals on a biennial basis (UNFCCC 2019) as opposed to current relatively ad hoc inventory reporting practices.

China's lack of transport sector–wide emissions targets and decarbonization accountability mechanisms is due mainly to two factors:

First, as in many emerging economies, China lacks a fully fledged statistical system to support reliable transport target setting and emissions reporting. Many necessary inputs for transport emissions estimations (such as transport fuel sales) are absent in the current statistical system. As a result, uncertainties in transport emissions are large.

Second, China does not yet have agreed upon methods to quantify subnational transport emissions and allocate emissions of transboundary trips. Different allocation approaches result in large variations in subnational transport emissions estimates. For example, in Hong Kong, when including transboundary aviation emissions, city-level total GHG emissions increase by 25 percent (Harris et al. 2012). The variations in local transport emissions not only cause disputes among local governments, but also deter them from declaring more ambitious emissions-reduction targets.

Approach and Methodology

To address these challenges, our research aims to provide recommendations to help unify the transport emissions accounting methodologies for China's national and subnational governments and improve the country's statistical data system. The ultimate objectives of transport emissions accounting include the following:

- Help policymakers at all levels understand the magnitude of GHG emissions, project emissions trajectories, set sectoral emissions-reduction targets, regularly track decarbonization progress over time, and hold different levels of government to account for their decarbonization commitments
- Determine significant sources of GHG emissions (such as roadways or aviation) to target actions
- Inform the creation of decarbonization policies and resource prioritization

For simplicity, other objectives such as increasing climate finance are not considered in this study.

To achieve these research objectives, this study investigates transport emissions accounting methods and statistical data used globally and in China through a literature review and interviews with stakeholders from a dozen cities and provinces.[2] Using an evaluation

Box 1 | The Scope of Transport Emissions in This Study

Non-CO_2 GHG emissions from the transport sector: For China's near-term goal of peaking emissions before 2030, emissions refer to CO_2 emissions; for the long-term goal of achieving carbon neutrality in 2060, emissions refer to all GHG emissions, including CO_2, methane (CH_4), and nitrous oxide (N_2O).

This study addresses the near-term scope—focusing only on CO_2 emissions. Of note, the accounting methods for CH_4 and N_2O emissions differ from those for CO_2 emissions,[a] where deployment of vehicle aftertreatment devices, vehicle age, and driving conditions are considered. The exclusion of non-CO_2 GHG emissions in this study does not significantly impact our transport emissions estimations because CH_4 and N_2O emissions represent about 1 percent of China's transport GHG emissions.[b]

Emissions from transport infrastructure construction and operation: According to the National Development and Reform Commission in China, China's transport decarbonization efforts also include reducing emissions from construction, operations, and maintenance of transport infrastructure (NDRC 2021).

Because existing accounting methodologies (see Section 2) do not account for emissions from transport infrastructure construction and operations, these emissions are not included in this study. Interested readers can refer to community-wide infrastructure footprint methodologies for quantifying life-cycle emissions from in-boundary or transboundary transport infrastructure.[c]

Notes: [a] IPCC 2006. [b] MEE 2018b. [c] Ramaswami et al. 2008.

Table 2 | **Scope of This Study**

	INCLUDED IN THIS STUDY	EXCLUDED FROM THIS STUDY
Geographic scopes of transport emissions	• National territories • Provincial territories • Municipal territories	• Infrastructure investment projects (like metro investments) • Corporations
Upstream or downstream emissions	• Vehicle operations	• Upstream emissions of fossil/biofuels, electricity, and hydrogen • Vehicle manufacturing • Vehicle/battery disposal • Infrastructure construction and operation
Coverage of transport subsectors	Domestic transport such as the following: • Road transport • Railway • Water navigation • Aviation • Off-road transport	International transport such as aviation and shipping
Types of GHG emissions	• CO_2	• CH_4 • N_2O • HFC
Objectives of emissions accounting	• Estimate emissions, track decarbonization progress, benchmark performance • Identify sources of emissions and craft mitigation interventions	• Leverage climate finance • Coordinate efforts on GHG and air pollutant emissions reductions • Evaluate international aviation and maritime emissions

Notes: Abbreviations: GHG = greenhouse gas; CO_2 = carbon dioxide; CH_4 = methane; N_2O = nitrous oxide; HFC = hydrofluorocarbon.

Source: Authors' summary.

framework of criteria including data availability, estimation uncertainty, and policy relevance, among others, the study compares transport emissions estimated under different accounting methods, and evaluates these methods' applicability to China. We provide short- and long-term recommendations for improving the statistical data system and accounting methods.

The scope of this study is outlined in Table 2. Of note, this study conforms to the *Revised IPCC [Intergovernmental Panel on Climate Change] Guidelines for National Greenhouse Gas Inventories* (IPCC 1997) and the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) (the "IPCC 1996 and 2006 Guidelines"), where transport's upstream emissions—including electricity generation and hydrogen production emissions—are counted toward the power and industrial sectors.

2. REVIEW OF EXISTING ACCOUNTING METHODOLOGIES

Many methods are available to calculate transport CO_2 emissions.

2.1 Global Methodologies

This section reviews global transport emissions accounting methods, with a focus on the following:

- The IPCC 1996 and 2006 Guidelines (IPCC 1997, 2006)
- The *Global Protocol for Community-Scale Greenhouse Gas Inventories* (referred to as "the GPC") (WRI et al. 2014)

Although some developed cities employ PAS 2070 *Specification for the Assessment of Greenhouse Gas Emissions of a City* (referred to as the "PAS 2070") to estimate consumption-based transport emissions (see Appendix A; BSI 2013), this methodology is not discussed in this study due to its limited applicability to emerging economies.

IPCC 1996 and 2006 Guidelines

The IPCC 1996 and 2006 Guidelines provide guidance for countries as they develop national GHG inventories to fulfill their reporting obligations under the UNFCCC framework. The IPCC 2006 Guidelines are an updated version of the 1996 Guidelines.

Currently, only Annex I Parties (primarily Organisation for Economic Co-operation and Development countries) are required to report national inventories annually using the IPCC 2006 Guidelines, while non-Annex I Parties (including China) can report their national inventories less frequently, using the IPCC 1996 Guidelines (UNFCCC 2012). However, starting in 2024, the Paris Agreement's ETF requires that all parties shall report annual national inventories every two years—using the 2006 IPCC Guidelines and common reporting tables (see Table 3; UNFCCC 2019).

For the transport sector, the IPCC 1996 and 2006 Guidelines proposed tiers of methods to evaluate country-level transport emissions: The 1996 Guidelines introduced the Tier 1 and Tier 2 methods, while the 2006 Guidelines updated the Tier 2 method and added a Tier 3 method (for non-CO_2 GHG emissions calculations) (Tanabe 2016). Among the tiers, national transport emissions for road transport, railway, and water navigation are best calculated with the top-down method using fuel sale statistics, that is, the Tier 1 and 2 methods (IPCC 2000, 2006) (Table 4), where fuel sales are obtained from the national energy balance—a statistical accounting system that documents the sources, transformation, and end users of energy products.

Notably, national-level transport emissions cover only domestic emissions, and emissions from international maritime and aviation[3] are reported as "memo items." Because of the ambiguous accountability for international shipping and aviation emissions, some studies recommend that the Paris Agreement include international shipping and aviation emissions as national responsibilities to accelerate the decarbonization of both (Lee 2018; Rayner 2021). The UK even announced that emissions from international aviation and shipping will be included in its sixth national carbon budget starting in 2033 (UK CCC 2020). Therefore, in the future, international shipping and aviation emissions will possibly be included in national emissions accounting.

Table 3 | **Changes in Inventory Reporting for Non-annex I Parties before and after 2024**

	TIME INTERVAL	LATEST REPORTING YEAR	GUIDELINES	TIME-SERIES CONSISTENCY
Before 2024	Unspecified	Four years prior to submission	IPCC 1996 Guidelines	Unspecified for biannual update reports
After 2024	Annual inventories	Three years prior to submission (2020–21 inventories upon 2024 submission)	IPCC 2006 Guidelines and common reporting tables	Recalculation from the starting year (2005 in China's case) and all subsequent years

Notes: IPCC 1996 Guidelines refer to IPCC (1997) and IPCC 2006 Guidelines refer to IPCC (2006).

Source: Authors' summary based on UNFCCC (1996, 2012, 2019).

Table 4 | **Methods for Estimating Transport Carbon Dioxide Emissions in the IPCC 2006 Guidelines**

	TIER 1	TIER 2	TIER 3
Road transport	**2nd option**[a] $\sum_a (Fuel_a \times EF_{a\_Default})$ Where, $Fuel_a$ is the fuel consumption of fuel type a $EF_{a\_Default}$ is the IPCC default CO_2 emission factor	**1st option** $\sum_a (Fuel_a \times EF_{a\_CS})$ Where, $Fuel_a$ is the fuel consumption of fuel type a EF_{a_CS} is the country-specific CO_2 emission factor	None
Railway	**2nd option** $\sum_a (Fuel_a \times EF_{a\_Default})$	**1st option** $\sum_a (Fuel_a \times EF_{a\_CS})$	None
Water navigation[b]	**2nd option** $\sum_a (Fuel_a \times EF_{a\_Default})$	**1st option** $\sum_{a,b} (Fuel_{a,b} \times EF_{a,b\_CS})$ Where, $Fuel_{a,b}$ is the fuel consumption of fuel type *a* and engine type *b* EF_{a,b_CS} is the country-specific CO_2 emission factor	None
Aviation	**3rd option** $\sum_a (Fuel_a \times EF_{a\_Default})$	**2nd option**[c] *LTO emissions + cruise emissions* *LTO emissions = number of LTOs × Emission factor_LTOs* *Cruise emissions = (totalFuelconsumption-LTOFuelconsumption) × Emission factor_Cruise*	**1st option** Estimated aviation emissions based on flights' origins and destinations (Tier 3A), or flights' movements and trajectories (Tier 3B).
Off-road transport	**3rd option** $\sum_a (Fuel_a \times EF_{a\_Default})$	**2nd option** $\sum_{a,b} (Fuel_{a,b} \times EF_{a,b\_CS})$	**1st option** $\sum (N_{ab} \times H_{ab} \times P_{ab} \times LF_{ab} \times EF_{ab})$ Where, N_{ab} is the population H_{ab} is the annual hours of operation P_{ab} is the average rated power LF_{ab} is the load factor

Notes: Abbreviations: IPCC = Intergovernmental Panel on Climate Change; IPCC 2006 Guidelines refer to IPCC 2007; CO_2 = carbon dioxide; GHG = greenhouse gas; EF = emission factor for carbon dioxide; CS = country specific; LTO = landing and takeoff.

[a] The first option indicates the method that is preferred per IPCC (2006) whenever data inputs are available. The second and third options are recommended when the data for the first option are not available.

[b] Shipment movement data should be used to differentiate emissions between domestic shipping and international shipping.

[c] The calculation is applicable to only jet fuel. Further, the number of LTOs include only domestic flights.

Source: Authors' summary based on IPCC (2006).

The GPC

The GPC builds upon the IPCC guidelines and offers local governments detailed frameworks to calculate urban transport emissions.

Besides the top-down method, the GPC also recommends using bottom-up methods to estimate subnational transport emissions and carry out climate action planning (see Box 2).

Box 2 | Types of Bottom-Up Methods

Bottom-up methods estimate transport emissions based on transport activities, like vehicle kilometers travelled (VKTs), passenger kilometers (pkm), freight tonne-kilometers (tkm), operating hours for off-road machinery equipment, and flight landing and takeoff (LTO) cycles.

Depending on activities, the bottom-up methods can be classified as the following:

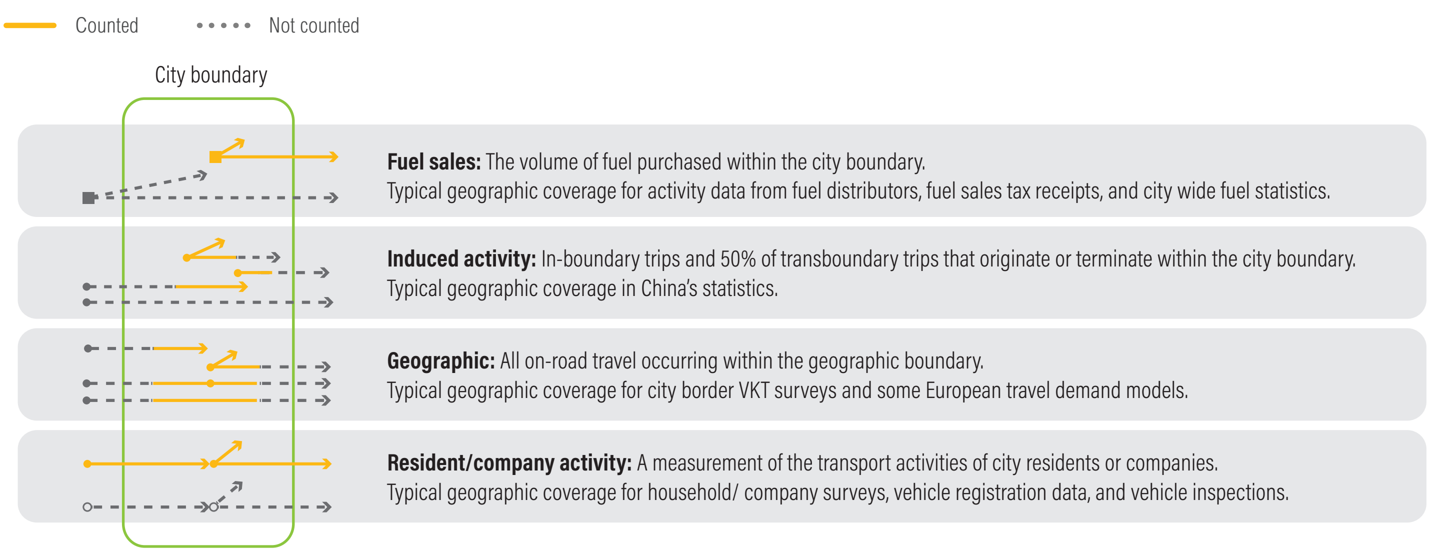
- The vehicle/bunker method: Transport emissions are estimated based on fleet composition, VKTs (or operating hours), and fuel efficiency.
- The pkm/tkm method: Transport emissions are estimated based on pkm/tkm and fuel efficiency per pkm/tkm.
- The LTO method: Aviation emissions are estimated based on flights' LTOs.

Further, the GPC provides different approaches to allocate emissions from transboundary trips (WRI et al. 2014). Subnational transport CO_2 emissions (except from off-road machinery) involve emissions from transboundary trips. How the emissions are attributed to different places is critical to accurately calculating subnational emissions. To this end, the GPC outlines four allocation approaches (Figure 1):

- For the top-down method:
  1. **Fuel sales by local distributors:** Allocation according to the region where transport fuel is sold.
- For the bottom-up methods:
  2. **Induced activity:** Allocation to both the trips' origins and destinations by splitting the emissions in half. Alternatively, allocation of departing trips' emissions to the trips' origins. Through-traffic emissions are not included.
  3. **Geographic:** Allocation to the region where the emissions were generated. The method includes emissions from transport activities occurring within the region's boundary, regardless of the origin or destination. Through-traffic emissions[4] are also included.
  4. **Resident activity:** Allocation to the registered locations of vehicles/bunkers (or the residency of passengers).

The GPC prescribes no standard approach for allocating transboundary emissions. It recommends that subnational

Figure 1 | Illustration of the GPC's Allocation Approaches



Source: WRI et al. 2014.

governments choose a method fitting the local context based on data availability and inventory objectives (Appendix B). However, the GPC's high degree of flexibility makes it difficult to compare decarbonization progress across regions if allocation methods vary.

2.2 China's Methodologies

In China, the IPCC 1996 Guidelines were used to develop the 1994, 2005, and 2010 national emissions inventories (NDRC 2004, 2012, 2016) and the IPCC 2006 Guidelines were employed to develop the 2012 and 2014 national emissions inventories (MEE 2018a, 2018b) (Table 5).

At the provincial level, based on the IPCC Guidelines, the *Guidelines for the Development of Provincial-Level GHG Emission Inventories (Trial Version)* (NDRC 2011) and the *Guidelines on the Development of Provincial Carbon Emission Peak Action Plans (Consultation Version)* (MEE 2021) (together referred to as the "Provincial Guidelines") are used to shepherd the development of subnational emissions inventories using the top-down method.

Although the use of the Provincial Guidelines is voluntary, they are widely adopted by provinces (Shan et al. 2017).

Further, to support climate action planning and derive transport emissions breakdowns, bottom-up methods are also employed. Unlike the top-down method, no guidelines were developed for the bottom-up methods. As a result, provinces (and cities) adopt different allocation approaches and emissions scopes to quantify transport emissions using the bottom-up methods. For example, some provinces employ the resident activity approach to allocate transboundary emissions, while other provinces use the geographic method (Pers. Comm. 2022b).

At the city level, the adoption of inventory methods is more diverse. Although energy balances are required for provinces, they are not required for cities—only large cities like provincial capitals compile energy balances on a regular basis (Shan et al. 2017). Due to the lack of energy balances, the top-down Provincial Guidelines are no longer the primary method used; bottom-up methods are equally common (Shan et al. 2017; Jiang et al. 2019; Shan et al. 2021; Pers. Comm. 2022b).

Table 5 | **Transport Carbon Dioxide Emissions Accounting Practices in China**

	GUIDELINES	DATA SOURCES	INVENTORIES
National level	• IPCC 1996 Guidelines (Tier 1 method)[a,b,c,d]	• National energy balance	National inventory 1994,[b] 2005,[c] 2010[d]
	• IPCC 2006 Guidelines (Tier 2 method)[e,f]		National inventory 2012[e] and 2014[f]
Provincial and city levels	• Top-down method: Provincial Guidelines[g]	• Provincial energy balances • Municipal energy balances (only for large cities)	X[h] (Subnational governments have no obligation to report transport inventories regularly or publicly)
	• Bottom-up methods: No official guidelines	• Statistical yearbooks and data from GPS, access surveillance, and others	

Notes: Abbreviations: IPCC = Intergovernmental Panel on Climate Change; IPCC 1996 Guidelines refer to IPCC (1997); IPCC 2006 Guidelines refer to IPCC (2006); Provincial Guidelines refer to NDRC (2011) and MEE (2021); X = not available; GPS = Global Positioning System.

[a] In the calculation, the IPCC default carbon content for fuels and country-specific oxidation fractions were used.
[b] NDRC 2004.
[c] NDRC 2012.
[d] NDRC 2016.
[e] MEE 2018a.
[f] MEE 2018b.
[g] NDRC 2011; MEE 2021.
[h] Pers. Comm. 2022a.

Top-Down Method

In China, following the IPCC 1996 and 2006 Guidelines, national transport emissions are estimated using the top-down method, wherein transport fuel consumption is extracted from the national energy balance. The same method is applied to calculate provincial/municipal transport emissions, following the Provincial Guidelines, provided that local energy balances are available.

However, in addition to the common global issues of fuel smuggling and illegal fuel blending that increase the uncertainty of the emission estimates using the top-down method (IPCC 2000), the top-down method faces a unique challenge in China: Transport fuel consumption statistics in the energy balance are incomplete and cover only some subsectors. For example, road transport energy statistics encompass fuel consumption from operating fleets that represented only 3.5 percent of the vehicle fleet in China in 2019 (NBS 2020). Fuel consumption from non-operating fleets such as private cars, light-duty trucks (LDTs), and some heavy-duty trucks (HDTs) are unaccounted for (State Council 2007) (Table 6). Therefore, in China's energy balance, the fuel consumption of non-operating fleets—with unknown quantities—is combined with other non-transport sectors.

To separate transport fuel consumption among the non-transport sectors, both government entities and World Resources Institute (WRI) have proposed apportioning ratios based on expert judgement and empirical evidence (Tables 7 and 8). For example, in the *Guidelines on the Development of Provincial Carbon Emission Peak Action Plans (Consultation Version)* (MEE 2021; also referred as "the Guidelines"), the national government recommended reclassifying 79 percent of gasoline and 26 percent of diesel from the industry sector to the transport sector. WRI's *Greenhouse Gas Accounting Tool for Chinese Cities* proposed apportioning ratios that are relatively larger as they consider off-road machinery and assume a higher share of transport fuel consumption (WRI 2013).

Table 6 | **Coverage of Transport Energy Statistics in China**

ENTITIES	INCLUDED IN THE ENERGY STATISTICS
Road freight	
Operators of HDTs (GVW above 4.5 tonnes)	✓
Some own-account operators of HDTs[a]	✗
Operators of LDTs (GVW below 4.5 tonnes)	✗
Road passenger	
Operators of public transit, taxis, and intercity coaches	✓
Private car owners	✗
Motorcycle owners	✗
Railway, water navigation, and aviation	
Operators for aviation, water navigation, and railways	✓
Off-road machinery[b]	
Off-road machinery operators	✗

Notes: Abbreviations: HDT = heavy-duty truck; GVW = gross vehicle weight; LDT = light-duty truck.
[a] Own-account carriers with trucks that operate in restricted premises are not included in the energy statistics.
[b] Off-road machinery includes equipment used in construction, agriculture, industry, and airport ground operations.

Source: State Council 2007.

Table 7 | **Reallocation Ratios in MEE (2021)**

		GASOLINE	DIESEL	FUEL OIL	NATURAL GAS	ELECTRICITY	KEROSENE
1	Agriculture, forestry, fisheries	80%	10%	0	0	0	0
2	Industry (excluding non-energy use)	79%	26%	0	0	0	0
3	Construction	0	0	0	0	0	0
4	Transport, storage, and post	100%	100%	100%	100%	0	100%
5	Wholesale, retail, trade, hotels	98%	0	0	0	0	0
6	Residential consumption	98%	0	0	0	0	0
7	Others	99%	95%	0	0	0	0

Source: MEE 2021.

Table 8 | **Reallocation Ratios in WRI (2013)**

		GASOLINE	DIESEL	FUEL OIL	NATURAL GAS	ELECTRICITY	KEROSENE
1	Agriculture, forestry, fisheries	97% (17%)	30% (20%)	0	0	0	0
2	Industry (excluding non-energy use)	95% (16%)	35% (9%)	0	0	0	0
3	Construction	95% (95%)	35% (35%)	0	0	0	0
4	Transport, storage, and post	100% (0%)	100% (0%)	100% (0%)	100% (0%)	95% (95%)	100% (0%)
5	Wholesale, retail, trade, and hotels	95% (-3%)	35% (35%)	0	0	0	0
6	Residential consumption	100% (2%)	95% (95%)	0	0	0	0
7	Others	95% (-4%)	35% (-60%)	0	0	0	0

Note: The percentage in parentheses indicates the difference between the WRI ratio and the MEE (2021) ratio.

Source: WRI 2013.

Bottom-Up Methods

In China, the transport subsectors employ different bottom-up methods (see Table 9):

- For road transport, both the "vehicle/bunker method" and the "pkm/tkm method" are used. However, the two methods are not employed interchangeably. The pkm/tkm method can be used to estimate emissions from only operating fleets (like HDTs) because pkm/tkm statistics have the same issue as transport fuel consumption, which is that the statistics do not cover private cars or LDTs. Therefore, to estimate road transport emissions more comprehensively, the pkm/tkm method should be complemented with the vehicle/bunker method.
- For railways, water navigation, and aviation, the pkm/tkm method is commonly used.

Table 9 | **Bottom-Up Methods by Transport Subsector and Their Adoption in China**

	VEHICLE/BUNKER METHOD	TKM/PKM METHOD	LTO METHOD
Road transport	✓✓✓[a] $\sum_i P_i \times FE_i \times VKT_i \times EF_i$ Where, P_i is the vehicle stock for vehicle segment *i* FE_i is fuel efficiency VKT_i is annual VKT EF_i is the CO_2 emission factor by fuel type	✓✓✓ $\sum_i PKM_i \times FE_{pkm,i} \times EF_i$ $\sum_i TKM_i \times FE_{tkm,i} \times EF_i$ Where, $FE_{pkm,i}$ and $FE_{tkm,i}$ are fuel efficiency per pkm and tkm, respectively EF_i is CO_2 emission factor by fuel type	N/A
Railway	✓ $\sum_i N_i \times H_i \times P_i \times LF_i \times EF_i$ Where, P_i is the number of locomotives of type *i* H_i is annual hours of operation Pi is average rated power of locomotive *i* LF_i is load factor of locomotive *i* EF_i is the CO_2 emission factor	✓✓✓ (Same equation as above)	N/A
Water navigation	✓✓ $E_{hoteling} + E_{manouvering} + E_{cruisng}$ For each trip phase: $E_{trip,e,p,j} = \sum_p H_p \times \sum_e (P_e \times LF_e \times EF_{e,p,j})$ Where, H_p is annual operation hours of engines by trip phase *p* P_e is nominal power by engine category *e* LF_i is the load factor by engine category *e* EF_i is the CO_2 emission factor per trip phase *p*, engine category *e*, and fuel type *j*	✓✓✓ (Same equation as above)	N/A
Aviation	N/A	✓✓✓ (Same equation as above)	✓✓ (See the tier 2 method in Section 2.1)
Off-road machinery	✓✓✓ $\sum_i P_i \times FE_i \times VKT_i \times EF_i$ (mobile sources) or $\sum_{ab} (N_{ab} \times H_{ab} \times P_{ab} \times LF_{ab} \times EF_{ab})$ (stationary sources) Where, *a* is fuel type *b* is equipment type N_{ab} is population H_{ab} is annual hours of operation P_{ab} is average rated power LF_{ab} is load factor	N/A	N/A

Notes: Abbreviations: N/A = not applicable; tkm = freight tonne-kilometers; pkm = passenger kilometers; LTO = landing and takeoff; VKT = vehicle kilometers travelled; CO_2 = carbon dioxide.
[a] The check marks (✓) denote the frequency with which a method is used in China, with three check marks representing the greatest frequency.

Sources: Authors' summary based on IPCC (2006), MEE (2015), EEA (2019), and Pers. Comm. (2022b).

Of note, the data-intensive bottom-up methods face severe data constraints in China (see Table 10), such as the following:

- It is challenging to accurately estimate road transport emissions following the vehicle/bunker method because of a lack of robust statistics on VKTs and fuel efficiency (see Section 4.1).
- Estimating road transport emissions using the tkm/pkm method also has associated challenges due to a lack of up-to-date and localized statistics on fuel efficiency per tkm/pkm (Pers. Comm. 2022b).
- Estimating the emissions from off-road machinery is near impossible due to missing statistics for all inputs.

Table 10 | **Data Availability of the Most-Used Bottom-Up Methods**

	DATA AVAILABILITY[a]	EXPLANATION
Road transport: Vehicle/bunker method		
Fleet composition by vehicle category, technology, and size	◕	Detailed information on fleet composition by technology and size is scattered among departments, some of which is not publicly available.
Annual VKT by vehicle category	○	--
Fleet-average fuel efficiency by vehicle category	◐ (Annual report on energy-saving and new energy vehicles)	Only type-approved fuel efficiency is available. Real-world and localized statistics are lacking.
Road, railway, water navigation, and aviation: Tkm/pkm method		
Freight tkm and passenger pkm	◐ (Annual statistical yearbook)	Roadway tkm do not include those of non-operating fleets, while roadway pkm do not include those of private cars.
Mode shares (in tkm/pkm)	● (Annual statistical yearbook)	--
Fuel efficiency per tkm/pkm	◐ (National transport sector development statistical communiqué)	National statistics are available for only certain years. Local statistics are not available.
Aviation: LTO method		
Number of LTOs	● (Annual airport production statistical communiqué)	LTOs for general aviation are not included.
Fuel efficiency per LTO	○	Country-specific fuel efficiency is lacking.
Off-road machinery: Vehicle/bunker method		
Equipment population by power ranges	○	The statistics are lacking because equipment registration is not required.[b]
Operating hours by equipment	○	--
Average load factors	○	--

Notes: Abbreviations: tkm = freight tonne-kilometers; pkm = passenger kilometers; LTO = landing and takeoff; VKT = vehicle kilometers travelled; LDT = light-duty truck. Carbon dioxide emission factors are not included in the table.
[a] ● = a high level of data availability; ◐ = a moderate level of data availability; ○ = no data are available.
[b] VECC 2015.

Source: Authors' summary.

Transboundary Emissions Allocations

Because of China's unique transport energy statistics, for the top-down method, the approach used to allocate transboundary trips in China is different from those enumerated in the GPC.

Specifically, because China's transport fuel consumption statistics are gathered from fuel end users (like transit operators or freight carriers) rather than fuel distributors (like PetroChina), transboundary emissions are allocated to the registered locations of fuel end users (Table 11). In this study, this China-specific allocation approach is termed "fuel consumption by local companies."

The fuel consumption by local companies approach does not share the same emissions boundary as other allocation approaches (like the fuel sales by distributors or the resident activity approaches) because local companies' fleets can be fueled anywhere, and nonlocal vehicles can join local companies' fleets. Therefore, switching to a different allocation approach to estimate subnational transport emissions from a specific year will trigger a time-series inconsistency issue.

3. EVALUATION OF ACCOUNTING METHODS IN CHINA

China has conformed to the IPCC 1996 and 2006 Guidelines for transport emissions accounting, where the top-down method is recommended as the primary method to calculate transport emissions, and bottom-up methods are used in regions without energy balances or in circumstances when transport emissions by mode and climate action planning are needed.

This study couples the accounting methods with allocation approaches that could work under China's current statistical system and categorizes them as follows:

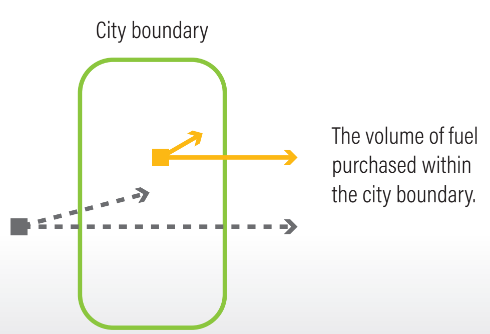
- Top-down: Fuel consumption by local companies
- Bottom-up: Resident activity
- Bottom-up: Geographic

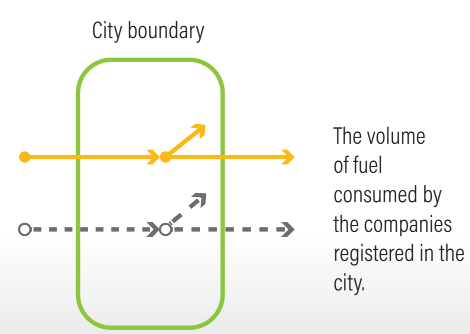
To evaluate if the above methods meet the inventory objectives outlined in Section 1, this study uses six criteria adapted from Larsson et al. (2018), Kander et al.

Table 11 | **Allocation Approaches for the Top-Down Method**

Counted   Not counted

Fuel Sales by Distributors	Fuel Consumption by Local Companies
Allocation according to the region where transport fuel is sold.	Allocation according to the registered locations of fuel end users.





Source: Authors' summary.

(2015), and Wood et al. (2010) to evaluate the above four methods:

- *Data availability:* The method has a reasonable level of data requirements that fit the varying data conditions across China.
- *Jurisdiction alignment:* The method is sensitive to disparate responsibilities among entities.
- *Estimation uncertainty:* The method and inputs lead to an accurate estimation of emissions that "agree with the true emissions without over- or underestimation" (IPCC 2006).
- *Additivity:* The method ensures that the sum of subnational transport emissions is equal to the nation's total.
- *Source identification:* The method can identify different sources of transport CO_2 emissions.
- *Policy relevance:* The method can inform the formulation of decarbonization policies.

3.1 Data Availability

China's current statistics could support all the methods except for the fuel sales by distributors and induced activity methods (Table 12). The induced activity method is not applicable because data on the origins and destinations of transboundary trips are unavailable, and regional transport demand/emissions models simulating transboundary trips are nonexistent and take years to develop. The reason the fuel sales by distributors method is not applicable is explained in Section 2.2.

Of note, data availability is inconsistent across methods:

- For the top-down fuel consumption by local companies method, energy balances are not available in all Chinese cities. Further, energy balances are not frequently updated—the most recent energy balances were dated to 2019 and are therefore not able to monitor rapidly growing emissions to devise timely countermeasures.
- The geographic method is not applicable to regions that have limited data collection measures (due to

Table 12 | **Data Availability Assessment**

METHODS	DATA REQUIREMENTS	DATA AVAILABILITY	FREQUENCY OF DATA UPDATES
Top-down method			
Fuel consumption by local companies	• Information on locally registered companies' fuel consumption	Available in all provinces and certain cities	Infrequent updates
Fuel sales by distributors	• Information on local distributors' fuel sales	Not available	N/A
Bottom-up methods			
Resident activity	• *Vehicle/bunker method:* Information on local vehicles/bunkers • *Pkm/tkm method:* Information on local pkm/tkm	Available in all regions	Frequent updates
Geographic	• *Vehicle/bunker method:* Information on local and **nonlocal** vehicles/bunkers occurring within the region's boundary (collected through the region's access surveillance or vehicles' GPS) • *LTO method:* Information on LTOs	Available in a few regions	Infrequent model updates
Induced activity	• *Vehicle/bunker method:* Information on local and **nonlocal** vehicles/bunkers (collected through GPS or travel surveys)	Not available	N/A

Notes: Abbreviations: pkm = passenger kilometers; tkm = freight tonne-kilometers; GPS = Global Positioning System; LTO = landing and takeoff; N/A = not applicable. The green indicates the highest level of data availability, and the red denotes the least.

Source: Authors' summary based on Pers. Comm. (2022b).

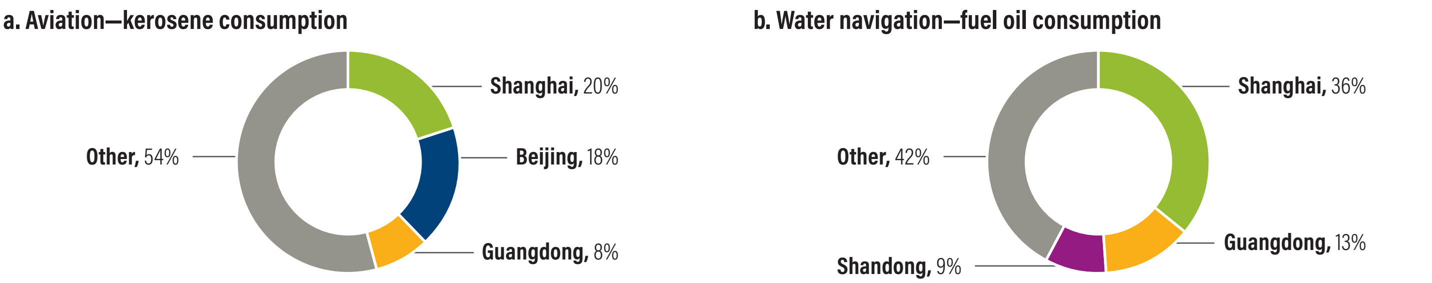
poor coverage of access surveillance[5] or inaccessible vehicle Global Positioning System [GPS] data) or financial resources to build transport demand/emissions models. Further, existing transport emissions models using the geographic method also face the challenge of infrequent data collection and model updates (Pers. Comm. 2022b).

3.2 Jurisdiction Alignment

Accounting methods need to ensure that different levels of government are assigned appropriate levels of responsibility for emissions mitigation. If a subnational government is allocated a level of transboundary emissions disproportionate to its responsibility for mitigating them, it would not only affect the government's ability to reach its emissions-reduction targets, but also deter it from committing to more ambitious targets.

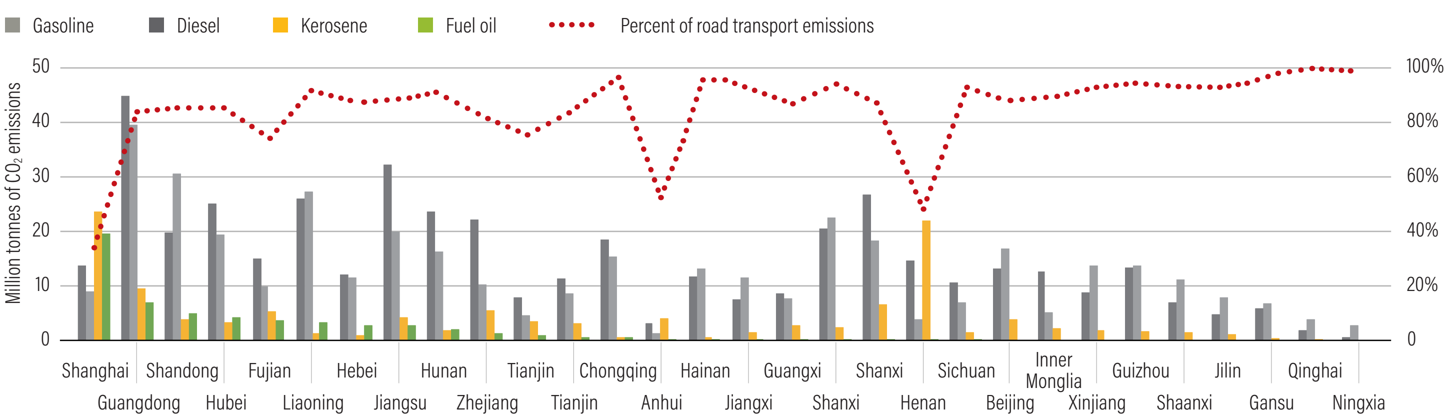
In China, the above accounting methods have jurisdiction issues, particularly when it comes to aviation and water navigation emissions. Because large airlines and water navigation corporations are registered in only a few Chinese cities and provinces, using the fuel consumption by local companies and resident activity methods would lead to disproportionately large emissions-reduction burdens falling on these places. For example, using the fuel consumption by local companies method, Beijing, Shanghai, and Guangdong Province alone would represent 46 percent of China's aviation kerosene consumption, and aviation CO_2 emissions would comprise 52 percent of Beijing's transport CO_2 emissions in 2019 (Figures 2 and 3). However, Beijing cannot single-handedly mitigate aviation emissions because some air travel demands stem from outside of Beijing and the city has limited jurisdiction over state-owned airlines[6] that serve the whole country.

Figure 2 | **Regions with Greatest Fuel Consumption from Aviation and Navigation**



Note: We calculated emissions using the top-down method and ratios from MEE (2021).
Source: Authors' calculations based on NBS (2019).

Figure 3 | **Transport Carbon Dioxide Emissions by Fuel and Province**



Notes: Abbreviation: CO_2 = carbon dioxide.
- Tibet, Hong Kong, Macau, and Taiwan are not included.
- We calculated emissions using the top-down method and ratios from MEE (2021).
- Because it is difficult to identify road transport emissions using the top-down method, this study assumes that the emissions from gasoline, diesel, natural gas, and liquefied petroleum gas stem from road transport. However, doing so overestimates road transport carbon dioxide emissions.

Source: Authors' calculations based on NBS (2019).

In China, three entities are responsible for transport decarbonization—the national government, subnational governments, and large state-owned corporations (Table 13)—and it is crucial to allocate transport emissions to the entities that are best capable of reducing them:

- For the road and off-road transport subsectors, subnational governments have more discretion and policy options in their arsenal such as urban planning and new energy vehicle (NEV) promotion to mitigate emissions. Therefore, the emissions should be allocated to subnational governments.
- The railway, aviation, and water navigation subsectors are predominated by state-owned enterprises (SOEs) under the national government's purview with more resources to mitigate emissions. Therefore, the emissions are best allocated to the corporations. For this reason, these emissions are excluded from the subnational emissions estimation in Section 3.3.

Table 13 | **Division of Transport Decarbonization Responsibilities**

	NATIONAL GOVERNMENT	SUBNATIONAL GOVERNMENTS	CORPORATIONS
Road transport	• Promotion of NEV production[a] • Fuel-efficiency standards • Mode shift and demand-side management • Carbon pricing	• Compact urban planning • Mode shift and demand-side management • Vehicle occupancy improvements • Fuel efficiency retrofits of in-use vehicles • NEV promotion • Carbon pricing	• None[b]
Railway	• Railway planning and investment • Carbon pricing	• Railway planning and investment • First-/last-mile connectivity • Carbon pricing	• Railway planning and investment • Railway electrification • Service quality and operation efficiency improvements • First-/last-mile connectivity
Water navigation	• Waterway planning and investment • Carbon pricing	• Waterway planning and investment • First-/last-mile connectivity • Clean offshore power • Carbon pricing	• Zero-emission/fuel-efficient bunkers • Low-carbon fuel adoption • Clean offshore power • Service quality and operation efficiency improvements • First-/last-mile connectivity
Aviation	• Airport planning • Mode shift and demand-side management • Efficient air traffic management and ground operation • Carbon pricing	• Airport planning and investment • First-/last-mile connectivity • Carbon pricing	• Zero-emission/fuel-efficient aircrafts • Sustainable aviation fuel adoption • Service quality and operation efficiency improvements
Off-road transport	• Promotion of zero-emission equipment production • Fuel-efficiency standards	• Fuel-efficiency retrofits of in-use equipment • Promotion of zero-emission equipment • Early retirement of high-emitting equipment	• None[c]

Notes: The highlighted areas indicate the allocation recommended by this study. Abbreviations: NEV = new energy vehicle; CAFC = corporate average fuel consumption.

[a] The national government promotes NEV production through the NEV and CAFC credit mechanism, where the accrued CAFC and NEV credits can be traded among original equipment manufacturers under the Parallel Management Regulation for CAFC and NEV Credits (MIIT 2021).

[b] Lack of large stated-owned enterprises; local governments have jurisdiction.

[c] Lack of large stated-owned enterprises; local governments have jurisdiction.

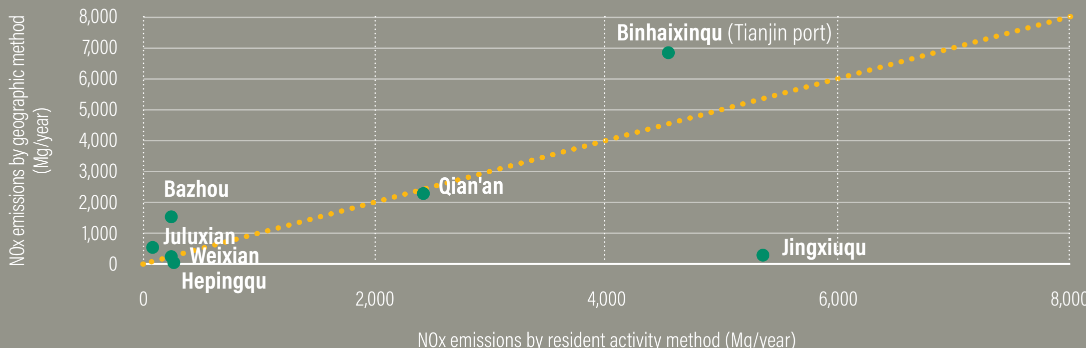
Source: Authors' summary.

Box 3 | **Choice of Allocation Method for the Road Transport Sector**

Because the responsibility for mitigating road transport emissions is retained at the local level, the choice of allocation method is crucial since different methods would result in different emissions estimates. For example, Deng et al. (2020), a study on the nitrogen oxide (NOx) emissions associated with HDTs in the Beijing-Tianjin-Hebei regions, found that using the resident activity method leads to –50 to 150 percent variations in HDT NOx emissions compared with the geographic method (Figure B3.1).

The geographic method is reliable for estimating pollution,[a] but that may not be the case for estimating CO_2. Regions should choose methods based on their local context and needs (Table B3.1). At present, the resident activity method is widely applicable in China; in the future, the induced activity and geographic methods will be useful in supporting the design of diverse decarbonization policy options.

Figure B3.1 | **Comparison of Nitrogen Oxide Emissions Estimates Using the Resident Activity and Geographic Methods for Select Counties in the Beijing-Tianjin-Hebei Regions**



Notes: Abbreviations: NOx = nitrogen oxides; Mg = milligrams.
Source: Deng et al. 2020.

Table B3.1 | **Applicability of Different Allocation Methods**

	REGIONAL APPLICABILITY	RELEVANT POLICIES
Top-down method	Regions with • few illegal fuel stations; and • limited fuel tourism	N/A
Resident activity	Regions with few nonlocal vehicles	• Avoid-shift-improve[a] policies for local vehicles
Geographic	Regions with • many nonlocal vehicles; and • local vehicles that make few transboundary trips	• Avoid-shift-improve policies for both local and nonlocal vehicles • Policy analysis of coordinated reduction of GHG and air pollutant emissions • Location-specific policies such as zero-emission zones
Induced activity	Regions with • many nonlocal vehicles; and • limited through traffic	• Avoid-shift-improve policies for both local and nonlocal vehicles • Integrated land use and transport planning policies • Policy analysis on coordinated reduction of GHG and air pollutant emissions • Location-specific policies

Notes: Abbreviations: N/A = not applicable; GHG = greenhouse gas.
[a] The avoid-shift-improve policy framework categorizes mitigation policies into three groups: avoiding unnecessary travel demand, shifting trips from high-emission to low-emission modes, and improving vehicle technologies.

Source: Authors' summary.

Notes: [a] Deng et al. 2020.

3.3 Estimation Uncertainty

At the national level, the top-down method is the only recommended method in the IPCC 1996 and 2006 Guidelines: The uncertainty of national transport emissions estimates using the top-down method is around ±5 percent provided reliable fuel statistics are available (IPCC 1996, 2006). As suggested in IPCC (2000) and EEA (2019), the difference between the top-down and bottom-up estimates can be reconciled by adjusting VKTs.

However, at the subnational level, the uncertainty of both methods is larger, and the scale of difference between road transport emissions estimated using both methods is significant: Although the top-down estimates of China's national road transport emissions in 2019 were about 5 to 10 percent lower than the bottom-up estimates in that year (after adjusting VKTs), the subnational top-down estimates were from 157 percent lower to 42 percent higher than the corresponding bottom-up estimates. Overall, the 30 provinces and municipalities under the jurisdiction of China's central government[7] (Table 14) can be divided into two groups:

- There are 15 provinces and municipalities for which the top-down estimates were lower than the bottom-up estimates in 2019. The top-down estimates are extremely low in Hebei, Ningxia, and Shandong Provinces—in those places, the top-down estimates are only one-third to one-half the bottom-up estimates.
- For the remaining 15 provinces and municipalities, the top-down estimates were larger than the bottom-up estimates. The top-down estimates were particularly high in Guizhou, Liaoning, and Hunan Provinces, where the estimates were 35 to 42 percent higher than the bottom-up estimates.

Table 14 | **Comparison of Road Transport Carbon Dioxide Emissions in 2019 by Province Using the Top-Down and Bottom-Up Methods**

		CHANGES IN TOP-DOWN ESTIMATES (RATIO 1) W.R.T. BOTTOM-UP ESTIMATES	CHANGES IN TOP-DOWN ESTIMATES (RATIO 2) W.R.T. BOTTOM-UP ESTIMATES
1	Beijing	27%	29%
2	Tianjin	24%	32%
3	Hebei	-157%	-145%
4	Shanxi	-41%	-30%
5	Inner Mongolia	-4%	3%
6	Liaoning	38%	37%
7	Jilin	-19%	-8%
8	Heilongjiang	-18%	-5%
9	Shanghai	17%	20%
10	Jiangsu	-8%	-3%
11	Zhejiang	-36%	-18%
12	Anhui	-11%	-3%
13	Fujian	18%	27%
14	Jiangxi	-4%	3%
15	Shandong	-69%	-60%
16	Henan	-31%	-19%
17	Hubei	32%	39%

Table 14 | **Comparison of Road Transport Carbon Dioxide Emissions in 2019 by Province Using the Top-Down and Bottom-Up Methods (Cont.)**

		CHANGES IN TOP-DOWN ESTIMATES (RATIO 1) W.R.T. BOTTOM-UP ESTIMATES	CHANGES IN TOP-DOWN ESTIMATES (RATIO 2) W.R.T. BOTTOM-UP ESTIMATES
18	Hunan	35%	39%
19	Guangdong	20%	25%
20	Guangxi	-25%	-16%
21	Hainan	8%	16%
22	Chongqing	30%	37%
23	Sichuan	20%	24%
24	Guizhou	42%	38%
25	Yunnan	17%	23%
26	Shaanxi	-9%	5%
27	Gansu	-2%	3%
28	Qinghai	28%	34%
29	Ningxia	-95%	-82%
30	Xinjiang	25%	29%
	National	**-10%**	**-5%**

Notes: Abbreviation: w.r.t. = with regard to.

- Tibet, Hong Kong, Macau, and Taiwan are not included.
- Ratio 1 refers to the apportioning ratios in MEE (2021) and ratio 2 refers to those in WRI (2013).
- Because it is impossible to identify road transport emissions using the top-down method (see Section 3.5), this study assumes that the emissions from gasoline, diesel, natural gas, and liquefied petroleum gas stem from road transport. However, doing so overestimates road transport carbon dioxide emissions.
- For the bottom-up method, the vehicle/bunker method (based on the resident activity method) is used, because the pkm/tkm method covers only operating fleets. Because of the limited data available on new energy vehicle (NEV) stocks in each province, NEVs are treated as internal combustion engine vehicles. Further, this study assumes that annual vehicle kilometers travelled for private cars is 10,000 kilometers, and that those for light- and heavy-duty trucks are 28,000 and 55,000 kilometers, respectively. Fuel efficiency by vehicle type and year is from CATARC (2021).

Source: Authors' calculations based on national and subnational energy balances (NBS 2020), fleet composition (NBS 2021), and data from CATARC (2021).

Further, key indicators used to inform decision-making such as the ranking of road transport emissions, emissions per capita, and emission growth trajectories vary considerably by method as shown through these examples:

- Guangdong, Jiangsu, and Liaoning Provinces are the largest road transport emitters using the top-down method; however, Shandong, Guangdong, and Hebei Provinces rise to the top using a bottom-up method (Table 15).
- The trend in road transport emissions per capita is reversed when switching between methods: Using the top-down method, Hebei Province's road transport CO_2 emissions per capita (about 0.35 tonnes) were the lowest in 2019, while the province's CO_2 emissions per capita became the second-biggest (0.9 tonnes) in that year using a bottom-up method (Figure 4).
- Different emission growth trajectories are observed for the same region using different methods (Figure 5): Using the top-down method, road transport emissions during 2012 and 2019 were stable in Hebei Province and declining in Shandong Province, while both provinces demonstrated steady growth trends using a bottom-up method.

These cases show that different emissions estimate methods result in different—or even conflicting—conclusions that will misguide local decarbonization policymaking or national funding allocations.

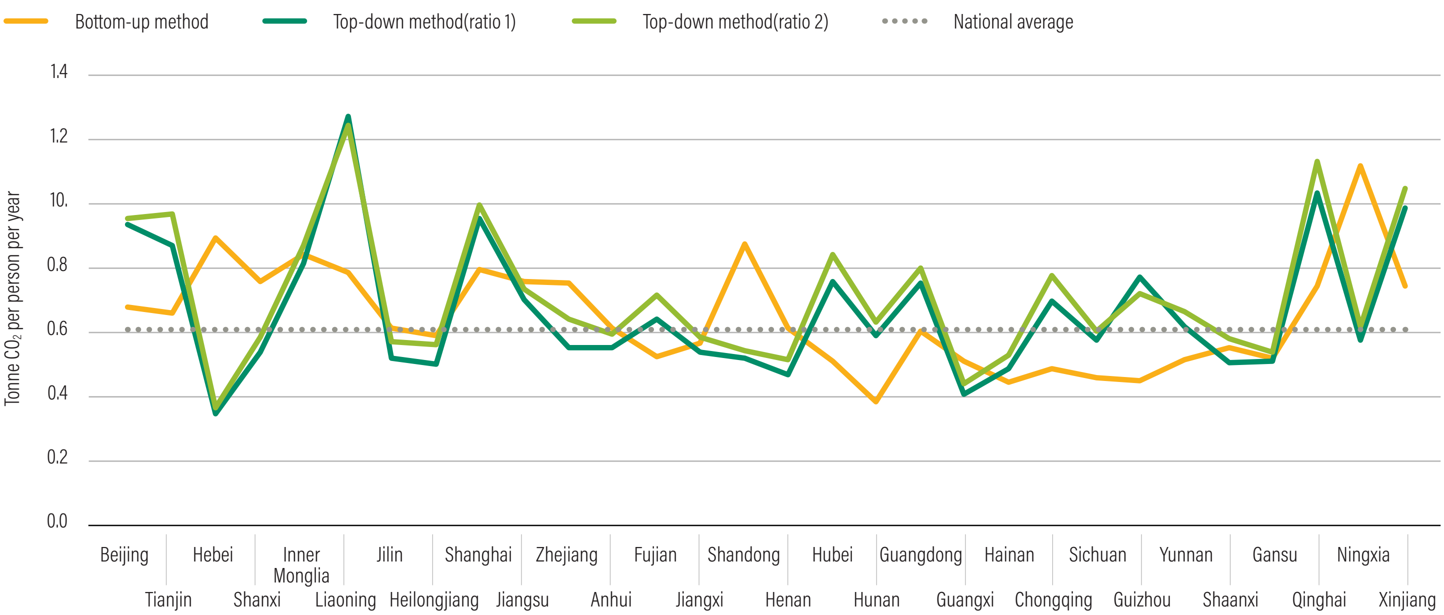
Table 15 | **Ranking by Province of Road Transport Carbon Dioxide Emissions in 2019**

		RANK BY TOP-DOWN EMISSIONS	RANK BY BOTTOM-UP EMISSIONS	CHANGES IN RANKING W.R.T. TOP-DOWN RANKING
1	Beijing	22	25	**-3**
2	Tianjin	27	27	**0**
3	Hebei	13	3	**10**
4	Shanxi	21	11	**10**
5	Inner Mongolia	19	18	**1**
6	Liaoning	3	9	**-6**
7	Jilin	25	22	**3**
8	Heilongjiang	24	16	**8**
9	Shanghai	17	20	**-3**
10	Jiangsu	2	4	**-2**
11	Zhejiang	10	6	**4**
12	Anhui	9	7	**2**
13	Fujian	14	19	**-5**
14	Jiangxi	15	13	**2**
15	Shandong	4	1	**3**
16	Henan	7	5	**2**
17	Hubei	6	10	**-4**
18	Hunan	8	12	**-4**
19	Guangdong	1	2	**-1**
20	Guangxi	20	14	**6**
21	Hainan	29	30	**-1**
22	Chongqing	18	24	**-6**
23	Sichuan	5	8	**-3**
24	Guizhou	12	23	**-11**
25	Yunnan	11	15	**-4**
26	Shaanxi	23	17	**6**
27	Gansu	26	26	**0**
28	Qinghai	28	29	**-1**
29	Ningxia	30	28	**2**
30	Xinjiang	16	21	**-5**

Notes: Abbreviation: w.r.t. = with regard to.
- Tibet, Hong Kong, Macau, and Taiwan are not included.
- For the top-down method, the ranking in road transport emissions calculated using ratio 1 (MEE 2021) and ratio 2 (WRI 2013) are identical.

Source: Authors' calculations based on NBS (2020), NBS (2021), and CATARC (2021).

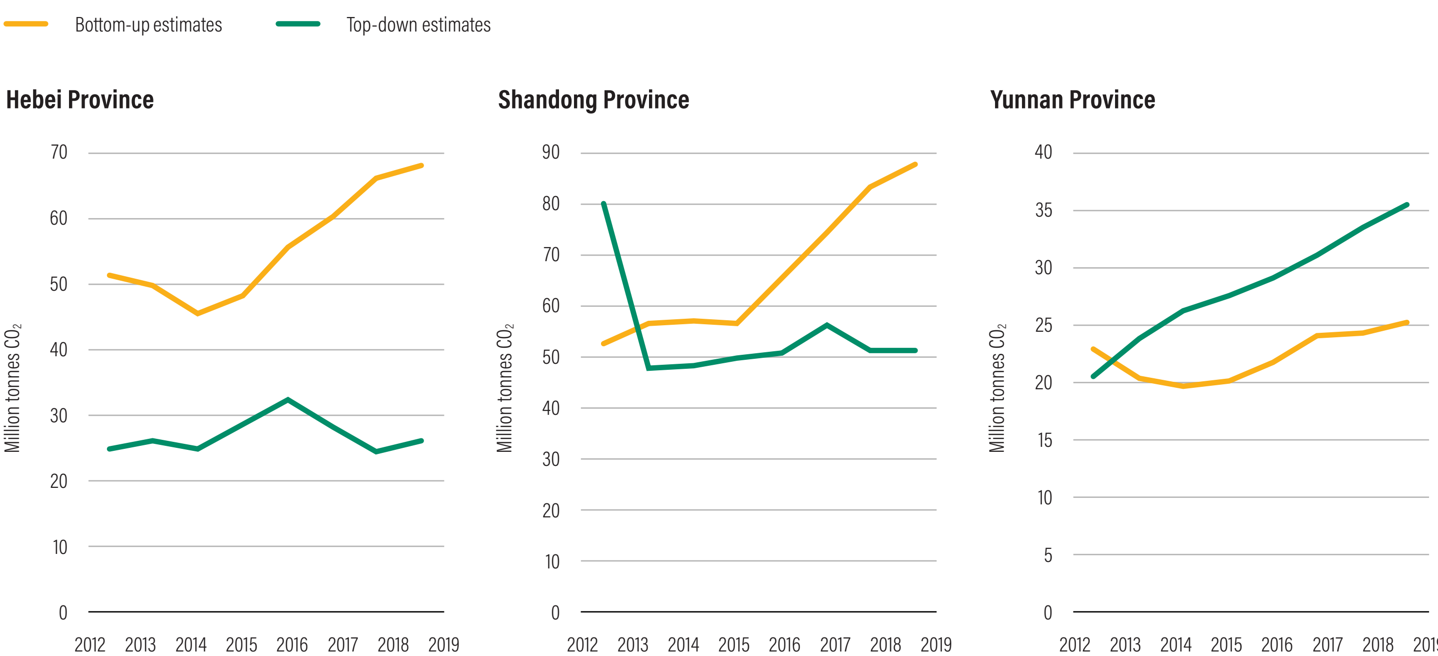
Figure 4 | **Road Transport Carbon Dioxide Emissions Estimates per Capita in 2019 by Province**



Notes: Abbreviation: CO_2 = carbon dioxide. Ratio 1 refers to the ratios in MEE (2021); ratio 2 refers to those in WRI (2013).

Source: Authors' calculations based on NBS (2020), NBS (2021), and CATARC (2021).

Figure 5 | **Growth Trajectories of Road Transport Emissions in Select Provinces (2012–19)**



Notes: Abbreviation: CO_2 = carbon dioxide. We used the apportioning ratios from MEE (2021) to calculate the top-down emissions estimates.

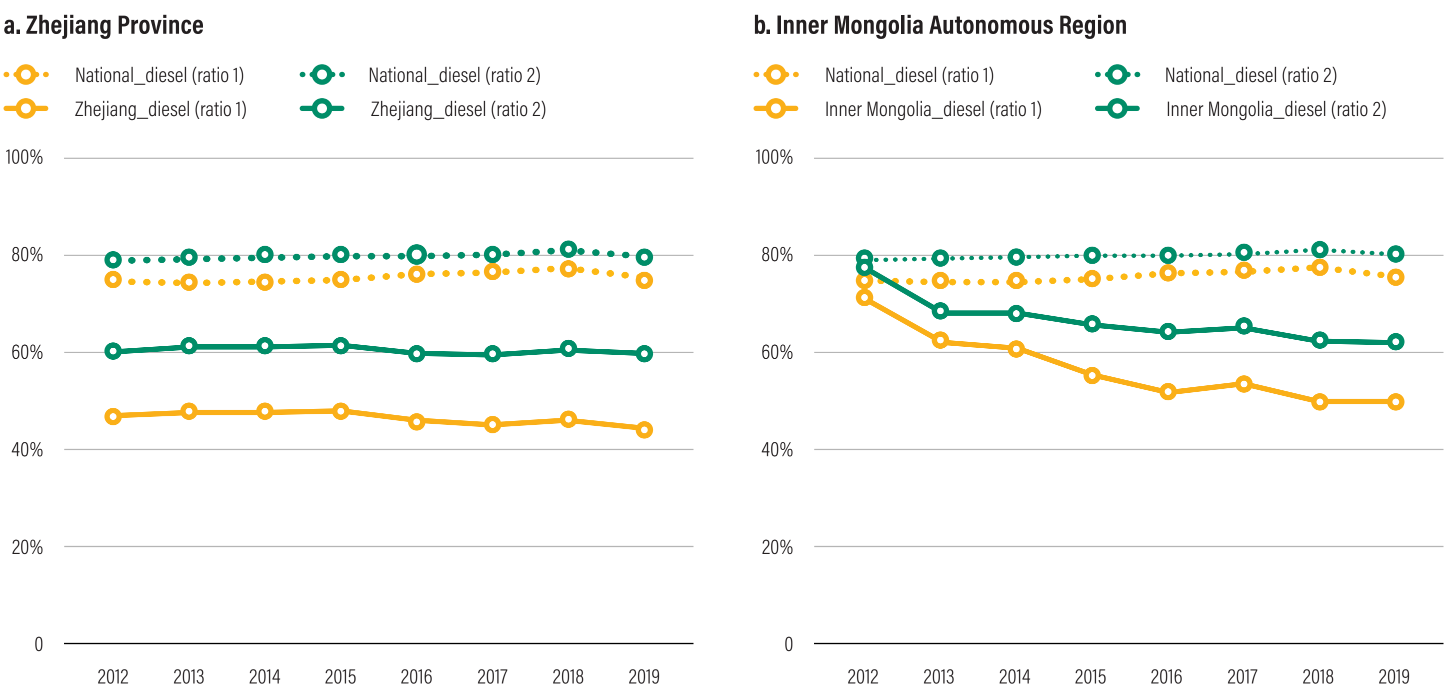
Source: Authors' calculations based on NBS (2020), NBS (2021), and CATARC (2021).

For the top-down method, apart from authors' estimation errors, such as including non-road transport emissions in the top-down method and omitting NEVs in the bottom-up method, uncertainty surrounding subnational emissions estimates also exists due to the presence of illegal fuel stations and incomplete statistics:

- A consequence of cheap prices and large profits, illegal fuel stations are becoming widespread across China (Yang 2020), where low-quality fuels are sourced from illegal refineries or fuel blenders[8] with fuels for non-transport purposes. Although illegal fuel stations have limited impact on national emissions estimates (IPCC 2006), their impacts at the subnational level are noteworthy. For example, during a joint operation against illegal fuel stations in the Jing-Jin-Ji region and surrounding areas in 2019 by multiple ministries (MEE 2019), 1,466 illegal fuel stations were found and closed. Among them, 40 percent of the illegal stations were in Hebei Province and 36 percent in Shandong Province, two provinces that have large disparities in their road transport emissions estimates using the different methods, and partly explaining the underestimation of their top-down estimates.

- China's current transport energy statistics are incomplete. Although apportioning ratios are used, applying the same ratios to the subnational level and over time is questionable. For example, due to provinces' different development stages and economic structures, the shares of transport diesel consumption in total diesel consumption differ greatly across them, and some variations are difficult to explain (see Figure 6 and Appendix C): In Zhejiang Province, for example, transport diesel consumption represented only 46 percent of the province's diesel consumption (ratio 1) (compared with 75 percent at the national level), with 24 percent of the province's diesel consumed in the agriculture sector in 2019—compared with 9 percent at the national level. However, Zhejiang's economy is predominated by industries and services; agriculture made up only 3 percent of its gross domestic product in 2019 compared with 7 percent at the national level (NBS 2020). Further, with industrial decarbonization and increased adoption of zero-emission vehicles, the ratios should be updated over time.

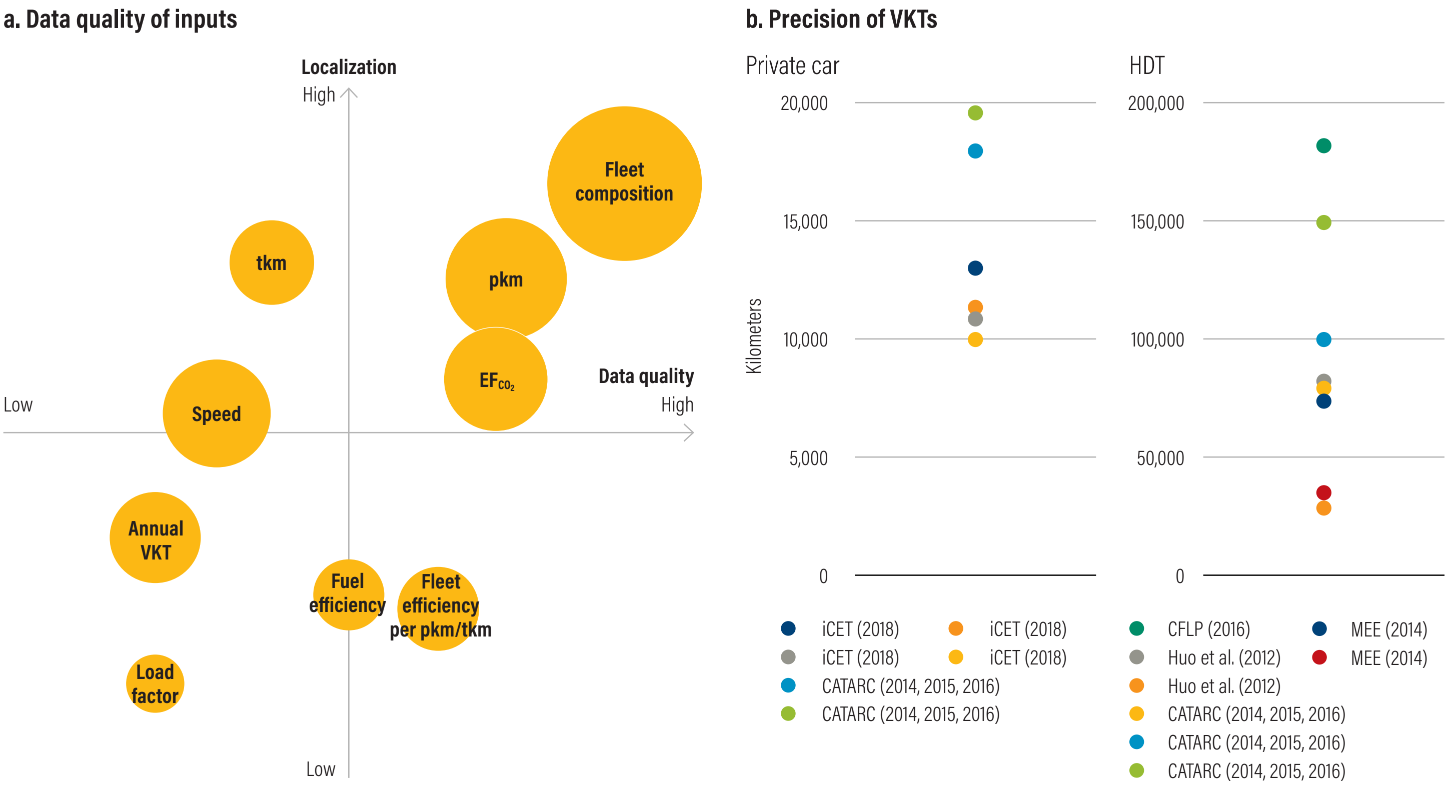
Figure 6 | **Transport Diesel Consumption as a Share of Total Diesel Consumption, 2012–19**



Note: Ratio 1 is from MEE (2021); ratio 2 is from WRI (2013).

Source: Authors' calculations based on NBS (2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019).

Figure 7 | **Data Quality Assessment of Inputs for the Bottom-Up Methods (Road Transport)**



Note: Abbreviations: EF$_{CO_2}$ = carbon dioxide emission factor; pkm = passenger kilometers; tkm = freight tonne-kilometers; VKT = vehicle kilometers travelled; HDT = heavy-duty truck.

Sources: Figure a is the authors' adaptation of Song (2017) based on Pers. Comm. (2022b). Figure b is based on data from iCET (2018), CATARC (2014, 2015, 2016), Qu et al. (2019), MEE (2014), CFLP (2016), and Huo et al. (2012).

For the bottom-up methods, the uncertainty of both national and subnational estimates is affected by limited data quality and a lack of input localization.

- The national bottom-up estimates are uncertain because of limited input quality. For road transport, the data quality of annual VKTs is particularly low (Figure 7): Estimates of annual VKTs for private cars at the national level range from less than 10,000 kilometers to nearly 20,000 kilometers (iCET 2018; CATARC 2014, 2015, 2016; Ou et al. 2019; MEE 2014). The variation in annual VKTs for HDTs is even greater, from 35,000 to 182,500 kilometers (CFLP 2016; CATARC 2014, 2015, 2016; Huo et al. 2012; MEE 2014).

- At the local level, using national averages to calculate subnational emissions would introduce additional uncertainties. For example, due to severe congestion, the fuel efficiencies of passenger cars in Beijing and Chongqing were estimated to be higher than the national average (Lv et al. 2021).

Because the uncertainties associated with both the top-down and bottom-up methods are large, the differences between the top-down and bottom-up estimates at the subnational level suggest that there may be systematic over- and underestimations of transport emissions using either method. Therefore, it is not possible to reconcile the differences by simply adjusting VKTs; instead, systematic improvements to the statistical data are needed.

3.4 Additivity

"The sum of the parts equals the whole" is an important validation measure. However, not all the emissions accounting methods guarantee additivity.

- The top-down method does not. In China, the sum of subnational energy consumption data does not equal the national total. Similarly, the sum of subnational road transport CO_2 emissions is unequal to national emissions and was about 7 to 10 percent higher than the national total in 2019.

- Among the bottom-up methods, the resident activity method does not have additivity issues if all the data inputs are national averages. However, if there is no standardized data collection approach, the resident activity method could have the additivity problem. The geographic method can guarantee additivity.

3.5 Source Identification

Although IPCC (1997) and IPCC (2006) recommend using the top-down method to estimate national transport emissions, one drawback with using the top-down approach is that it does not allow for source identification. The challenge is particularly prominent in China: Its energy balance reports only lump-sum transport emissions (Table 16) instead of subsector breakdowns as with European countries (Table 17).

To identify transport emissions by source as required by the IPCC 1996 and 2006 Guidelines, China uses bottom-up methods combined with energy statistics.[9] However, considering the bottom-up methods are unreliable, this will introduce new levels of uncertainty. Therefore, a viable solution is to distinguish transport fuel use by subsector when the fuel consumption/sales data are collected and revise energy balances into those with detailed subsector breakdowns.

3.6 Policy Relevance

Another disadvantage of the top-down method is that using transport fuel consumption as an input has limited policy relevance. To forecast transport emissions and formulate decarbonization policies, bottom-up methods should be employed.

Table 16 | **Energy Balance in China, 2019**

Unit: million tonnes

	GASOLINE	DIESEL OIL	FUEL OIL	LPG	NATURAL GAS (billion cubic meters)	ELECTRICITY (billion kWh)	KEROSENE
Transport	62	99	20	2	27	175	37

Notes: Abbreviations: LPG = liquified petroleum gas; kWh = kilowatt-hours. Liquified natural gas and lubricants consumed by the transport sector are not included.

Source: NBS 2020.

Table 17 | **Energy Balance in Spain Based on the Eurostat Standard, 1999**

Unit: 1,000 toe

	LPG	GASOLINE	KEROSENE	DIESEL OIL	NATURAL GAS	FUEL OIL	ELECTRICITY
Transport	**82**	**9,393**	**4,198**	**17,681**	**220**	**10**	**307**
Railways	-	-	-	485	-	-	307
Road transport	82	9,383	4,198	15,832	-	10	-
Air transport	-	11		-	-	-	-
Inland navigation	-	-	-	1,364	220	-	-

Notes: Abbreviations: toe = tonne of oil equivalent; LPG = liquified petroleum gas.

Source: IEA 2004.

Different bottom-up methods support the formulation of different decarbonization policies: For example, the pkm/tkm method is helpful in devising mode-shift policies, while the vehicle/bunker method is instrumental in formulating policies that promote NEVs (Table 18). Likewise, different allocation methods can support different policies (see Box 3). To craft a comprehensive transport decarbonization roadmap, we recommend that subnational governments employ all possible bottom-up methods (given the limited coverage of pkm and tkm statistics, caution should be taken when using the pkm/tkm method).

4. RECOMMENDATIONS

China has largely adopted the IPCC 1996 and 2006 Guidelines to calculate national and subnational transport emissions. However, this study's evaluation reveals that weaknesses remain (Table 19):

- A lack of complete and up-to-date data is the primary obstacle for conducting accurate transport emissions accounting in China. Even using the top-down method, energy balances are absent in many cities and, in several cases, infrequently updated.
- The top-down and bottom-up methods result in uncertain estimates when applied to quantify subnational transport emissions. The differences between estimates for transport emissions using the two methods in select provinces are so large that they are difficult to reconcile using IPCC recommended procedures.
- Guidelines for what scope of transport emissions to cover, how to select which bottom-up method to use, how to collect relevant input data, and how to validate emissions results are lacking.
- The current methods have the issue of misaligned responsibilities: A few regions have been responsible for disproportionately large shares of aviation and water navigation emissions, but do not have a commensurate responsibility for mitigating these emissions.

In the near term (from 2021 to 2025), China needs to develop credible transport CO_2 emissions inventories

Table 18 | **Relevance of the Accounting Methods to Decarbonization Policies (Road Transport)**

	DEMAND	MODE SHARE	FUEL EFFICIENCY	POLICY INSTRUMENTS
Top-down method				
	Fuel consumption	--	--	--
Bottom-up methods				
Pkm/tkm method *(using tkm as an example)*	tkm	Mode share (in percent of tkm)	Fuel efficiency (in liters per tkm)	Mode shift; efficiency improvements
	tkm/loadF	Mode share (in percent of vkm)	Fuel efficiency (in liters per tkm)	Mode shift; vehicle occupancy and fuel efficiency improvements
Vehicle/bunker method	veh * VKT	Mode share (in percent of vkm)	Fuel efficiency (in liters per vkm)	Travel demand management; NEV promotion; fuel efficiency improvements

Note: Abbreviations: veh = number of vehicles; loadF = load factor; vkm = vehicle-kilometers; tkm = freight tonne-kilometers; pkm = passenger-kilometers; NEV = new energy vehicle.

Source: Authors' summary.

Table 19 | **Evaluation of the Existing Accounting Methods Used in China**

CRITERIA	TOP-DOWN METHOD	RESIDENT ACTIVITY METHOD	GEOGRAPHIC METHOD
Data availability	Available in provinces and a few cities	Available in all regions	Available in a few regions
Jurisdiction alignment	No	No	No
Estimation uncertainty	• National level: Certain • Subnational level: Uncertain	• National and subnational levels: Uncertain	X
Additivity	No	Only in certain cases	Yes
Source identification	No	Yes	Yes
Policy relevance	No	Yes	Yes

Note: Abbreviations: X = Unable to assess.

Source: Authors' summary.

so that it can set sectoral emissions-reduction targets, monitor its decarbonization progress, and meet the Paris Agreement's ETF (effective from 2024). Since it can take years to introduce sophisticated methods such as the induced activity method, this study proposes the following stepwise recommendations:

4.1 Near-Term Recommendations (2021–25)

Transport emissions inventories should be required for subnational governments and be regularly updated from the base year. To retain vertical consistency across national emissions inventories and ensure the time series is consistent with historic emissions, this study recommends using the top-down method to estimate both national and subnational transport emissions. However, the use of the top-down method is contingent on China ensuring that transport fuel consumption statistics are complete and, whenever possible, using a bottom-up method with reliable statistics as a complementary method.

First, the uncertainty associated with the top-down method must be improved:

- Comprehensive fuel sale statistics—especially those from private cars, LDTs, own-account HDTs, and off-road machinery—should be collected at all administrative levels, using fuel tax receipts, mandatory reporting requirements (on fuel distributors), or fuel supplier surveys. Particularly, China could follow California's experience (see Box 4) in mandating that fuel distributors—including SOEs (such as PetroChina) and private-owned operations—report Scope 3 emissions.

- Of note, switching from the conventional fuel consumption by local companies method to the fuel sales by distributors method would create inconsistency between the estimated emissions and historic emissions at the subnational level since the emissions estimated by the two methods are not comparable. Therefore, to keep time series consistency—particularly when tracking emissions changes from the base year, recalculating base year and all subsequent year emissions will be necessary (WRI et al. 2014). This also means that fuel sale statistics tracing back to the base year should be obtained.

- Fuel sale statistics should be documented by subsector, where the following two conditions are met: The fuel sold for off-road machinery should be distinguished from the fuel sold for road transport; and diesel, electricity, and natural gas sold for road transport, water navigation, and railways should be separately reported. The tabular structure of energy balances should be refined to subsectors and be consistent with the ETF's common reporting tables, which will become effective starting in 2024 (UNFCCC 2019).

- Fuel sales data should also be updated more frequently, considering China's most up-to-date official transport emissions are from 2014 and the most recent energy balances are from 2019. Starting in 2024, when the Paris Agreement's ETF becomes effective and official annual GHG inventories will be reported, energy balances and inventories should be updated annually to better monitor transport emissions.

- A QA/QC process should be established for energy statistics. First, the coverage of energy balances should be improved so that all cities have them. Second, the sum of subnational transport fuel sales should be equal to national fuel sales. Lastly, transport energy statistics (in energy balances) should be consistent over time and abnormal values should be explained.

- Enforcement of the regulations regarding illegal fuel stations, refineries, and fuel blenders (MOFCOM 2020) in provinces such as Shandong and Hebei is crucial. Preventing vehicles from getting their fuel from informal sources would help mitigate the uncertainty surrounding fuel sale statistics and reduce air pollutants from the combustion of low-quality fuels.

Second, the bottom-up methods should be used with reliable statistics:

- VKTs by vehicle category should be collected on an annual/biannual basis, through vehicle GPS data collection, odometer readings upon vehicle inspection, or traffic counts (see Appendix D). In China, heavy-duty commercial vehicles' VKTs can be collected through on-board GPS systems; to prevent drivers from speeding or working overtime, MoT (2014) requires all heavy-duty vehicles to install GPS. Unless the GPS malfunctions, VKTs collected via GPS reliably cover all heavy-duty vehicles. For private cars, VKTs can be gathered via odometer readings or traffic counts.

- Real-world fuel efficiency data should be collected (possible measures are listed in Appendix D). Like VKTs, an on-board diagnostic system (OBD) is an ideal way to collect fuel efficiency information about heavy-duty commercial vehicles, while users' self-reporting using mobile applications is the preferred method for private cars.

- Statistics to estimate off-road machinery's CO_2 emissions should be collected. We recommend that local governments that aim to abate air pollutants collect the detailed activity data of off-road machinery, including equipment population, rated powers, operating hours, and load factors.

Third, CO_2 emissions from aviation, railways, and water navigation need to be allocated to the responsible corporations. The national government should develop guidelines for businesses to accurately estimate transport emissions with improved data collection on engine types, power rates, operation hours, and fuel efficiency.

Lastly, the national and subnational governments should establish administrative safeguards for transport emissions accounting:

- The national government should update the top-down Provincial Guidelines in accordance with improvements in transport energy statistics and develop guidelines for bottom-up methods, with clear recommendations on emissions scope choices, method selection, data collection, and QA/QC procedures.

- National and subnational governments should assign dedicated offices or personnel to be responsible for transport emissions data collection, calculations, reporting, and QA/QC. Cross-departmental data sharing and validation should be encouraged.

- Validation procedures should be established at all levels. Compulsory, third-party review of subnational inventories should be performed on a regular basis to ensure they are credible.

4.2 Long-Term Recommendations (2025 Onwards)

Over the long run, we recommend using the geographic and induced activity methods to enable more granular climate action planning and an evaluation of air pollution reduction co-benefits.

Further, China needs to develop guidelines to estimate transport-related CH_4, N_2O, and other GHG emissions. Statistical data should be improved to be able to accurately estimate these non-CO_2 GHG emissions.

Last but not the least, depending on changes in global governance for international aviation and shipping, China could consider including these emissions in its national emissions estimates.

Box 4 | California's Mandatory Greenhouse Gas Emissions Reporting Regulation

Mandatory reporting is a method to gather timely transport emissions data from fuel distributors while reducing administrative complexity. One typical example comes from California, United States: Since 2006, California has required fuel distributors to report their Scope 3 emissions[a] under the California Global Warming Solutions Act. Specifically, fuel distributors—including refiners, position holders, and fuel importers—with emissions of transport fuel sold over 10,000 tonnes of carbon dioxide equivalent—should report GHG emissions.[b]

Notes: [a] Scope 3 emissions are indirect emissions from the value chain of a reporting company that are not entirely controlled by the company.
[b] EPA 2010.

APPENDIX A. ABOUT THE PAS 2070 METHODOLOGIES

While the IPCC 2006 Guidelines use a production-based method, PAS 2070 uses a consumption-based approach. The scope of PAS 2070 includes both direct emissions from sources within a region and indirect emissions from products produced outside a region. PAS 2070 has two assessment methodologies: a direct-plus-supply-chain methodology that captures direct emissions and those associated with the largest supply chains serving cities; and a consumption-based methodology that includes direct emissions and life-cycle emissions from all goods and services consumed by the region's residents (BSI 2013).

For the transport sector, the PAS 2070 methodologies have two emissions scopes (BSI 2014):

- The direct-plus-supply-chain methodology covers transport emissions from transboundary travel and upstream well-to-tank emissions from transport fuel use and electricity/hydrogen generation. The allocation approaches of transboundary emissions follow the methods outlined in the GPC.
- The consumption-based method has a larger scope that also includes emissions from producing vehicles. However, the emissions from transport infrastructure construction (such as cement production) and operations are not included.

PAS 2070's methodologies are applicable to developed regions that tend to be net importers of goods and services. Further, because of intensive information needed on national/subnational input-output matrices to calculate the consumption-based emissions, the adoption of PAS 2070 is limited. At present, only a few cities such as London have officially deployed this approach for city-level emissions inventory development (BSI 2014).

APPENDIX B. ALLOCATION APPROACHES IN THE GPC

The GPC offers four approaches to allocate transboundary transport emissions (WRI et al. 2014). The four emissions allocation approaches have obvious advantages and disadvantages (Table AB.1).

Globally, different allocation approaches have been used, including the following (see Table AB.2):

- California, United States, follows the conventional fuel sales by fuel distributors method. This method is sufficient to monitor transport emissions and benchmark local government performance. Of note, according to the Commercial Vehicle Registration Act (DMV 2001), commercial vehicles and trailers must be registered in California before entering the state. It also enables the state to track transboundary commercial vehicles.
- In Seattle, United States, varying data availability gives rise to diverse allocation approaches. For example, the induced activity method is used to estimate road transport and passenger railway emissions, while the geographic method is used to calculate inland navigation and freight railway emissions. The adoption of bottom-up allocation approaches helps the city perform climate action planning and informs policymaking.
- The Greater London Authority in the United Kingdom employs the geographic method based on a transport model where CO_2 and air pollutant emissions are calculated at a 1-km grid resolution. The benefit of using this method is that the scope of CO_2 emissions is identical with air pollutants; therefore, the method can assess a decarbonization policy's air pollution reduction co-benefits. Further, the method is advantageous in evaluating the environmental performance of location-sensitive policies, such as ultra-low emission zones.

Table AB.1 | **Comparison of Allocation Approaches**

METHODOLOGY	ADVANTAGES	DISADVANTAGES	IMPLEMENTATION DIFFICULTY
Allocation approaches for the top-down method			
Fuel sales by local distributors/fuel consumption by local companies	• More consistent with national inventory practices • Less costly and time-consuming to conduct • Does not require high-level technical capacity	• Does not capture all on-road travel, as vehicles may be fueled at locations outside the city • Does not identify emissions sources by mode • Does not support policymaking	★
Allocation approaches for the bottom-up methods			
Resident activity	• Supports the identification of emissions sources • Can link to more actionable mitigation policies	• Does not capture all on-road travel, particularly vehicles registered outside the city	★★ (Requires statistics on VKTs and fuel efficiency)
Geographic method	• Supports the identification of emissions sources • Can link to more actionable mitigation policies, particularly capable of analyzing location-sensitive policies • More consistent with air pollution analysis and can evaluate air pollution reduction co-benefits	• More expensive and time-consuming • Less comparable among cities due to variations in models used	★★★★ (Requires sophisticated city-level transport models)
Induced activity	• Supports the identification of emissions sources • Can link to more actionable mitigation policies, and is particularly capable of managing travel demand from outside the city	• More expensive and time-consuming • Less comparable among cities due to variations in the models used	★★★★★ (Requires sophisticated regional-level transport models)

Note: Abbreviation: VKT = vehicle kilometers travelled.

Source: Authors' adaptations based on WRI et al. (2014).

Table AB.2 | **Allocation Approaches Used in Greater London, Seattle, and the State of California**

	GREATER LONDON, ENGLAND, UNITED KINGDOM	SEATTLE, WASHINGTON, UNITED STATES	CALIFORNIA, UNITED STATES
Road transport	• Geographic method	• Induced activity (half of the emissions associated with trips that begin or end in Seattle are attributed to the city)	• Fuel sales by local distributors
Railway	• Geographic method (emissions from London-based railway routes)	• Induced activity (passenger railways) • Geographic method (freight railways)	• Fuel sales by local distributors
Water navigation	• Geographic method (emissions from domestic and international shipping vessels operating on the River Thames)	• Geographic method (hoteling and maneuvering emissions from domestic and international shipping vessels operating in the Port of Seattle)	• Fuel sales by local distributors
Aviation	• Geographic method (LTO cycles up to 1,000 meters in height)	• Fuel sales scaled to the size of the local population	• Fuel sales by local distributors
Off-road machinery	• Fuel sales (counted in industrial and construction sector emissions)	• Calculated using EPA's NONROAD model[a]	• Fuel sales by local distributors
Transport inventory purpose	Evaluate the air pollution reduction co-benefits and assess decarbonization potential of location-sensitive policies	Support city-level climate planning	Monitor major annual emissions changes and historic trends of GHG emissions

Notes: Abbreviations: LTO = landing and takeoff; GHG = greenhouse gas; EPA = United States Environmental Protection Agency.
[a] EPA n.d.

Sources: For London: Road, railway, and aviation emissions were calculated based on the London Atmospheric Emissions Inventory (TfL 2020); water navigation data come from shipping emissions estimates by PLA and TfL (2017); and off-road mobile machinery data are included in the United Kingdom National Atmospheric Emissions Inventory (Desouza et al. 2021). For California: Transport emissions estimates follow the 2006 IPCC Guidelines. For Seattle: SOSE 2020.

APPENDIX C. CHANGES IN TRANSPORT DIESEL CONSUMPTION LEVELS IN SELECT PROVINCES

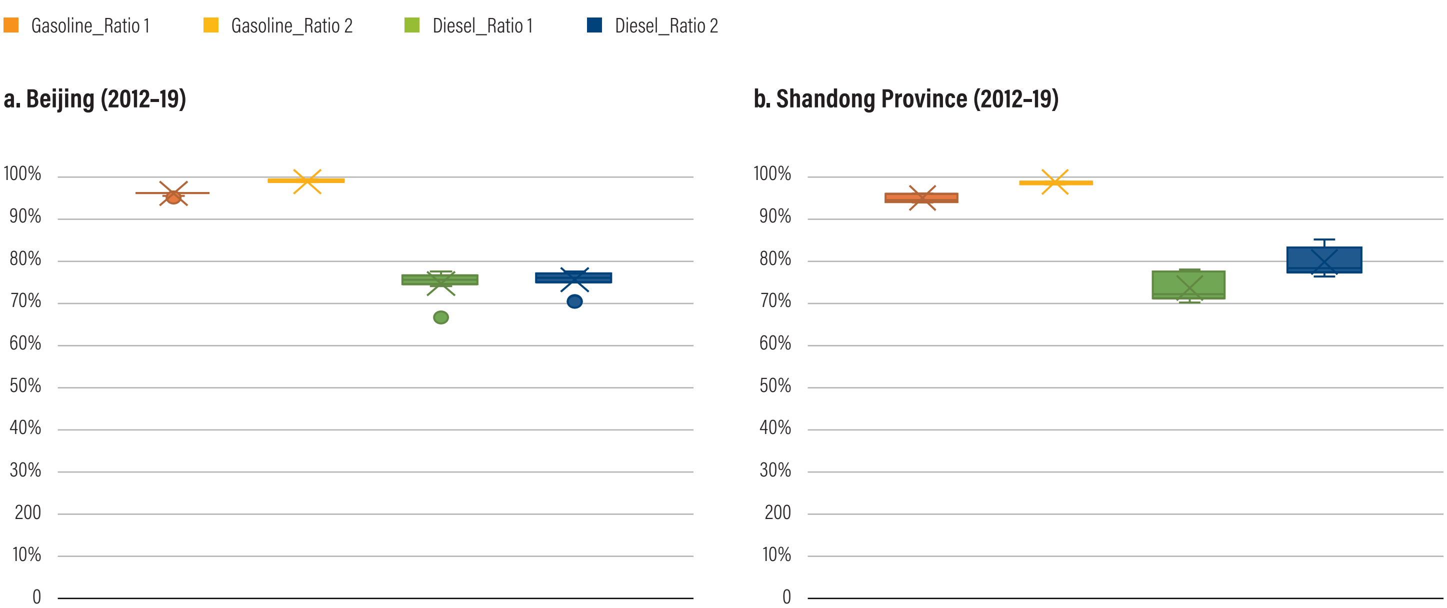
Based on this study's calculations, at the subnational level, the shares of transport diesel consumption as a proportion of total diesel consumption varied more greatly than they did at the national level from 2012 to 2019. The provinces can typically be categorized into three groups:

The first group of provinces and municipalities, including Beijing and Shandong Province, showed a similar trend as the national trend, where the shares of transport diesel consumption in total diesel consumption were fixed at around 70 to 80 percent from 2012 to 2019 (see Figure AC.1).

The second group includes provinces like Guizhou, Sichuan, Hebei, and Liaoning, where the shares of transport diesel consumption in total diesel consumption have varied greatly over time, from 50 to 90 percent. The variations could be attributable to economic structural shifts, changes in diesel consumed in other sectors (such as industry and residential heating), or statistical uncertainties (see Figure AC.2).

The third group, which includes provinces such as Zhejiang and Heilongjiang, had steady low consumption of diesel in the transport sector compared with other sectors. The share of transport diesel consumption in total diesel consumption was fixed around 40 percent (Diesel_Ratio 1), which is lower than the national average. The continuous low consumption of diesel in the transport sector could be the result of stable diesel demand in other sectors or a statistical underestimation of transport diesel consumption (see Figure AC.3).

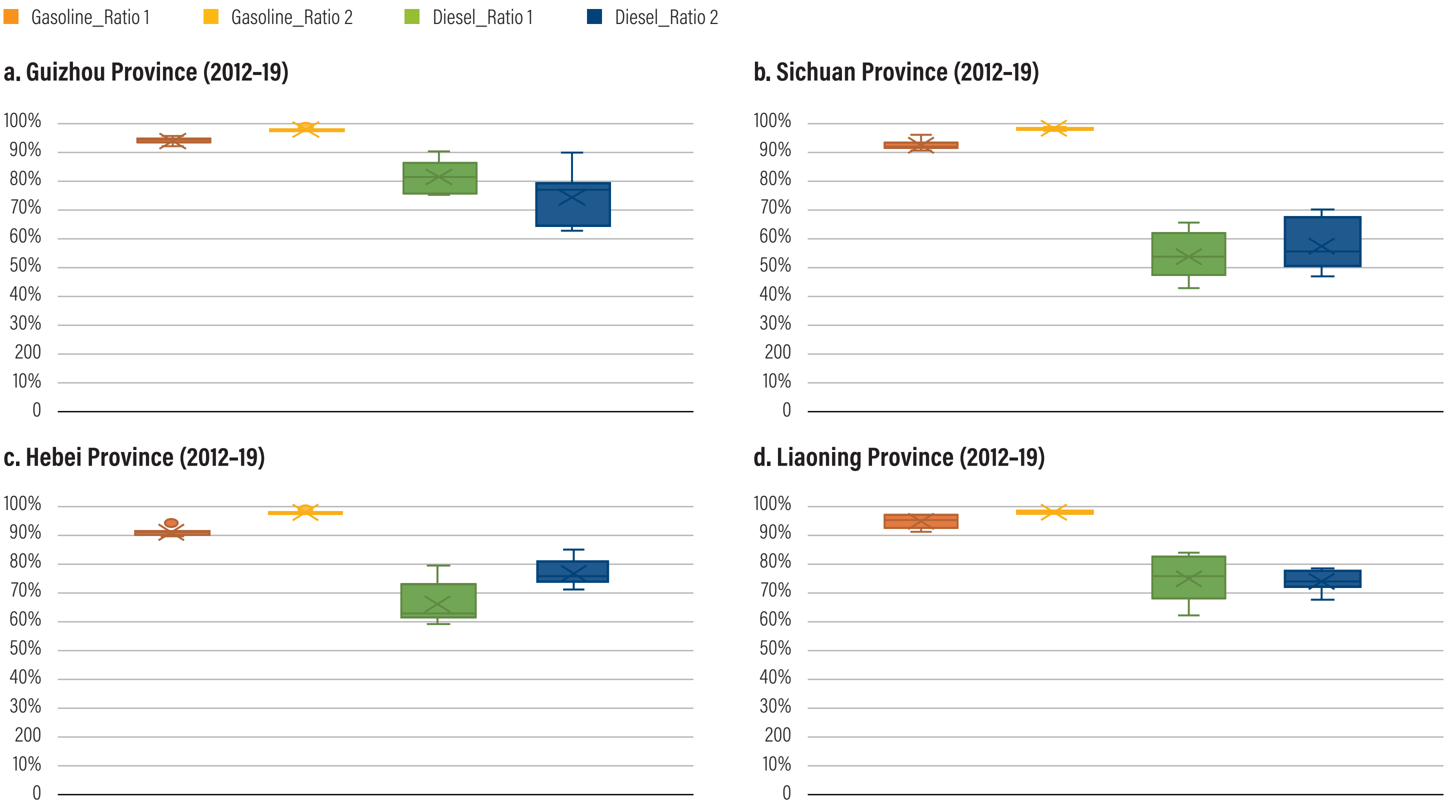
Figure AC.1 | **The Percent of Transport Fuel (Gasoline and Diesel) Consumption in Total Fuel Consumption in Beijing and Shandong from 2012 to 2019**



Notes: Ratio 1 refers to the apportioning ratios proposed by MEE (2021); ratio 2 refers to those proposed by WRI (2013).

Source: Authors' calculations based on national and subnational energy balances (NBS 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019).

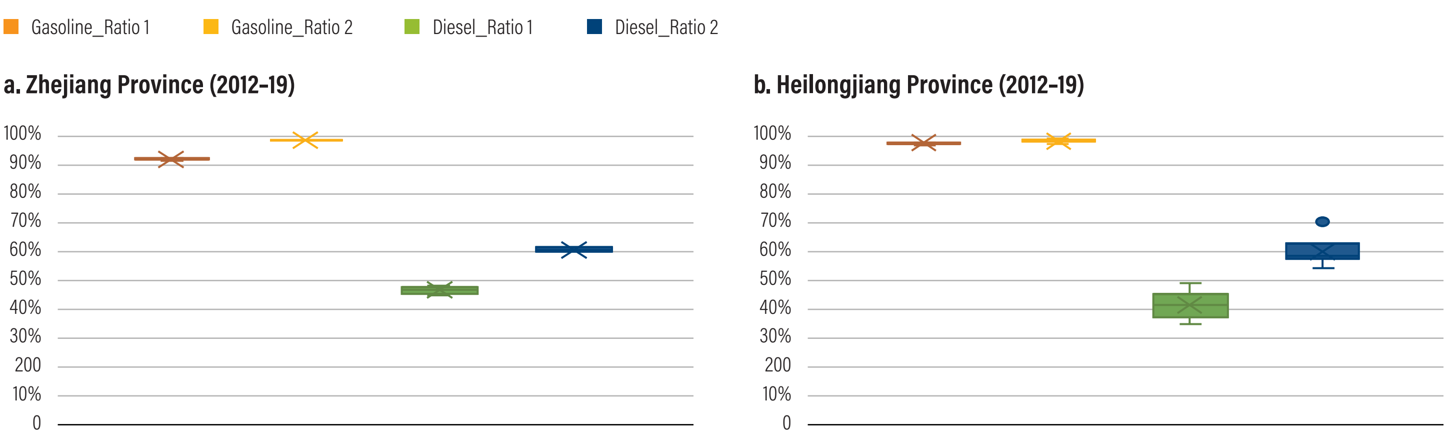
Figure AC.2 | **The Percent of Transport Fuel (Gasoline and Diesel) Consumption in Total Fuel Consumption in Guizhou, Sichuan, Hebei, and Liaoning Provinces from 2012 to 2019**



Notes: Ratio 1 refers to the apportioning ratios proposed by MEE (2021); ratio 2 refers to those proposed by WRI (2013).

Source: Authors' calculations based on national and subnational energy balances (NBS 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019).

Figure AC.3 | **The Percent of Transport Fuel (Gasoline and Diesel) Consumption in Total Fuel Consumption in Zhejiang and Heilongjiang from 2012 to 2019**



Notes: Ratio 1 refers to the apportioning ratios proposed by MEE (2021); ratio 2 refers to those proposed by WRI (2013).

Source: Authors' calculations based on national and subnational energy balances (NBS 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019).

APPENDIX D.
VEHICLE KILOMETERS TRAVELLED AND FUEL EFFICIENCY DATA COLLECTION METHODS

Tables AD.1 and AD.2 compare the prevailing data collection methods for vehicle kilometers travelled and fuel efficiency.

Table AD.1 | **Comparison of Data Collection Methods for Vehicle Kilometers Travelled**

	VEHICLE INSPECTIONS	TRAVEL SURVEYS	TRAFFIC COUNTS VIA ACCESS SURVEILLANCE/ LOOP DETECTORS/RTMS	GPS AND TELEMATIC SYSTEMS
Data collection procedure	Obtain VKTs upon annual/ biannual inspections	Conduct (sampled) surveys to households or fleet operators with a question on VKTs	Count vehicle numbers on sampled road links with automatic vehicle identification measures to distinguish among vehicle types and license plates (VKTs are equal to the number of vehicles times the length of road links)	Monitor VKTs via GPS and transport the data through telematic systems upon agreement with vehicle owners
Emissions allocation consideration	Resident activity method • Locally registered vehicles • Trips both inside and outside a region	Resident activity method • Locally registered vehicles • Trips both inside and outside a region	Geographic method • Vehicles registered both inside and outside a region • Trips only within a region	All allocation approaches • Both vehicles registered inside and outside a region • All types of trips
Applicability by vehicle type	• All vehicles	• All vehicles	• All vehicles	• HDTs • Heavy-duty coaches

Notes: Abbreviations: VKTs = vehicle kilometers travelled; RTMS = Remote Traffic Microwave Sensor; GPS = Global Positioning System; HDT = heavy-duty truck.

Source: Authors' adaptation based on Kuhnimhof et al. (2017).

Table AD.2 | **Comparison of Data Collection Methods for Fuel Efficiency**

	VEHICLE OBD DATA COLLECTION	VEHICLE USERS' SELF-REPORTING	PORTABLE EMISSION MEASUREMENT SYSTEM/CHASSIS DYNAMOMETER TESTING	MODELS BASED ON SOFTWARE LIKE PHEM AND MOVES[a]	REMOTE SENSING
Data collection procedure	Monitor vehicle fuel consumption via OBD and transport the data through telematic systems upon agreements with vehicle owners	Report fuel efficiency by vehicle users using applications such as Xiaoxiongyouhao	Obtain fuel consumption either under real-world driving conditions through PEMS or under laboratory tests through a chassis dynamometer	Calculate fuel efficiency in dedicated models such as PHEM and MOVES by feeding the models with localized driving conditions	Deploy roadside remote sensing devices combined with other equipment to gather vehicle license information and speeds to measure groups of vehicle emissions in real time
Disadvantages	• May have data accuracy issues, depending on the reliability of the OBD devices	• Limited coverage of vehicle types • Lack of representativeness	• Time consuming and expensive • Mismatch with real-world driving conditions	• Inconsistent with China's vehicle types and real-world driving conditions	• Accuracy needs improving for individual vehicles
Applicability by vehicle type	• HDTs • Heavy-duty coaches	• Private cars	• All vehicles	• All vehicles	• All vehicles

Notes: Abbreviations: PEMS = Portable Emission Measurement System; PHEM = Passenger Car and Heavy-Duty Emission Model; MOVES = Motor Vehicle Emission Simulator; OBD = on-board diagnostic system; HDT = heavy-duty vehicle.
[a] Hausberger 2003.

Source: Authors' summary.

ENDNOTES

1. Using the top-down method to estimate fuel consumption has limited policy relevance because fuel consumption is a lump-sum number, making it difficult for policymakers to understand what is driving the increases in fuel consumption and which policies (e.g., shifting to walking and biking, increasing vehicle fuel efficiency, switching to electric vehicles) would be most effective and reduce fuel consumption the most.

2. Interviewed cities and provinces are at different economic development stages with varying degrees of knowledge about transport CO_2 emissions accounting.

3. International aviation and shipping fuel sales refer to fuel consumption on trips that either begin or end outside a country.

4. According to the GPC, the method also includes partial emissions from international trips.

5. Cities should also have the capacity to automatically identify vehicle license plate numbers from surveillance footage to retrieve key information (like vehicle category, fuel type, and emissions standards) from a vehicle registration database.

6. Large stated-owned airlines include but are not limited to China National Aviation Holding Group, China Eastern Air Holding Company, and China Southern Air Holding Company.

7. Data from Tibet, Hong Kong, Macau, and Taiwan are not included.

8. Fuel blenders are those who mix fuel oil in vehicles' diesel oil.

9. The existing energy statistics could distinguish among railway, waterway, and aviation fuel consumption, but have limitations in separating roadway and off-road machinery fuel consumption.

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ACKNOWLEDGEMENTS

This publication is part of the NDC Transport Initiative for Asia (NDC-TIA), which supports China, India and Vietnam as well as regional and global decarbonization strategies to increase ambition around low-carbon transport. IKI is working under the leadership of the Federal Ministry for Economic Affairs and Climate Action, in close cooperation with its founder, the Federal Ministry of Environment and the Federal Foreign Office. The implementing organizations for the NDC-TIA China Component are Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), International Council on Clean Transportation (ICCT), World Resources Institute (WRI), and Agora Verkehrswende (AGORA).

For more visit: https://www.ndctransportinitiativeforasia.org/

The authors would like to thank World Resources Institute internal reviewers: Stephanie Ly, Maggie Dennis, Xiaoqian Jiang, Wenyi Xi, Christine Muthee, and Ramya Ma. We would also like to thank our external reviewers: Songli Zhu (Energy Research Institute of the National Development and Reform Commission, China), Danyang Yu (China Academy of Transportation Sciences of Ministry of Transport), Dong Ma (Vehicle Emission Control Center of the Ministry of Ecology and Environment, China), Huan Liu (Tsinghua University), Huiming Gong (Energy Foundation), Ying Huang (Chinese Academy of Science, Guangzhou Institute of Energy Conversion), and Gerald Ollivier (the World Bank).

Thank you also to Li Fang, Zhe Liu, Sarah DeLucia, Ye Zhang, Romain Warnault, and Emilia Suarez for advisory, editing, design, and administrative support.

ABOUT THE AUTHORS

Lulu Xue, China Mobility Manager, WRI China. E-mail: Lxue@wri.org

Daizong Liu, China Sustainable Cities Director, WRI China.

ABOUT WRI

World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

Our Challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

WITH SUPPORT FROM:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

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