The gigatonne gap in China's carbon dioxide inventories

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Reliable national statistics are fundamental for climate change science as well as for global negotiations about future emission targets and the allocation of responsibilities. China, the world's top CO_2 emitter[1,2], has frequently been questioned about its data transparency and accuracy of energy and emission statistics[3-7]. China implemented a top-down statistical system where energy statistics are compiled under the aegis of the National Bureau of Statistics (NBS) at the central government level, which oversees and coordinates the corresponding statistical departments at provincial and county levels[8]. The NBS publishes annually both national and provincial energy statistics. We compile the CO_2 emission inventories for China and its 30 provinces for the period 1997–2010. However, CO_2 emissions calculated on the basis of the two publicly available official energy data sets differ by 1.4 gigatonnes for 2010. The figure is equivalent to Japan's annual CO_2 emissions, the world's fourth largest emitter, with 5% of the global total. Differences in reported coal consumption in coal washing and manufacturing are the main contributors to the discrepancy in official energy statistics. This paper presents an initial step to share and validate data and discuss methodologies in full transparency towards better energy and emission data for China.

China's official energy data are collected, compiled, validated and published by the NBS and its local statistics offices. The NBS designs and publishes survey principles and reporting formats that are applied to all regional and local statistical departments for collecting energy data and information from firms and households. The statistics offices at provincial level conduct compilation and primarily validation processes, and submit the data to the NBS for final validation and compilation of the national energy inventory. The NBS publishes annually both national and provincial Energy Balance Sheets in China's Energy Statistical Yearbook[9], which provides detailed energy inventories and final energy consumption data for the country and each province. In this study, we calculate CO_2 emissions for both China and its provinces from 1997 to 2010 and investigate potential reasons for the data discrepancies between emission and energy inventories. We adopt publicly available energy statistics from Chinese authorities and follow the Intergovernmental Panel on Climate Change (IPCC) emission accounting approach[10] to compile emission inventories for the nation as well as every Chinese province (Methods). Furthermore, we identify the statistical and institutional factors responsible for the discrepancies in Chinese statistics and make policy recommendations for improving data quality in China's energy statistics.
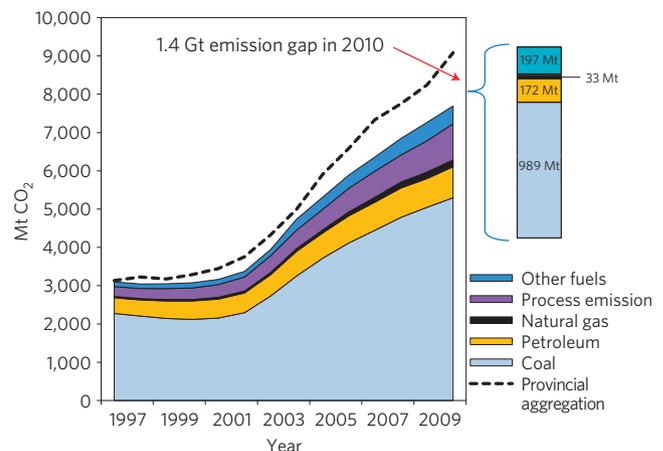

Figure 1 | The sources of China's CO_2 emissions by fuel type during 1997–2010. The area chart (left) illustrates the increase of CO_2 emissions calculated from the national energy statistics since 1997 broken down by different fuel type. Other fuels include, for example, coke oven gas, other gas, other coking products, LPG, refinery gas and other petroleum products. The dashed line represents the aggregated CO_2 emissions calculated from the provincial energy statistics 1997–2010. The column chart (right) presents the 1.4 Gt emission gap in 2010 between national and provincial statistics and the pattern of different fuel types in contributing to the emission gap. For data sources, see refs 9,24.

China conducts and publishes energy inventories in the same format for the nation and its 30 provinces, annually. In principle, the national energy statistics should be identical to the provincial ones. China has revised its energy consumption data at the national level twice in 2005 and 2010. Both revisions have adjusted only the total national energy use with special attention to the annual coal consumption from 1996 to 2008 (ref. 11). However, both updates have failed to address the data inconsistencies between China's national and provincial Energy Balance Sheets. Here, we present the sources of China's emission increases by fuel type during 1997–2010 using the latest revised data (as shown in Fig. 1). According to Chinese national statistics, on average, CO_2 emissions have been growing at 7.5%, annually, from 3,102 million tonnes (Mt) in 1997 to 7,693 Mt in 2010. In contrast, the aggregated emissions of all Chinese provinces have been increasing annually at 8.5%, on average, from 3,131 Mt in 1997 to 9,084 Mt in 2010. The emission discrepancy had increased initially with a peak of 10% (382 Mt) difference between the two data sets in 2003, then decreased to

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		2007	2008	2009	2010
CO$_2$ emission (Mt)	Provincial summation	7,334	7,731	8,240	9,084
	National total	6,359	6,848	7,266	7,693
	EIA	6,257	6,800	7,707	
	IEA	6,032	6,508		
	CDIAC	6,791	7,031	7,463	8,041
	World Bank	6,533	7,032		
	WRI	6,032	6,508		
	LBNL		6,666		
	EDGAR	6,953	7,649		
Raw coal (Mt)	Provincial summation	3,209	3,361	3,562	3,910
	National total	2,588	2,810	2,966	3,163
Crude oil (Mt)	Provincial summation	353	362	391	441
	National total	340	355	381	429
Natural gas (million m^3)	Provincial summation	71,484	82,833	96,823	111,612
	National total	69,523	81,293	89,520	94,167

Sectoral contributions to the 747 Mt discrepancy of raw coal use between national total and provincial summation in 2010

Energy transformation and loss (56%)
- Thermal power production (2%)
- Heating supply (14%)
- Coal washing (37%)
- Coking and others (3%)
- Energy loss (<1%)

Final energy consumption (44%)
- Agriculture (1%)
- Manufacturing (37%)
- Construction (<1%)
- Transportation (1%)
- Commercial sectors (2%)
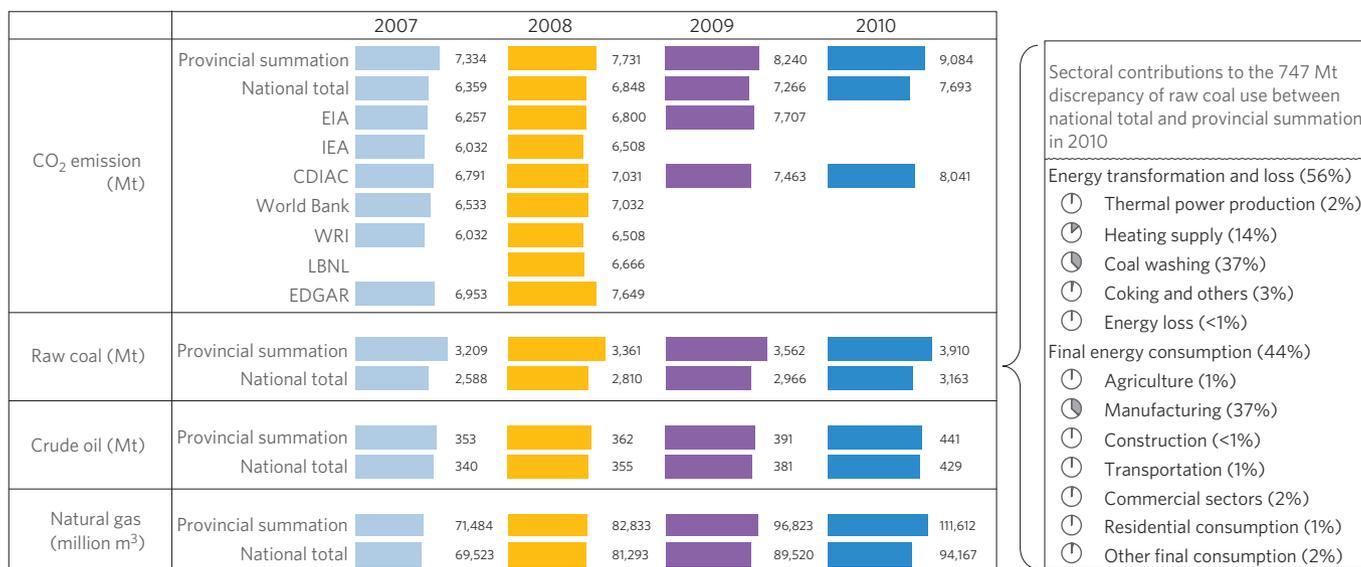- Residential consumption (1%)
- Other final consumption (2%)

Figure 2 | Comparison of China's emission and energy statistics. For data sources, see Supplementary Section S4. The starting point of all bars is '0'. National total and provincial summation CO$_2$ emissions are estimated by the authors (see Methods). We select raw coal, crude oil and natural gas to illustrate the differences in China's energy statistics. Each energy type includes the final energy consumption and energy for transformation. There are different representations of the total CO$_2$ emissions from international statistical sources, but their emission accounting approaches are different (the full data set and explanations of data sources are available at Supplementary Section S4). The pie charts and associated percentages on the right side of the figure explain the energy consumption sectors contributing to the discrepancy in raw coal consumption between provincial and national statistics in 2010. The total gap of 747 Mt was mainly caused by energy transformation and loss (56%) and final consumption sectors (44%).

5% (257 Mt) in 2004 and widened again to 18% (1,391 Mt) in 2010. An early emission divergence (1997–2004) was observed and analysed by several studies[4–6,12,13], but the later discrepancies since 2005 went almost unnoticed and were rarely discussed in the literature. China's emission discrepancy in 2010 is equivalent to about 5% of the global total (in 2008) and higher than the CO$_2$ emissions of the world's fourth largest emitter—Japan, or the combined emissions of all African countries. The emission gap is mainly due to the inconsistencies of coal consumption between national and provincial statistics. For example, emissions caused by coal consumption contribute 71% of the emission discrepancy in 2010, whereas emissions from petroleum, natural gas and other fuels (including coke oven gas, other gas, other coking products, LPG, refinery gas and other petroleum products) account for 12%, 2% and 14%, respectively. The data situation is better when accounting cement processing emissions, which show a much smaller difference between provincial and national statistics.

This hints already at the fact that the poor quality of energy data is the dominating factor in contributing to the emission discrepancy in China. In 2010, China's national energy consumption was 3,249 Mt standard coal equivalents, but the aggregated data from the provinces was 20% higher, that is 3,895 Mt standard coal equivalents. The official explanation offered by the NBS is: 'as (different) conversion factors (are applied in converting to standard unit of energy consumption), the sum of the data by region is not equal to the (national) total'[9]. If such differences can be fully explained by conversion factors, then the amount of energy consumed in physical units should still be identical. The amount of total raw coal consumption in 2010 from the national Energy Balance Sheet is 3,163 Mt, whereas the aggregated figure from provincial sheets is 3,910 Mt. The discrepancy of raw coal consumption between the two data sets is 24%, whereas the discrepancies of other types of primary energy consumption are relatively small (Fig. 2). The difference for reported raw coal consumption for coal washing and heating for energy transformation processes between the two data sources can contribute 37% and 14% of the total discrepancy of 747 Mt in raw

coal consumption, respectively, and manufacturing explains 37% of the gap (see Supplementary Section S2 for data discrepancies of other energy types).

There are two explanations for such a large uncertainty. First, the statistical approach on data collection, reporting and validation is opaque[14]. Large- and medium-size enterprises are the primary source for energy statistics; for example, the top 1,000 enterprises accounted for 33% of national energy consumption and 47% of industrial energy usage in 2004 (ref. 15). In many industrialized regions, those key energy-intensive industries (for example steel, cement and power production) have increasingly been clustered in industrial parks. This has simplified data collection and reporting procedures and has improved the quality of data provided by large- and medium-sized companies. Instead, regional and national energy statistics can be largely skewed by energy production and consumption of small enterprises as most of them have neither records nor qualified personnel to report energy consumption data. In fact, a growing number of small firms engaging in coal mining and washing flourish in many poor regions owing to the surging demand on electricity generation for producing materials for infrastructure construction nationwide. In 2009, 31% of coal (including raw coal and washed coal) was produced by small firms[16], who use outdated technologies, but their energy consumption data were not well captured in official statistics[17]. The production capacity of energy quickly accumulated in economically less developed provinces. For example, the average annual growth rate of washed coal production in western China was 22%, compared with 10% in eastern provinces, between 2005 and 2010. Furthermore, since the late 1990s, many small coal mines and coal washing mills had been closed owing to low energy efficiency and safety concerns by order of the government to 'shutting down the 15 smalls'; however, many of them have re-opened or moved their operation to different locations owing to a lack of continuity of policy implementation and monitoring[5]. This has contributed to the inconsistencies in provincial energy balances between energy production and consumption and to Chinese national energy
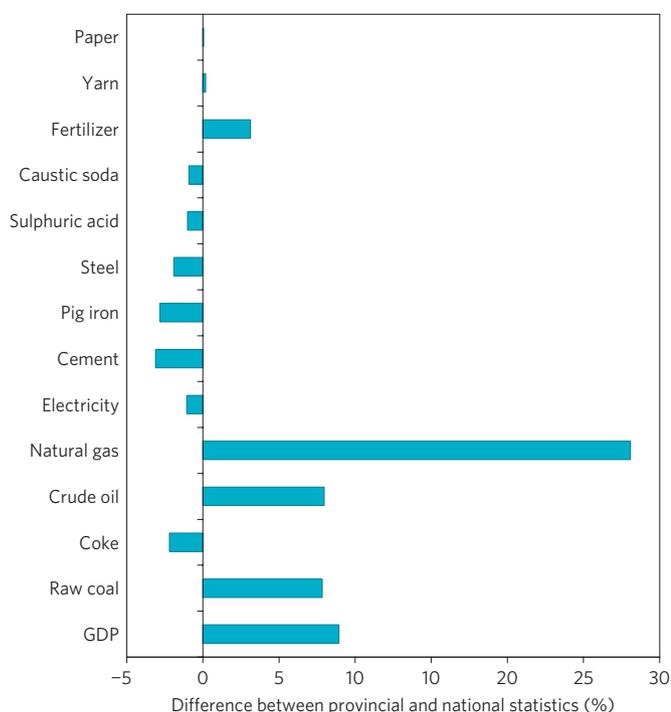
Figure 3 | Comparison of industrial outputs in physical units between China's national and provincial statistics in 2010. A positive percentage shows how much larger the provincial statistics are compared with the national statistics. Data set and data source explanation is available in Supplementary Table S2.1.

statistics. For example, the aggregated provincial primary energy consumption in 2009 was 3,512 Mt for raw coal, 391 Mt for crude oil and 96,843 million m³ for natural gas. In contrast, the total available energy supplies (including imports) of the three types of fuel in the provincial statistics were 2,990 Mt, 381 Mt and 89,690 million m³, respectively. Hence, there was a gap of 522 Mt or 17% for raw coal, which may be largely explained by those small coal mines unaccounted for in official statistics (full data set and other years' comparison available at Supplementary Table S2.2). The discrepancies between supply and consumption of crude oil and natural gas are relatively small.

Second, the statistics departments in China are not politically independent agencies, but are often pressurized by other government agencies to provide statistical data 'to fit' different political purposes[3]. The performances of Chinese local authorities are usually measured by gross domestic product (GDP) growth, leading to significant over-reporting on local and regional outputs. Thus, local authorities frequently report higher energy consumption data to match their reported GDP. This can be detected by investigating the data mismatch of physical industrial outputs between the provincial and national statistics (as shown in Fig. 3). The aggregation of provincial GDP in 2010 is about 9% larger than the national figure, whereas all key primary energy production is closely correlated with GDP: that is, the aggregation of provincial production of natural gas, crude oil and raw coal is respectively 28%, 9% and 8% larger than the national figures. However, the statistical differences for other energy-intensive products such as cement, pig iron and steel are small, and within an error range of 2% to ~3%. This can further indicate that there exists over-reporting in energy statistics at the provincial level. On the other hand, to improve environmental quality and sustain economic development, the Chinese government developed a national emission reduction policy for its 11th five-year plan (2006–2010). This plan presents a 20% efficiency improvement for energy consumption[18]. Owing to

the international pressure on emission reduction, this commitment has been extended to a 40–45% reduction of carbon intensity by 2020 when compared with the level of 2005 (ref. 19). Therefore, the national government unintentionally causes under-reporting of energy consumption data especially on coal consumption[7]. Satellite data have confirmed that there was significant under-reporting of coal production and consumption in China's official statistics[20].

These discrepancies have a number of important implications. The large deviation of China's CO_2 emissions can significantly skew the global total[21], resulting in an incorrect understanding and modelling of the global carbon cycle[7], and thus hampering the ability of many climate models to produce trustworthy and accurate predictions. The sad fact is that Chinese energy and emission data as primary input to the models will add extra uncertainty in modelling simulations of predicting future climatic change. Such an uncertainty of CO_2 emissions also brings challenges in allocating responsibilities and setting emission targets during international negotiations for post-Kyoto to achieve global emission reductions. Moreover, China is planning a domestic emission cap-and-trade mechanism between different provinces[22], which requires an effective measuring, reporting and verification system at both the provincial and national level. Therefore, it is of critical importance to reform the present statistical system with special attention to coal statistics in small-scale manufacturing and coal washing to derive better estimates for energy consumption and the corresponding CO_2 emission. Using remote-sensing data is another effective tool to reduce the statistical gap and monitor and verify CO_2 emissions. CO_2 emissions, in turn, depend on reliable energy consumption data and appropriate understanding of emission factors. Increasing the qualified statistical labour forces and their on-site surveys would help the national and regional statistical offices to improve and update the fuel combustion factors they have been using since 1990. The information provided by the Chinese Energy Statistics Yearbook should include important factors such as quality of coal, oxidation rates and so on. More bottom-up research is required to fully understand the variation of these factors within and between provinces and over time.

Methods

As the world largest CO_2 emitter, China does not officially publish annual estimates of CO_2 emissions[23]. In this paper, we estimate China's national CO_2 emissions as well as the aggregation of all provinces from 1997 to 2010, based on two different official and publicly available energy data sources. We account for fossil-fuel combustion, emissions from cement production (including processing emissions of clinker production) and international bunker fuel emissions. This method is used for estimating both national and provincial CO_2 emissions. Then, we compare and analyse both estimates with regards to the potential reasons behind the data gap. Both data sets obtained are from official statistical bureaus in China, which are available from the Chinese Energy Statistics Yearbook[24]. Our estimation of the national total CO_2 emissions is based on the energy statistics from the NBS whereas the provincial summation is based on data from 30 provincial statistics offices (excluding Tibet, Hong Kong, Macao and Taiwan). To keep the consistency of the energy statistics, we collect the Energy Balance Sheets in the format of 18 types of fuel in physical units, which are available at the provincial as well as the national level. Supplementary Sections S1 and S2 provide all energy data and data sources available in China's national and provincial statistics.

We adopt the IPCC sectoral approach[10] to calculate the CO_2 emissions from energy combustion and cement production as described previously[25] and applied in other studies[1,26–29]. We applied the method to calculate emissions for all provinces and the national total from 1997 to 2010. The inventories include emissions from fuel combustion and cement production. Total energy consumption by production sectors and residents provides the basis for calculating the energy combustion CO_2 emissions[25]. We construct the total energy consumption data for production purposes based on final energy consumption (excluding transmission losses), plus energy used for transformation (primary energy used for power generation and heating) minus non-energy use. Transmission energy losses refers to the total loss of energy during the course of energy transport, distribution and storage and the loss caused by any objective reason in a given period of time[9]. The loss of various kinds of gas due to discharges and stocktaking is excluded[9]. Supplementary Section S3 provides steps for estimating China's emissions at national and provincial levels.

CO_2 emissions of each fuel type and each final use have been estimated by multiplying the total energy consumption with their respective emission factors of different fuel types and oxidization rates for different final use. As energy efficiency in China is generally lower than that of developed countries, we use sector-specific values for oxidation rates of coal (Supplementary Section S3—part 1), which are generally lower than the IPCC default value. We assume those emission factors and oxidization rates are equal among regions and stable over time. In fact, there are large differences in the coal quality within China, which may also result in different coal types used by different end users (for example, coal used in power stations versus coal briquettes used by households). However, owing to data availability, we cannot fully explore such differences. Compared with the difference in raw coal consumption between national and provincial sources, those emission parameters would play a rather minimal role in affecting the size and trend of China's emission gap.

To estimate the industrial process emissions of cement production, we omit the emissions from the production of ammonia, carbides and soda, because of their relatively low share and the lack of physical production data for all provinces.

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Author contributions

D.G. and Z.L. designed the research; Z.L., S.L. and D.G. compiled the data; D.G. and Z.L. performed initial analysis; all authors contributed to the results' interpretations and writing.

Additional information

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In the version of this Letter originally published online, the affiliation for Dabo Guan, Zhu Liu and Yong Geng should have been 'Key Laboratory of Pollution Ecology and Environmental Engineering, Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, China'. This has been corrected in all versions of the Letter.