Behind the Data -
A Comparative Analysis of China's Carbon Emission Data from Different Institutions

看见数据背后的逻辑与局限
——不同机构中国碳排放数据比较分析

报告 Report

2023 年 7 月

July 2023

Acknowledgements

We would like to thank the experts Hu Xiulian and Tian Zhiyu from the Energy Research Institute of the National Development and Reform Commission for suggestions and comments that helped us improve this report.

We would like to thank Fu Sha and Yang Zhuoxiang from Energy Foundation China for their support and advice.

Thanks also to iGDP colleagues Hu Min, Yao Zhe, Wang Yanhui and Chen Meian for their support and advice during the completion of the report.

We would like to thank Liu Zhen and Diego Montero for translation and dissemination support, and iGDP colleague Bao Linjie for the report's layout and design.

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Disclaimer

Suggested Citation

LI Xindi, YANG Li. Behind the Data - A Comparative Analysis of China's Carbon Emission Data from Different Institutions. 2023. Report. Beijing: Institute for Global Decarbonization Progress.

Content

Executive Summary

To support China's carbon peaking and carbon neutrality efforts and address both national and international concerns over their progress, it is important to ensure that carbon emissions data is reliable, continuous, and authentic. It is also important to ensure that carbon emission accounting methods are scientific and comparable. China's National GHG Emissions Inventory and other government energy reports provide official CO_2 emission data. Multiple domestic and foreign research institutions and government think tanks also offer Chinese carbon emission data to cater to different requirements. Due to variations in how emissions are accounted for, accounting methods used, and the factors that affect emissions, the emissions data published by different institutions can vary significantly. It is crucial to compare and analyze these different datasets to identify and understand any disparities between them.

This report offers a comparative analysis of the methodologies and results associated with the most recently released China carbon emissions data by ten domestic and foreign research institutions. This data was directly or indirectly calculated using official Chinese sources, and is timely, continuous, and consistent, allowing analysts to track, evaluate, forecast, and perform international comparisons of China's carbon emissions. This report focuses on energy-related CO_2 emissions and includes the following features:

1) The analysis is based on the latest methodology and emissions data released by each institution as of the first quarter of 2023;
2) The analysis includes the carbon emissions databases released by domestic Chinese research institutions in recent years;
3) The report maps out energy data sources and relations between databases, and provides an analysis of differences in energy data accounting methods.

In addition, this report estimates China's 2013-2021 annual serial baseline carbon emissions data[1] (hereafter referred to as the "baseline data") based on official data, and uses this as a benchmark to measure the gaps between the carbon emissions data of each institution and China's official data.

[1] Continuous carbon emissions data for 2013 – 2021, calculated based on the published decline rate of CO_2 emissions per unit of GDP and combined with four annual carbon emissions datasets for 2005, 2010, 2012, and 2014, officially published in the national communications. These data, referred to as "baseline data," serve as a criterion for determining whether domestic or foreign data are overestimated or underestimated.

This report finds that the carbon emissions calculated in all databases are either directly or indirectly based on China's official energy statistics, but no organization currently has emission accounting boundaries that are fully consistent with official Chinese boundaries. In terms of total carbon emissions estimates, China Carbon Accounting Datasets (CEADs) and the Global Carbon Budget (GCB) are the closest to China's official data. These sources are a potential supplement to China's official intermittent data (China's GHG inventory has been released for only 1994, 2005, 2010, 2012, and 2014). In terms of energy-related CO_2 emissions, all research institutions, except for U.S. Energy Information Administration (EIA), present similar data. A comparison of data from 2005 to 2021 shows that the energy consumption data published by British Petroleum (BP) and the International Energy Agency (IEA) are very close to China's energy balance table. In terms of industrial process emissions, the estimates of the Carbon Dioxide Information Analysis Center (CDIAC) at Oak Ridge National Laboratory, U.S., are significantly higher than those of other research institutions, and even higher than China's official total estimates for the non-metallic mineral products industry (cement, lime, building materials, glass, ceramics, etc.) for individual years. CEADs and GCB only estimate process emissions from cement production, not including glass, ceramics, etc. Their estimates are relatively similar, with CEAD's estimate lower overall than GCB's.

The report finds that when compared to China's official emission accounts, international research institutions generally report higher carbon emissions. In 2014, for example, the energy-related CO_2 emissions data published by each foreign institution was 1.3% to 19.3% higher than that published in China's greenhouse gas inventory, with IEA coming closest and EIA having the largest gap with China's official data. These discrepancies in carbon emission data are primarily due to differences in accounting boundaries, emissions factors, accounting methods, energy data sources, sectoral divisions, fuel classifications, and calorific value used to convert fuel use to standard units.

The total CO_2 emissions estimated by CEADs using the reference approach and estimates by GCB are suitable as a reference for long-duration temporal analysis. These estimates are close to the intermittent GHG emissions inventories submitted by China to UNFCCC. Despite having higher estimates compared to China's official accounts, EDGAR has the most thorough coverage of emission sources, especially for process emissions. Other than BP, all other organizations provide emissions by fuel or sector. IEA and CEADs provide emissions by sector and fuel, making them appropriate references for sectoral emissions.

Literature Review

Systematic comparative study of China's carbon emission data can be traced back ten years. Zhu Songli (2013)[1] compared the carbon emission data officially released by China in 1994, 2004 and 2015, as well as the data on CO_2 emissions from energy combustion and cement production processes from 2005 to 2011 published by eight foreign research institutions against the author's calculations, focusing on emission boundaries, accounting methods, and basic data sources. Zhu argued that caution is needed when citing emissions data from foreign research institutions, but that IEA and the Climate Analysis Indicators Tool (CAIT) of the World Resources Institute can be used as reliable references. Zhu also suggested that China increase the frequency of releasing CO_2 emissions data, strengthen cooperation with international research institutions on energy statistics, regularly publish official statistics on coal calorific value, and include CO_2 fugitive emissions during coal, oil, and gas extraction in energy production, as well as flaring emissions during oil and gas extraction.

Focusing on the similarities and differences in carbon accounting methods, Li Qingqing et al. (2018)[2] selected four foreign research institutions, IEA, EDGAR, CDIAC and EIA to carry out comparative analysis in terms of data range, sector coverage, accounting method, calculation formula, fuel category, activity level data source, international fuel bunkers, non-energy use, carbon emission factors, and oxidation rate coefficient source. The study found that IEA and EDGAR provide more detailed explanations of fuel classification and methodology, and that their data are relatively more accurate. It recommended that China regularly publish official statistics based on international benchmarks.

To identify the main challenges in China's carbon emission accounting, Li Jifeng et al. (2020)[3] compared China's carbon emission data from 1970 to 2017 provided by two foreign institutions, EDGAR v4.2, and CDICA, and compared annual datasets officially published by China in 1994, 2005, 2010, 2012 and 2014 with data provided by CEADs[4], BP, EIA, IEA, CDICA, and EDGAR v4.2. The study found that the estimates of China's carbon emissions by foreign institutions and databases were generally higher, with a gap of up to seven percent, and suggested that China's carbon emission accounting is constrained by existing energy statistics, which lead to relatively large uncertainties.

These studies clarify how to correctly use foreign research institutions' China carbon emission data and call for the improvement of China's carbon emission accounting system. With the strengthening of the global climate change governance system and the improvement of international rules on carbon emission accounting, the Intergovernmental Panel on Climate Change (IPCC) has continuously revised the methodology for the compilation of national greenhouse gas inventories based on the latest scientific evidence. In 2019, IPCC adopted the "2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories," based on which foreign research institutions updated their carbon emission statistics and accounting methodologies. This report aims to improve the authoritativeness and consistency of China emission data by providing a comparative analysis of most recent calculation of this data by Chinese and foreign institutions.

Carbon Emissions Database Selections

This report reviews the Chinese carbon emissions databases of ten foreign and Chinese research institutions (Table 1), all of which contain data that is timely, consistent, and suitable for tracking and evaluating China's carbon emission reductions. Eight are foreign databases from the International Energy Agency, British Petroleum, the U.S. Energy Information Administration, the Carbon Dioxide Information Analysis Center at Oak Ridge National Laboratory, the Emissions Database for Global Atmospheric Research, the Global Carbon Budget, the Climate Watch platform of the World Resources Institute, and the World Bank. Chinese databases include the China Emission Accounts and Datasets and China Multi-resolution Emission Inventory Model, both of which are published by Tsinghua University.

These databases vary in terms of the countries or regions they assess and in the time spans they cover. The foreign databases have a global focus, covering as few as 70 countries or regions, and as many as 224 countries or regions. In terms of time spans, the earliest data on China's carbon emissions is traced back to 1899 (Carbon Dioxide Information Analysis Center). The domestic Chinese databases focus on China and its provinces, as well as some developed countries and emerging economies.

Introduction to Databases

- **International Energy Agency (IEA):** Contains energy and carbon emissions statistics for 203 countries and 42 regions, with data on OECD countries and regions from 1960 to 2020, and data on non-OECD countries from 1971 to 2020. The statistics are usually published 1 or 2 years after the statistical year.
- **British Petroleum (BP):** Contains statistics covering 79 countries and regions, providing energy consumption and CO_2 emission data from 1965 to 2021. The "BP Statistical Review of World Energy 2022" report provides the sum of process emissions from the methane processing industry and emissions from natural gas flaring from 1990 to 2021. In March 2023, BP announced that it would stop updating the seventy-year-old "Statistical Review of World Energy" and transfer it to the Energy Institute (EI).
- **U.S. Energy Information Administration (EIA):** Contains the energy and CO_2 emissions data of 211 countries, national unions, and regions going back to 1980. The data is usually published two years after the statistical year.
- **Carbon Dioxide Information Analysis Center (CDIAC):** Run by the Oak Ridge National Laboratory, U.S., this database provides CO_2 emissions data for 224 countries going back to 1751. CDIAC stopped updating its data in 2015.
- **Emissions Database for Global Atmospheric Research (EDGAR):** A joint project of the European Commission's Joint Research Center (JRC) and the Netherlands Environmental Assessment Agency (PBL), EDGAR provides greenhouse gas emissions data for 226 countries going back to 1970. The data is calculated into monthly sectoral emissions data and mapped onto $0.1^{\circ} \times 0.1^{\circ}$ grid data.
- **Global Carbon Budget (GCB):** Falls under the Global Carbon Project (GCP). Focusing on CO_2 emissions, it provides CO_2 emissions data for fuel energy combustion, cement production, land-use change, and land use going back to 2005.

- **World Resources Institute Climate Watch (WRI):** As successor to the Climate Analysis Indicators Tool (CAIT), this database contains greenhouse gas emissions data on 185 countries (including the EU) from 1990 to 2019. CAIT integrates fossil fuel combustion emissions, industrial process emissions, and land use and forestry data from several institutions and databases. The CO_2 data on fossil fuel combustion emissions is from the IEA.
- **World Bank (WB):** This database's CO_2 emissions data draws from WRI's Climate Watch.
- **China Emission Accounts and Datasets (CEADs):** Contains emissions data for China and its 30 provinces from 1997 to 2019. It also contains data for Japan, Belarus, Kazakhstan, Russia, Kyrgyzstan, and other emerging economies.
- **Multi-resolution Emission Inventory for China (MEIC):** Developed and maintained by Tsinghua University, this database provides provincial emissions and gridded emission data for 10 air pollutants and greenhouse gases in mainland China since 1990. It includes sectoral emission data including electricity, industry, civil use, transportation, and agriculture for each province in China since 2008.

Database Comparison

- **Greenhouse Gas Coverage:** All the databases in this study cover CO_2 emissions , and some of them also contain non-CO_2 GHGs emissions data.

  EDGAR provides emissions data for CO_2, CH_4, N_2O, and F-gases. IEA provides statistics on total energy-related GHG emissions (including CO_2, CH_4, and N_2O), and separately reports methane emissions from the energy sector. The Global Carbon Project, which the GCB belongs to, also has the Global Methane Budget and Global Nitrous Oxide Budget, which provide methane and nitrous oxide emissions statistics, last updated to 2017 and 2019, respectively. BP provides total GHG emissions, including methane and industrial process emissions, as well as methane emissions from natural gas flaring, in its Statistical Review of World Energy 2022. WRI provides data on methane, nitrous oxide, and F-gases emissions. Its non-CO_2 GHG emissions data on land use, land use change and agriculture are drawn from the Statistics Division of the United Nations Food and Agriculture Organization (FAO), and its energy-related non-CO_2 GHG emissions data is drawn from IEA.

- **Emission Sector Coverage:** All databases in this review cover energy-related CO_2 emissions. Except for IEA and EIA, all databases include industrial process emissions, but most only cement production process emissions. EDGAR provides more comprehensive industrial process emissions data including cement production, lime production, chemical industry and metal industry (see table 4 for specific coverage comparison).
- **Frequency of Data Publication:** All databases provide yearly emission data except EDGAR, which provides monthly emissions data.
- **Emissions Data Granularity:** The foreign databases in this study report country and region level emissions data. The domestic Chinese databases, CEADs and MEIC, provide provincial level data in addition to total national emissions. IEA, EIA, CDIAC, GCB, and CEADs provide CO_2 emissions data by energy type. IEA, EDGAR, Climate Watch, WB, and CEADs provides CO_2 emissions data by sector.

Table 1 Comparison of Main Domestic and Foreign CO_2 Emissions Databases

Institute or Database	Covering Countries or Regions	Time Span	Frequency of Publication	By Energy Type	By Sector
IEA	203 countries and 42 regions	1960-2020 (OECD countries) 1971-2020(non-OECD countries)	Yearly	√	√
EIA	211 countries or regions	1980-2021	Yearly	√	×
EDGAR	Global 0.1° x 0.1° grid data	1970-2021	Monthly	×	√
CDIAC	224 countries or regions	1751-2014	Yearly	√	×
GCB	220 countries or regions	1907-2021，2022 (forecast)	Yearly	√	×
BP	More than 70 countries or regions	1965-2021	Yearly	×	×
WRI-Climate Watch	194 countries and EU	1990-2019	Yearly	×	√

Institute or Database	Covering Countries or Regions	Time Span	Frequency of Publication	By Energy Type	By Sector
WB	194 countries and EU	1990-2019	Yearly	×	√
CEADs	China and its 30 provinces, some cities and counties; Japan, Belarus, Kazakhstan, Russia, Kyrgyzstan, etc.	1997-2019	Yearly	√	√
MEIC	China and its provinces	1990-2021	Yearly	×	√

➢ Relationship between Databases and China's Official Statistics

The accounting of China’s carbon emissions provided by domestic or foreign institutions is directly or indirectly derived from China’s official energy statistics. IEA, BP, and EIA calculate energy activity data and carbon emission based on China’s official statistics. EDGAR calculates carbon emissions based on IEA energy data. CDIAC calculates carbon emissions based on the energy data provided by the United Nation Statistics Division, which is drawn from China’s official energy statistical yearbook and a questionnaire. GCB and WRI Climate Watch integrate data from the above databases. Citation relationships between these databases are shown in Figure 1 below. Specific differences in statistical scope, methodology, and data sourcing are discussed in the following sections.

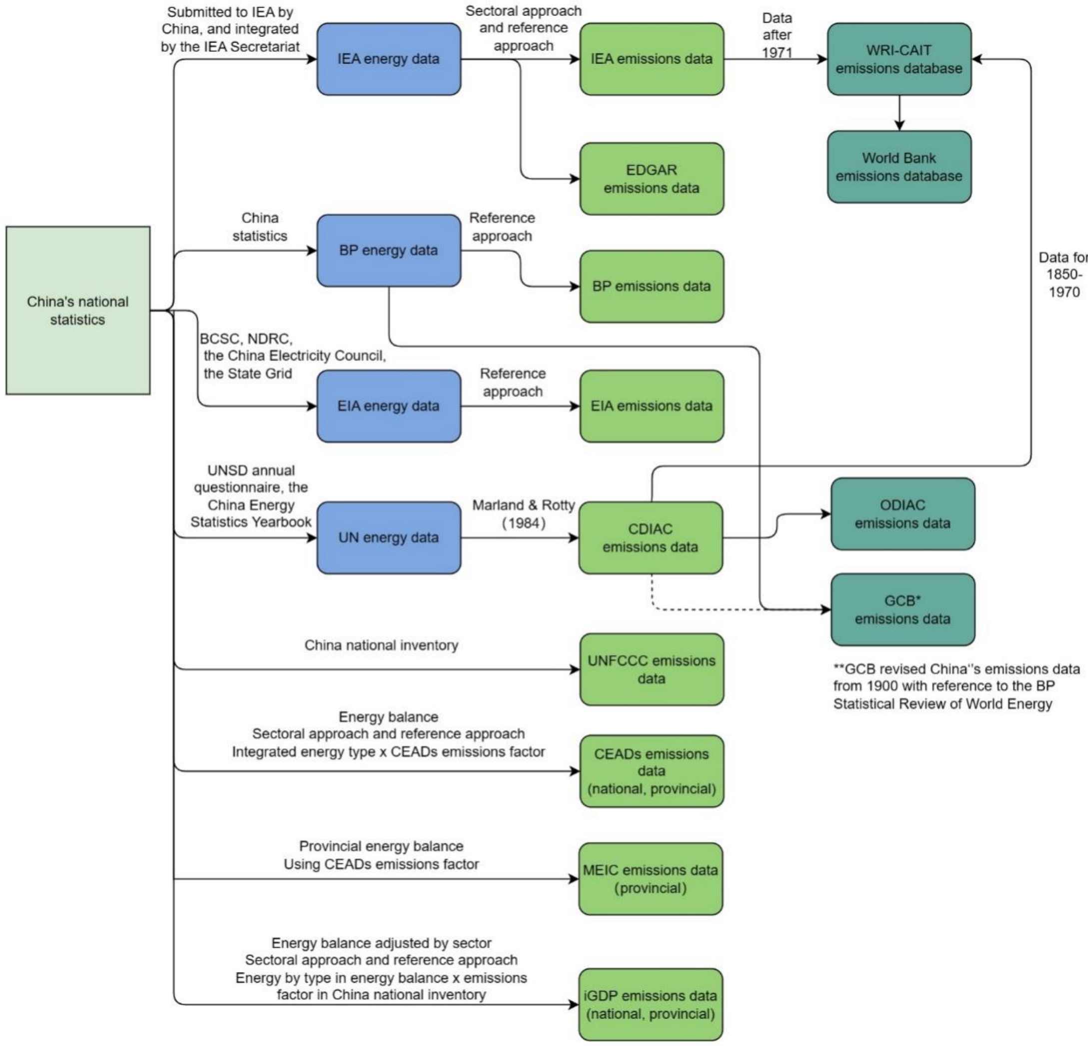

Figure 1 Sources and Relationships between Major Energy and Energy-related Carbon Emissions Databases

Note: Blue represents an energy database; light green represents a primary carbon emissions database; deep green represents a secondary integrated carbon emissions database; EDGAR uses BP's energy data to calculate carbon emissions for 2020 and 2021.[5]

China's Carbon Emissions Baseline

China has not yet built an official mechanism for publishing its annual total energy-related CO_2 emissions. Researchers obtain authoritative CO_2 emissions data primarily from two sources. One is the national emissions inventory. As a non-Annex I Party to the United Nations Framework Convention on Climate Change (UNFCCC), China has intermittently provided total energy-related CO_2 emissions data for the years 1994, 2005, 2010, 2012, and 2014 in its submitted national communications and biennial update reports. The other source is the decline rate of CO_2 emissions per unit of gross domestic product (GDP), which has been used as a binding target for China's economic and social development since the 12th Five-Year Plan, as well as an international commitment target to address climate change. China regularly publishes cumulative decline rate based on different base years (1990, 2005, 2010, 2015), as well as annual decline rate compared to the previous year. CO_2 emissions can be roughly estimated based on the GDP change rate and decline rate of CO_2 per unit of GDP.

National Emission Inventory Data

As a non-Annex I Party to the UNFCCC, China submits national communications every four years and biennial update reports every two years. To date, China has submitted three national communications and two biennial update reports, publishing China's national GHG emissions inventory for the five years of 1994, 2005, 2010, 2012, and 2014. Total energy-related CO_2 emissions data are available for these years based on the above submitted documents (see Table 2 below).

Table 2 Emissions Inventory Data Submitted by China[2]

Indicator	Unit	1994	2005	2005③	2010	2012	2014
Total CO_2 Emissions （excluding LUCF）	100Mt CO_2e	30.73	59.76	63.81	87.07	98.93	102.75
Energy-related CO_2 Emissions①	100Mt CO_2e	27.96	54.04	56.65	76.24	86.88	89.25
Proportion of Total CO_2 Emissions②	%	90.95%	90.04%	88.80%	87.60%	87.80%	86.90%
Energy-related CO_2 Emissions per unit of GDP④	Tonnes/1000 CNY, at constant 2005 prices	-	2.88	3.02	2.38	2.30	2.04
Document Date		2004.12	2012.11	2018.12	2018.12	2016.12	2018.12

[2] Data sources: The People's Republic of China Initial National Communication on Climate Change, the People's Republic of China Second National Communication on Climate Change, the People's Republic of China Third National Communication on Climate Change, the People's Republic of China First Biennial Update on Climate Change, and the People's Republic of China Second Biennial Update on Climate Change;
Note: ①All from fossil fuel combustion emissions; ②LULUCF are not included; ③Data in this column are from the 2005 GHG inventory recalculation in the People's Republic of China Third National Communication on Climate Change published in 2018; ④Energy-related CO_2 emissions per unit of GDP are extrapolated data, and GDP data is from the National Bureau of Statistics of China.

Although China's national emissions inventory is compiled based on IPCC guidelines, these guidelines are periodically refined and adjusted in terms of emissions source classification, scope of calculations, and calculation methodology. The accounting of fuel-related CO_2 emissions in China's national GHG inventory is also based on a sectoral approach. Additionally, the inventory data compiled in different years may differ due to the continuous revision of China's fossil fuel consumption, calorific value, carbon content per unit of calorific value, and carbon oxidation rate. For example, *The People's Republic of China Third National Communication on Climate Change* released in 2018 revised the data of 2005.

China's latest published recalculated data of 2005 adopts the same calculation methodology and scope as in 2010 and 2014, making the data for these years commensurate, while the data of 1994 and 2012 are not. It is for this reason that CO_2 emissions increased by 1,044 million tonnes between 2010 and 2012 while CO_2 emissions only increased by 237 million tonnes between 2012 and 2014.

National Published Decline Rate of CO_2 Emissions Per Unit of GDP

The decline rate of CO_2 emissions per unit of GDP (for short, carbon emissions per unit of GDP) refers to the decline rate of CO_2 emissions produced per unit of GDP produced compared with the base year,[6] which is an important indicator for evaluating a country's economic and social development in terms of energy transition and low-carbon development. This is a key indicator of China's progress in controlling GHG emissions, as well as an important binding target for China's 12th and 13th Five-Year plans. In 2009, China made a public commitment to the international community to reduce CO_2 emissions per unit of GDP by 40%-45% by 2020 compared with 2005. After that, CO_2 emissions per unit of GDP were incorporated as an important binding target into the Outline of the 12th Five-Year Plan for National Economic and Social Development and the Outline of the 13th Five-Year Plan for National Economic and Social Development. In October 2021, the Opinions of the Central Committee of the Communist Party of China and the State Council on the Complete and Accurate Comprehensive Implementation of the New Development Concept and Doing a Good Job in Carbon Peak and Carbon Neutrality stated that by 2025, CO_2 emissions per unit of GDP will decrease by 18% compared with 2020. In the same month, China submitted to the UNFCCC “China’s Achievements, New Goals and New Measures for Nationally Determined Contributions,” proposing that by 2030, CO_2 emissions per unit of GDP will be reduced by more than 65% compared with 2005.

Performance on reducing CO_2 emissions per unit of GDP has also been incorporated into China’s comprehensive evaluation system of local (industrial) economic and social development and the performance appraisal system of cadres. From time to time, the National Bureau of Statistics and climate change mitigation authorities publish the performance of the indicator in certain years (as shown in the table below). In the data collected and published to date, the types of decline rate of CO_2 emissions per unit of GDP released by China include the five-year cumulative decline rates during the 12th FYP and 13th FYP periods, with 2010 and 2015 as the base years, the cumulative decline rates with 1990 and 2005 as the base years, and the year-on-year decline rates. This is due to the need to meet the assessment requirements of different periods and targets. Data are missing for some years in the publicly available data from different sources (2011 and 2012). In addition, there are inconsistencies in the data for the same indicator from different sources, which may be due to inconsistencies in the timing of data releases, different sources of cited data, and revisions of indicators such as GDP and energy consumption data.[7]

Table 3 Historical Published National Energy-related CO_2 Emissions of 10,000 CNY GDP (%)

Cumulative Decline Rate (Base Year: 1990)											
2005	**2010**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Source**
46%											The People’s Republic of China Second National Communication on Climate Change [8]
Cumulative Decline Rate (Base Year: 2005)											
2005	**2010**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Source**
	20%										The People’s Republic of China Third National Communication on Climate Change [9]
	19.1%										China’s Policies and Actions for Addressing Climate Change 2011[10]
		28.56 %									China’s Policies and Actions for Addressing Climate Change 2014[11]
			33.8%								Enhanced Actions on Climate Change: China's Intended Nationally Determined Contributions [12]
				38.6%							The People’s Republic of China First Biennial Update Report on Climate Change [13]
					40.7%						Interpretation on The People’s Republic of China Third National Communication and Second Biennial Update Report on Climate Change[14]
						46%					China’s Policies and Actions for Addressing Climate Change 2018[15]
							45.8%				China Air Quality Improvement Report (2013 – 2018) [16]

								47.9%			China's Policies and Actions for Addressing Climate Change 2020[17]
									48.4%		China's Policies and Actions for Addressing Climate Change [18]
										50.3%	Xinhua News Agency[19]
										50.8%	Ministry of Ecology and Environment of the People's Republic of China[20]
Cumulative Decline Rate (Base Year: 2010)											
	2010	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Source**
		10.68 %									Chinese Central Government's Official Web[21]
			15.8%								China's Policies and Actions for Addressing Climate Change 2015[22]
				20%							Outline of the 13th Five-Year Plan for National Economic and Social Development [23]
				20%							China's Policies and Actions for Addressing Climate Change 2016[24]
				21.7%							The People's Republic of China First Biennial Update Report on Climate Change [13]
				21.8%							Xinhuanet[25]
				22%							The People's Republic of China Third National Communication on Climate Change [9]
Cumulative Decline Rate (Base Year: 2015)											
				2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Source**
						11.4%					Mid-term evaluation report: Progress on the main goals and targets of the Outline of the 13th Five-Year Plan generally meets expectations [26]
								17.9%			China's Policies and Actions for Addressing Climate Change 2020[17]
									18.8%		China's Policies and Actions for Addressing Climate Change [18]
Year-on-year Decline Rate											
	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Source**
		4.3%									China's Policies and Actions for Addressing Climate Change 2014[11]
			6.1%								China's Policies and Actions for Addressing Climate Change 2015[22]
					6.6%						China's Policies and Actions for Addressing Climate Change 2017[27]
					6.1%						The People's Republic of China Second Biennial Update Report on Climate Change [28]
						5.1%					Statistical Communiqué of the People's Republic of China on the 2017 National Economic and Social Development [29]
							4.0%				Statistical Communiqué of the People's Republic of China on the 2018 National Economic and Social Development [30]
								4.1%			Statistical Communiqué of the People's Republic of China on the 2019 National Economic and Social Development [31]
									3.9%		China's Policies and Actions for Addressing Climate Change 2020[17]
										3.8%	Xinhua News Agency [19]

Carbon Emissions Calculation based on Carbon Emissions Per Unit of GDP

Using the decline rate of CO_2 emissions per unit of GDP and the gross regional product index from the National Bureau of Statistics, the following formula can be applied to roughly estimate the emissions in the intermediate years, based on the energy-related CO_2 for the intermittent years published in the National Greenhouse Gas Emissions Inventory. Taking 2005 as an example:

$$\boldsymbol{Ems_X} = (\mathbf{1} - \boldsymbol{CarbonIntensityReduction}\%) * \boldsymbol{Ems_{2005}} * (\mathbf{1} + \boldsymbol{GDPGrowth}\%),$$

where Ems_{2005} is the CO_2 emissions of 2005, Ems_X is the CO_2 emissions of year X, $GDPGrowth\%$ is the cumulative GDP increase rate of year X compared with 2005, $CarbonIntensityReduction\%$ is the cumulative decline rate of CO_2 emissions per unit of GDP of year X compared with 2005.

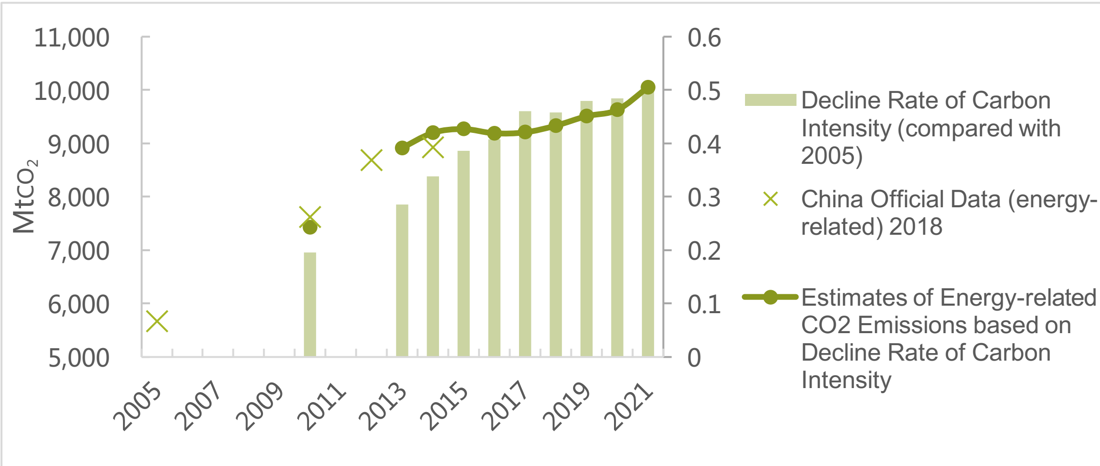

Figure 2 Estimates of Energy-related CO_2 Emissions Based on Decline Rate of Carbon Intensity[3]

Based on the above formula and the latest officially published 2005 energy-related emissions (6.381 billion tonnes CO_2), it can be calculated that China's CO_2 emissions rose from 8.92 billion tonnes in 2013 to 10.052 billion tonnes in 2021, with an average annual growth rate of about 1.59% (Figure 4). There are inconsistencies between different years when calculating China's CO_2 emissions based on the

[3] The energy-related carbon emissions for 2018 – 2021 use the 2005 recalculation data in the GHG emissions inventory. Because the data before 2018 might use the 2005 emissions data published in 2016, data for 2013 – 2017 use the year-on-year decline rate of carbon emissions per unit of GDP, while the 2015 year-on-year decline rate of carbon emissions per unit of GDP is derived indirectly from the 2015 and 2016 decline rate compared with 2005.

decline rate of CO_2 emissions per unit of GDP because different data sources are used for different estimated years. This report uses the decline rate of CO_2 emissions per unit of GDP from official sources published in the current year, but while indicators like GDP and energy data are continually being revised and updated, China has not published the updated decline rate of CO_2 emissions per unit of GDP for past years in accordance with changes in the source data. For this reason, comparing the 2014 CO_2 emissions from fossil fuel combustion in the National Communication (8.756 billion tonnes) with our calculation of 2014 CO_2 emissions based on the decline rate of CO_2 emissions per unit of GDP (8.925 billion tonnes)， there is a difference of about 170 million tonnes, with an error less than 2%. Therefore, this method cannot be used to calculate authoritative carbon emissions data for China.

Comparison of China's Emission Data

EDGAR, CDIAC, WRI, GCB, and CEADs cover fossil fuel combustion-related emissions and industrial production process emissions. Of these, CDIAC, GCB, and CEADs only include the process emissions of cement production; they do not take into account other industrial process emissions. Since industrial process emissions have a large impact on total emissions, accounting for about 15% of the total emissions according to China's official data, this report compares China's total CO_2 and energy-related CO_2 emissions as published by each institution separately.

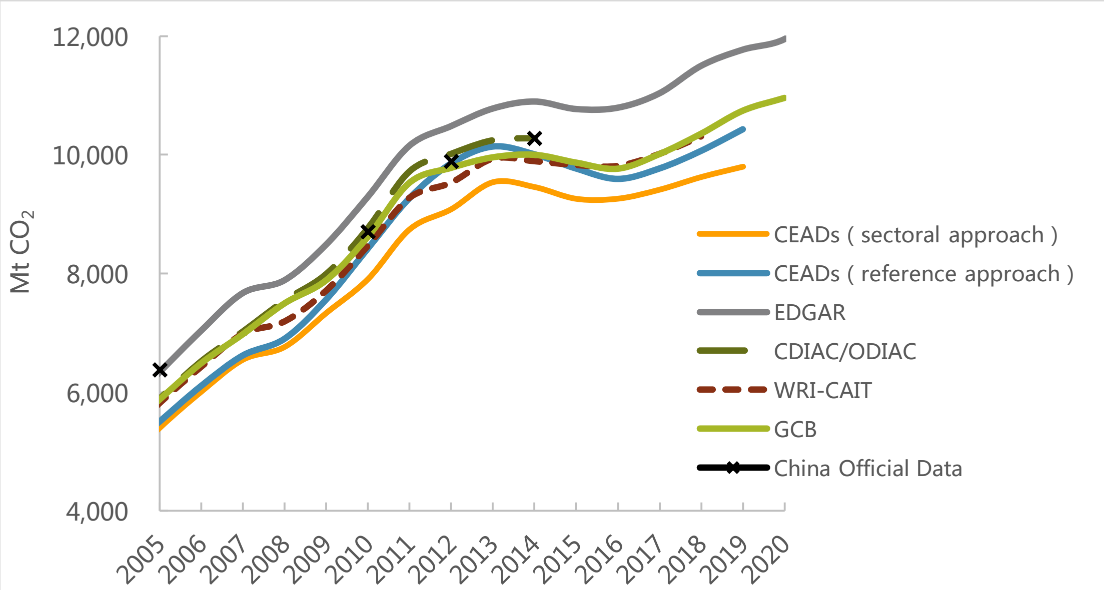

Figure 3 Comparison of China's total CO_2 Emissions Data (including industrial process emissions and excluding land use)[4]

Total CO_2 Emissions

Figure 3 compares China's CO_2 emissions from 2005 to 2021 published by EDGAR, CEADs, GCB, CDIAC, and WRI Climate Watch, as well as the official data submitted by China to the UNFCCC. The total CO_2 emissions in 2021 calculated by EDGAR and GCB are 12.466 billions tonnes and 11.472 billion tonnes, respectively, while other institutions have not yet released data for 2021. When benchmarked against China's officially published data for 2010, 2012, and 2014, the data for the same years published by CEADs (reference approach), Climate Watch, GCB, CDIAC/ODIAC are relatively closer to the official data, while the CEADs (sectoral

[4] Since World Bank's data is directly cited from CAIT database of WRI, its data is not included in the comparison figure. As for China's official data, data for years other than 2005, 2010, 2012, 2014 are from the research team's estimates based on the decline rate of carbon emissions per unit of GDP and GDP.

approach) and EDGAR's data gaps are larger. Taking 2014 as an example, EDGAR's data is 0.623 billion tonnes higher than China's official data (10.275 billion tonnes) while the CEADs data (sectoral approach) is about 1 billion tonnes lower. Because EDGAR includes the most comprehensive industrial process emissions, its estimation of CO_2 emissions is always higher than other institutions.

Energy-related CO_2 Emissions

Energy-related CO_2 emissions are the focus of China's carbon emissions reductions before 2030. Figure 4 shows a comparison of China's official energy-related CO_2 emissions with the data of the domestic and foreign institutions in this study; this study's estimate for the intermediate years based on China's official decline rate of carbon intensity per unit of GDP; and energy-related CO_2 emissions based on the national energy balance. Seven institutions – IEA, EIA, GCB, EDGAR, BP, CEADs, and CDIAC – have published data on China's energy-related CO_2 emissions data. The carbon emissions data provided by the foreign institutions are generally higher than the carbon emissions published in China's GHG emissions inventory. In 2014, the gaps in the data between the foreign institutions and China's GHG emissions inventory ranged from 1.3% to 19.3%. The smallest gap was with IEA and largest gap was with EIA.

Only four institutions, EIA, EDGAR, BP, and GCB have released energy-related CO_2 emissions data for 2021. BP's estimate is 10.523 billion tonnes, GCB 10.615 billion tonnes, and EDGAR 10.517 billions tonnes, all differing from each other by less than 1%. EIA's estimate is 11.42 billion tonnes, which is significantly higher than other institutions' results, and nearly 8.5% higher than BP's estimate. Based on China's national energy balance, this report estimates China's carbon emissions in 2021 to be 10.681 and 10.137 billion tonnes using a reference approach and a sectoral approach, respectively. Carbon emissions based on the decline rate of carbon intensity per unit of GDP are about 10.052 billion tonnes. China's carbon emissions in 2021 range from 10.052 to 11.42 billion tonnes, with a gap of up to 13.6%.

The main reason why EIA's estimate for China's carbon emissions is significantly higher than other institutions' estimates is that EIA chooses different data sources, different calorific value, and U.S. emission factors, while other institutions use default emission factors from the IPCC 2006 Guidelines. The emissions data presented by CEADs is generally lower than other institutions. This is because CEADs uses a measured value of China's coal emission factor that is lower than the IPCC default value. As coal accounts for a large proportion of China's energy consumption, relevant statistics do not show coal consumption by coal type. Additionally, different coal types differ in calorific value and carbon oxidation rate, leading to different emission factors, which affects the calculation of China's carbon emissions.

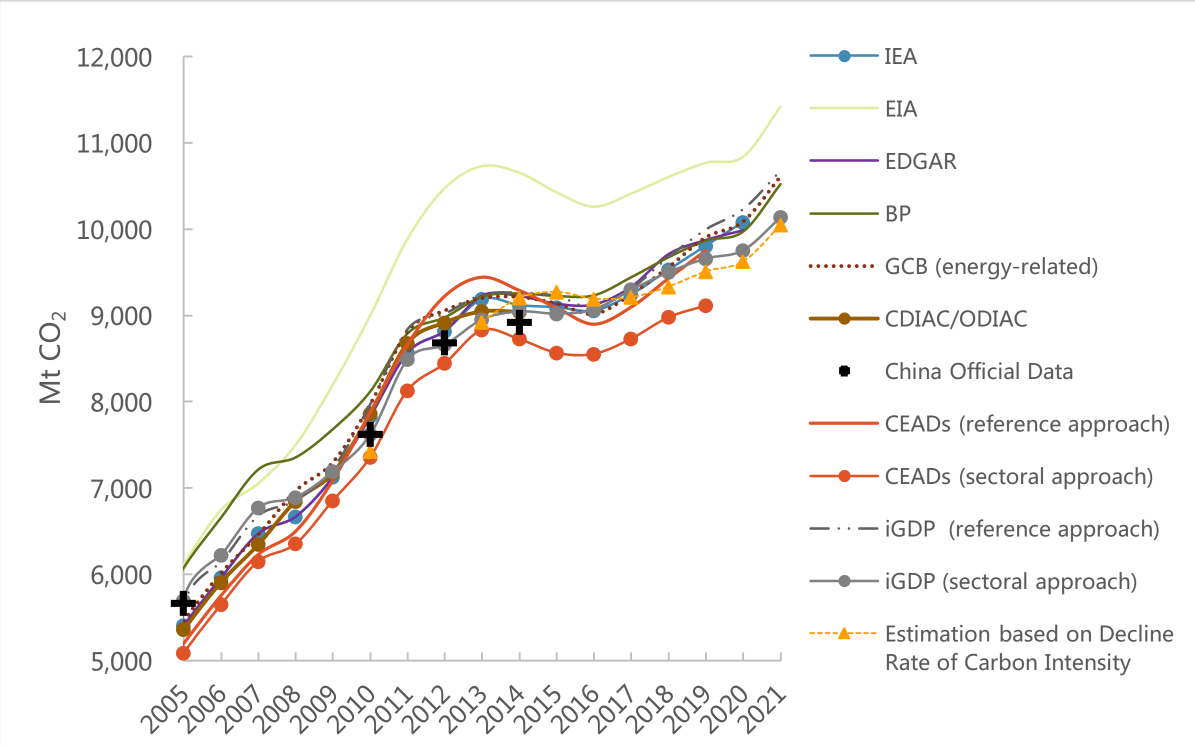

Figure 4 Comparison of Energy-related CO_2 Emissions (Mt CO_2)

Industrial Process Carbon Emissions

Most institutions only calculate industrial process emissions during cement production without considering other industries. China's official carbon emissions data for 2014 show that of the 1.33 billion tonnes of industrial process emissions, emissions from the non-metallic mineral products industry accounted for 68.8%, emissions from the chemical industry accounted for 10.7%, and emissions from metal smelting accounted for 20.5%. This is one of the reasons why EDGAR and

China's official CO_2 emissions, which cover more emission sources, are higher than other institutions. In addition, there are large differences in the cement production process emissions calculated by different institutions. CDIAC's estimate is significantly higher than other institutions, even higher than the official estimates for the non-metallic mineral product industry. The trend lines in CEADs and GCB are close to each other. But CEADs' estimate for cement production process emissions is lower than that of GCB - an average of 18% lower over the period 2000-2019 (as shown in Figure 5).

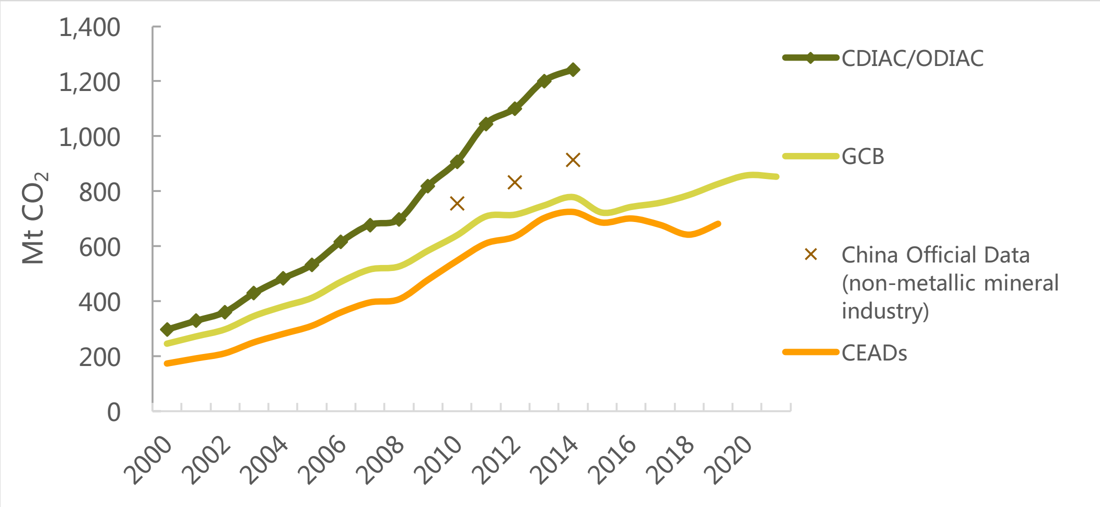

Figure 5 Estimation of Process Emissions during Cement Production by Different Institutions (China's official data is for process emissions from the non-metallic mineral industry)

Comparison of Carbon Accounting Methods of Domestic and Foreign Databases

Differences in carbon emissions data presented by domestic and foreign research institutions are due to differences in accounting boundaries. For energy-related CO_2 emissions, the differences mainly lie in emission factors, accounting method and energy data (as shown in Figure 6 below). Energy data is one of the key factors behind differences in carbon emissions. The differences in energy data source, sector definition, fuel classification, and calorific value (discount standard coal coefficient), all lead to differences in energy data, which in turn lead to differences in carbon emissions data.

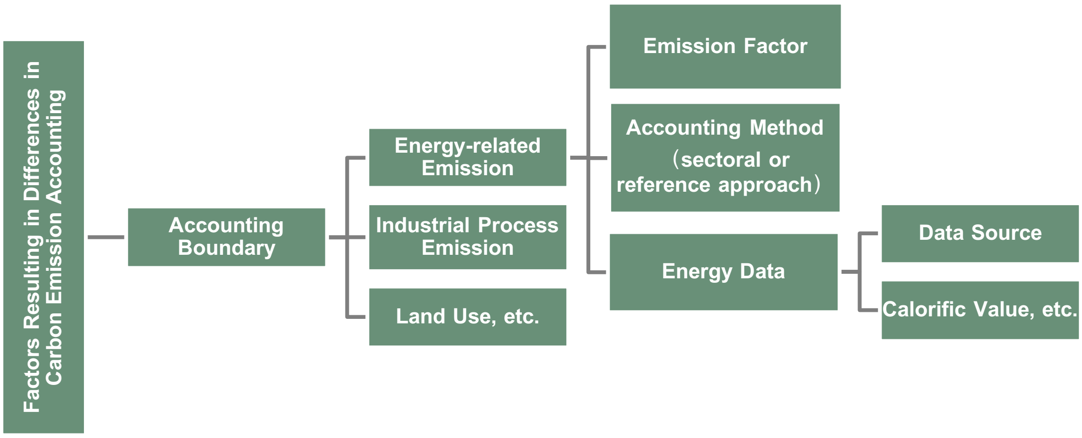

Figure 6 Factors Resulting in Differences in Carbon Emission Accounting by Domestic and Foreign Research Institutions

Accounting Boundary (Sources of Emissions)

CO_2 emissions from human activities can be classified as fossil fuel combustion emissions, non-energy use emissions (or emission from fuel used as raw material), flaring and venting, industrial process emissions, and emissions from waste management and land use change, etc. Analysis results are more informative when comparing data on the basis of consistent accounting boundaries.

Table 4 compares the accounting boundaries of carbon emissions or published data of major domestic and foreign institutions. Different institutions and databases choose different accounting boundaries when performing CO_2 emissions accounting. For example, EDGAR's carbon accounting boundary is the largest, covering almost all CO_2 emissions sources. IEA mainly covers fossil fuel-related CO_2 emissions. EIA's scope is the smallest, only including emissions from coal, oil, and gas combustion, but also considering emissions from non-energy use of oil-based fuels. The BP Statistical Review of World Energy includes and separately reports CO_2 emissions from flaring during natural gas extraction. BP deducts the non-fuel use portion of fossil fuel consumption (e.g., petroleum products and natural gas consumption in the petrochemical industry, and asphalt used in road construction) according to the share of non-combustion use fossil fuels in the IEA energy balance. BP, GCB, EIA, and IEA do not consider carbon emissions from biofuels. In addition, research institutions deal with international bunkers differently. Almost all foreign databases include or separately report emissions of international bunkers while the CEADs database does not. The MEIC database is not listed in the comparison table because its methodology is too simple.

The statistical scale may also be different for the same accounting object. For example, CEADs, GCB, and CDIAC only include cement production when accounting for industrial process emissions, while EDGAR includes cement production, lime production, the chemical industry, and the metal industry. This is one of the reasons for the large gap in the emissions data between CEADs and EDGAR.[32]

Table 4 Comparison of Accounting Boundary for China's CO_2 Emissions by Main Domestic and Foreign Databases[1,33]

Institute or Database	Fossil Fuel Combustion	Flaring During Fossil Fuel Extraction	International Bunkers	Non-energy Use	Industrial Process Emission	Bioenergy Combustion	Waste Management	LUCF
National GHG Inventory Submitted by China to UNFCCC [28]	√	×	× Report separately in the form of information	√ Included in others	√ Including cement and steel production and chemical industry	× Report separately in the form of information	√	√ Report separately
BP	√	√ Report separately	×	×	√ Report separately	×	×	×
CDIAC	√	√	√	√	√ Including cement production	×	×	√ Report separately
CEADs	√	×	×	×	√ Including cement production	×	×	×
Climate Watch[34]	√	√	√	×[5]	√ Including cement production	×	×	√ Report separately
EDGAR	√	√	× Not included in country statistics [35]	√	√ Including cement production, lime production, chemical industry and metal industry, etc.	√	√	√
EIA	√	×	√	√	×	×	×	×
GCB	√	√	× Not included in country statistics	-	√ Including cement production	×	×	√ Report separately
IEA	√	√	√	×	×[6]	×	×	×

[5] Although the CAIT methodology states that it includes non-energy use emissions, its fossil fuel combustion emissions are sourced from IEA, while IEA states in its latest methodology document that non-energy use emissions have been removed in accordance with the 2006 IPCC Guidelines. Here the information from IEA prevails.

Institute or Database	Fossil Fuel Combustion	Flaring During Fossil Fuel Extraction	International Bunkers	Non-energy Use	Industrial Process Emission	Bioenergy Combustion	Waste Management	LUCF
		Report separately						Not included

Accounting Methodology

According to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, accounting methodologies for energy-related carbon emissions are categorized into sectoral and reference approaches. The reference approach is a top-down method that calculates fossil fuel combustion-related carbon emissions based on the energy consumption data provided by each country. The sectoral approach is a bottom-up method that calculates CO_2 emissions by sector and by fuel type according to economic sector classifications.

The sectoral approach includes 3 tiers. Tier 1 methods are based on fuel type and average emission factor. Tier 2 methods use country-specific emission factors. Tier 3 methods use more detailed measurement data and facility-level data. The reference approach has relatively lower requirements for data, which is a relatively easy method to calculate CO_2 emissions.[36] China's national GHG inventory submitted to UNFCCC is estimated using the Tier 2 sectoral approach and calibrated with the reference approach. Domestic and international research institutions use different accounting methods. IEA and CEADs use both the sectoral approach and reference approach. EDGAR and MEIC use the sectoral approach. EIA, CDIAC, and BP use the reference approach or similar approaches (see Table 5 below).

Table 5 CO_2 Accounting Method and Emissions Factors Used by Domestic and Foreign Research Institutions

Institute or Database	Accounting Method	Emissions Factor
National GHG Inventory Submitted by China to UNFCCC	Estimated by sectoral approach (Tier 2) in the *2006 IPCC Guidelines* and calibrated with reference approach, referring to the *2006 IPCC Guidelines*	China specific emissions factors or referring to the *2006 IPCC Guidelines*
IEA	Sectoral approach (Tier 1) and reference approach in the *2006 IPCC Guidelines*	Default emission factors in the *2006 IPCC Guidelines*
EIA	Reference approach[35]	Emissions factors based on local fuel measured value in *Emissions of Greenhouse Gases in the United States 2006*

6 But including fuel combustion emissions under IPPU (industrial process and product use) category: emissions from coke, coke oven gas, blast furnace gas and other recovered gases in the iron and steel industry, and emissions from coke consumption in non-ferrous metal production.

Institute or Database	Accounting Method	Emissions Factor
EDGAR	Sectoral approach (Tier 1)[32] in the *2006 IPCC Guidelines*	Default emission factors in *the 2006 IPCC Guidelines*
CDIAC	Marlan and Rotty method, similar to the reference method[35]	CDIAC own emission factors
BP	Reference approach	Default emission factors in *the 2006 IPCC Guidelines*
CEADs	IPCC sectoral approach (Tier 2) and reference approach	Measured emission factors by CEADs
MEIC	Sectoral approach	Measured emission factors by CEADs

Emission Factors

An emission factor is defined as a coefficient characterizing GHG emissions per unit of production or consumption activity.[37] In this report, emissions factors refer to the CO_2 emissions per unit energy of fuel combustion. Emissions factors are determined by the carbon content and carbon oxidation rate of fuels, fuel quality and technological development level.[38] The carbon oxidation rate is nearly 100% when the fuel is completely combusted. Therefore, carbon content of the fuel is the main factor influencing fuel combustion emissions. The 2006 IPCC Guidelines provide default values and upper and lower limits of the carbon content of various kinds of oil, coal, gas, waste, and bioenergy with the unit in kg/GJ. On this basis, the 2006 Guidelines calculate the default value and upper and lower limits of the effective CO_2 emissions factors for each energy type on the assumptions that the oxidation rate is 100%, with the unit in kg/TJ. But the 2006 Guidelines also recommend that the actual carbon oxidation rate should be considered in higher tier calculation.

IEA, EDGAR, and BP use the default emissions factors in the 2006 IPCC Guidelines. EIA uses the emissions factors based on local fuel measured value in Emissions of Greenhouse Gases in the United States 2006.[2,39] CDIAC uses its own emissions factors. CEADs detects the carbon content per unit of mass of China's coal samples and estimates the carbon oxidation rate for each fuel.[4] Both CEADs and MEIC use the emissions factor calculated by the CEADs team.

In the energy-related CO_2 emissions in the national GHG inventory submitted by China to the UNFCCC, the energy, manufacturing, construction, transportation and other industries use China's specific emission factors, while different subsectors under the non-metallic mineral production industry, chemical production industry, and metal production industry use China's specific emission factors[14] or refer to default emissions factors in the 2006 IPCC Guidelines. The measuring accuracy of calorific value and carbon content of coal is specific by sector and by coal type in China's specific emission factors. The carbon oxidation rates of power station boilers and industrial boilers are obtained by sampling and measurement.[8]

Energy Data Statistical Differences

➢ Calorific Value of Fuels

A calorific value of a fuel, also known as fuel heat value, is the heat released during the combustion product's cooling to the pre-combustion temperature (generally ambient temperature) when a unit of mass (solid or liquid) or volume (gas) of the fuel is completely combusted. Calorific value of fuels is the main indicator for evaluating the quality of fuels and is the basis for determining the equivalent value of fuels when converted to standard coal. Calorific value is classified as gross calorific value and net calorific value. The difference between gross and net calorific value lies in whether the water in the fuel combustion products is liquid or gaseous, with water in the liquid state being the gross calorific value and water in the gaseous state being the net calorific value. Net calorific value is generally used as the calculation basis in energy use. Choice differs in different countries. Japan and North American countries are accustomed to using gross calorific value, while China, Russia, and other countries of the former Soviet Union, Germany, and OECD countries use net calorific value, and some countries use both gross and net calorific value. The gap between gross and net calorific value is about 5% for coal and oil, and about 10% for natural gas and coal gas.[40]

The default emission factors in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories use net calorific value[40]. Different databases use different calorific values for different energy types. IEA uses net calorific value. EIA uses gross calorific value. BP and UN use different calorific values according to different fuel types (shown in Table 6 below). CEADs uses net calorific value measured from China's coal sample. In addition, existing studies have found that the calorific values of China's coal samples are, on average, lower than the IPCC default value and international average value[4], which is likely to be one of the main reasons that the estimates of energy consumption and emissions by databases like EIA are higher than China's official data and other databases.

Table 6 Calorific Value Type Used by Different Databases[33,41,4]

Fuel	IEA[7]	EIA	BP	UN	CEADs/MEIC
Oil	NCV	GCV	NCV	NCV	NCV
Gas	NCV	GCV	GCV	GCV	NCV
Coal	NCV	GCV	GCV	NCV	NCV

In China's energy balance, all fuels use net calorific values. The net calorific value of each fuel can be calculated based on the physical quantity and standard quantity balances. The China Energy Statistical Yearbook, which is published annually, gives the reference coefficients for various energy types to be converted to standard coal.

➢ Data Sources

Energy data is the basis for carbon emissions accounting. Different data sources can also result in differences in energy data and follow-up carbon emissions accounting. On an annual basis, China publishes the China Energy Statistical Yearbook, which provides statistics on energy production and consumption. IEA, BP, EIA, and the UN Statistics Division obtain China's energy data mainly from the statistics submitted or published by the Chinese government. They also obtain relevant data through interview surveys or from collected literature. Other foreign databases' energy data are primarily based on the energy data provided by these four institutions.

According to the agreement between China and the IEA, the National Bureau of Statistics of China submits Chinese energy production and consumption data to the IEA Secretariat annually, based on which IEA processes the data and regularly publishes China energy statistics and energy balances. The energy data provided by the IEA are widely used by many research institutions. The Chinese energy data in the EIA database are mainly drawn from the public statistics provided by the China's National Bureau of Statistics and the National Development and Reform Commission[8], as well as the China Electricity Council, the State Grid, and relevant

[7] IEA uses China specific heat value coefficients for crude oil and liquefied natural gas among coal-based fuels and oil-based fuels, while other fuels use default values.

industry associations. Chinese statistics published by the UN Statistics Division are drawn mainly from the China Statistical Yearbook and other relevant publicly available yearbooks, as well as the annual energy statistics questionnaire.

As mentioned above, the energy data provided by foreign research institutions are based on China's official energy statistics, processed in accordance with each institution's accounting boundary and methodology as well as relevant research. As a result, there are differences in the energy data provided by each institution. As shown in the table below, China's energy consumption data from 2005 to 2021 provided by IEA, EIA, BP, and the UN Statistics Division differs in terms of both trends and absolute amount. The historical total primary energy consumption of China provided by BP is very close to the China energy balance using coal equivalent calculation.

Both of them use the same data sources and use the coal equivalent calculation for the conversion of primary electricity to standard coal. The total energy supply data from the UN is slightly lower than the statistics of other institutions, but the trend is very close to the China energy balance using calorific value calculation, with a small data gap. It is worth noting that EIA's statistics on total energy consumption are significantly higher than that of other institutions. The main reason is that EIA uses coal equivalent calculation to convert primary energy to standard coal, which will be larger than that using a calorific value calculation. Secondly, EIA's energy data is not only obtained from the China Energy Statistical Yearbook, but also industry associations, which is also one of the possible reasons for the differences in the data.

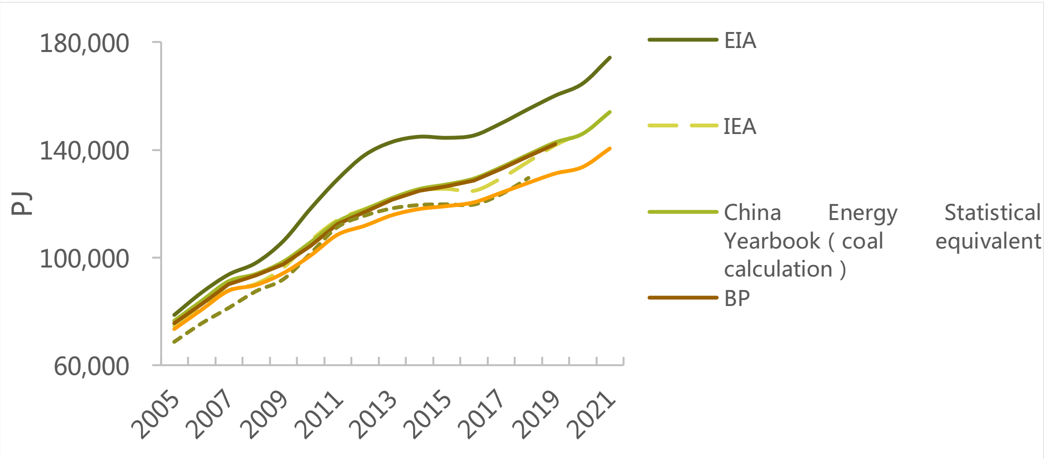

Figure 7 Accounting of China's Total Energy Consumption by Different Institutions[8]

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[8] Note: IEA and UN only provide data on total energy supply; the China Energy Statistical Yearbook provides total energy consumption data using coal equivalent calculation and calorific value calculation, respectively; EIA provides total energy consumption data and BP provides total primary energy consumption data.

Conclusions and Suggestions

Long time series analyses of China's carbon emissions data currently rely primarily on data provided by domestic and foreign research institutions. Comparisons in this report show that there are no data sources that are completely in accordance with the accounting boundary and methodology of the China GHG emissions inventory. The emissions calculated by these institutions may not reflect the real state of China's carbon emissions.

For data users, the total CO_2 emissions estimated by CEADs using the reference approach and by GCB are closer to the data for the reported years in China's GHG emissions inventory, which are more suitable as references for long time series analyses. Although there might be situations where EDGAR's emission calculations are higher than China's actual emissions due to the adoption of the default emissions factors in the 2006 IPCC Guidelines, EDGAR covers industrial process CO_2 emissions most thoroughly, encompassing the most emission sources. Except for BP, all other institutions provide emissions data by energy type or by sectors. Of these, IEA and CEADs provide emissions data by sectors and by energy types, making them suitable sectoral emission references.

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