Uncertainties around reductions in China's coal use and CO_2 emissions

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Chinese coal consumption dropped 2.9% in 2014 according to preliminary official statistics[1] released in 2015. This was hailed as historic after China's meteoric growth in the 2000s.[2] The International Energy Agency (IEA) used it to estimate ~1.5% reduction in Chinese fossil CO_2 emissions for 2014[3], and an unprecedented 0.2% reduction in global emissions[4]. Similar preliminary coal consumption statistics are announced every year, and will likely be watched closely after China's recent slowdown in emissions growth and pledge to peak emissions in 2030 or earlier. But Chinese energy statistics are frequently revised and often contain large anomalies[5,6], implying high uncertainty. For example, BP used different Chinese data to estimate a 0.9% *increase* in 2014 CO_2 emissions[7,8]. Here, we analyze these preliminary announcements, with an approach that can be used to assess robustness of similar future announcements. We show that the preliminary 2.9% reduction in coal consumption is inappropriate for estimating CO_2 emissions, that coal-derived *energy* consumption stayed flat, and that Chinese fossil CO_2 emissions likely increased ~0.8% in 2014, but likely decreased during 2015. We

also analyze recent revisions of official energy statistics, and find they imply 925 $MtCO_2$ (11.2%) higher emissions for 2013, and 7.6 $GtCO_2$ (9.2%) higher total emissions for 2000-2013.

The 2.9% reduction in coal consumption was reported by the Chinese National Bureau of Statistics (NBS) in late February 2015, in the annual "Statistical Communiqué on the 2014 National Economic and Social Development"[1]. The Communiqué also reported a 2.5% drop in coal production (to 3.87 Gt) and 10.9% reduction in coal imports (to 291 Mt), consistent with reduced consumption. Similar communiqués are published early every year, and the growth rate of coal consumption provided in them is a preliminary estimate based on reports throughout the year from large businesses and estimates of growth rates for December[9]. Because it refers to coal consumption measured in mass units and often deviates from growth measured in energy units, it can be misleading for estimating CO_2 emissions. It is often revised (Figure 1), but usually not until about 18 months later, with the publication of the following year's China Energy Statistical Yearbook. A means of assessing the robustness of this growth rate is therefore desirable, which we provide later in this paper.

Further energy consumption data later published by NBS (and used by BP) show an insignificant *increase* (0.06%) in total coal-derived energy use in 2014[7,8,10], which is measured in energy units rather than mass units, and includes energy from imports/exports and stock changes of coke and other products derived from coal (see Methods online). Such moderate differences between growth rates of coal consumption in mass units and growth rates of total coal-derived energy use are not uncommon in Chinese data, and they have increased in recent years (Figure 1). Coal-derived energy use is the most appropriate quantity to use for estimating CO_2 emissions, since it explicitly includes all coal-derived products, and because carbon content correlates more closely with energy content than with the mass of the coal[11]. Using NBS's energy consumption data for coal, oil and natural gas[10], combined with mean emission factors and oxidation rates from a recent study (Liu et al. 2015)[12], we estimate that Chinese fossil CO_2 emissions grew by 0.8% in 2014 (see Methods). Global estimates compatible with this data show global energy-related emissions likely went up by ~0.5%, much less than the average over the last decade[7,13].

Interpretation of Chinese coal statistics is further complicated by revisions after the recently conducted third National Economic Census (NEC), on which data in the 2014 Statistical Communiqué and subsequently published data are based. The third NEC collected comprehensive data on economic activity and energy use from (in principle) all entities in the industry and service sectors in 2013[9,14], but revised historical coal use for all years after 2000 upwards considerably (Figure 2). Total coal-derived energy use for 2013 was revised up 13.6% (to 2.81 billion tonnes of coal equivalents (Gtce))[15,16] – implying that 2014 coal-related CO_2 emissions in fact were much higher than existing estimates for 2013 – and every year since 2005 was revised up by 12-14%. Petroleum and natural gas saw only relatively minor revisions (0%-1.7% and 0.7%-3.4%, respectively). The cumulative addition for 2000-2013 is 2.86 Gtce (+9.5%) from coal, 58.9 Mtce (+0.7%) from petroleum and 18.8 Mtce (+1.2%) from natural gas. Converting this to CO_2 emissions using mean China-specific emission factors and oxidation rates[12], we find 925 $MtCO_2$ (11%) higher CO_2 emissions for 2013 relative to pre-third NEC energy use data[17], and 7.6 $GtCO_2$ (9.2%) cumulative increase for 2000-2013 (98% from coal).

Our estimate affects results of the paper by Liu et al.[12] , which claims that Chinese emissions were overestimated by up to 14%. We use the same emission factors as that study, but the revised energy use data from NBS – released after the submission of that paper – is higher. Note that our result relies on using unmodified NBS energy consumption data multiplied by the aforementioned emission factors. Existing emissions estimates use various methodologies, and will be affected differently by altered energy data and emission factors. Some may need to be revised up only slightly, or even down.

The methodology and key conclusions of Liu et al. have been challenged[18,19], including their value for carbon content of coal measured in mass units (tonnes carbon per tonne coal) and not accounting for possible changes over time. However, we use their carbon content in *energy* units (tonnes carbon per TJ), which varies less. Varying the parameters we use over a wide range and over time shows that our emission estimates change only moderately or very little (discussion in Methods). The estimate of the absolute change in CO_2 emissions due to the third NEC revisions can vary by a few percent, while the relative (percentagewise) change varies only slightly. The growth in CO_2 emissions from 2013 to 2014 is quite robust against uncertainty in carbon content that does not vary over time, but is somewhat more sensitive to abrupt changes in coal composition between 2013 and 2014 (see Methods).

The NEC revisions cast doubt on whether any recently published Chinese coal trends will persist after future NECs, including the reported drop in 2014 coal consumption and stagnation in coal-derived energy use. China has held an NEC twice before, collecting data for 2004 and 2008. Between NECs, annual data is collected only through sampling of smaller firms and reporting from large businesses fulfilling certain changeable criteria, by both provincial statistical agencies and the NBS. This creates sampling biases and inconsistencies[6,9,20]. While moderate revisions for the years between one NEC and the next are thus expected, coal consumption has typically been revised by 5-10% – even more in the latest NEC – and almost exclusively upwards. Years before the previous NEC year are also revised (through extrapolation – no data for those years is collected in the NEC). No official explanation is given for the large magnitude and scope of the revisions[9]. While the latest revised statistics are presumably more accurate since they reduce several inconsistencies present in earlier statistics (see below), it is clear that the uncertainty is still high based on historical precedent and lack of transparency alone. The current data – including the 2014 growth estimate – is thus likely to change at least somewhat in future revisions.

In addition to revisions, there have been three noteworthy inconsistencies in Chinese coal use data which indicate further uncertainty in the absolute consumption levels, but not necessarily the growth rates: 1) a gap between total provincial coal consumption data and national data; 2) a gap between reported and apparent (estimated from supply-side data) coal consumption; and 3) continued growth in coal-intensive industrial products in 2014, despite the reported reduction in coal use. We address these in turn.

The sum of coal consumption in individual provinces was much higher than the national figure before the third NEC – by 24% in 2012 – and this gap was widening[21] (Figure 3). The issue has been extensively debated[5,6,9]. The only official explanation is double-counting at the provincial level, e.g., by businesses with locations in more than one province[6,9,22], but it has been argued that this cannot account for the magnitude of the gap[6]. However, this gap was reduced in the third NEC revisions (Figure 3), and almost eliminated for the most recent year (2013). Further, the *growth rate* of summed provincial coal consumption correlates well with the national growth rate in most years (Figure 4). The provincial data therefore do not suggest further uncertainty in the coal consumption growth rates.

Before the third NEC revisions, apparent consumption (production plus net imports minus net stock increases) grew much faster than reported consumption after 2010 (Figure 3), and was 7.8% higher in 2012. This statistical difference of 274 million tonnes was more than the *total* consumption of any country except the United States or India[23]. While there is no official explanation for this gap, it was greatly reduced for all years in the latest revision, and virtually eliminated for 2013, the last year of complete data (down to 0.1%).

Despite reporting a 2.9% reduction in coal consumption, the 2014 Statistical Communiqué also reported continued growth in GDP, crude steel and cement production – quantities which should correlate with coal use – though at a much slower pace for the latter two (see Table 1). However, the reduced but still positive growth rates are not necessarily inconsistent with flat or modestly negative growth in total coal consumption. Growth in industrial production and thermal power output has typically been higher than growth in coal use (Figure 4), as would be expected with energy efficiency improvements. Further, thermal power generation and coke production fell slightly. Also, at least 25% of coal is used for activities other than power, iron/steel, coke and cement production[16] (see Methods), and thus not expected to correlate with output of those products directly.

Previous upwards revisions of coal use statistics are therefore the main reason for skepticism about reported growth rates in coal consumption and coal-derived energy use, including the low or negative growth rates in 2014. The revisions are substantial: Coal-derived energy use was revised up by 5-10% in most years after 2000 in the second NEC and 10-15% in the third NEC. But revisions in *growth rates* are smaller and less biased than the revisions of absolute values. If we exclude the highly volatile years up to 2000, the average revision in one-year growth rates from 2001 to 2013 is +0.38 percentage points, with a mean sample standard deviation (1σ) of 0.93 percentage points. The maximum revision is 4.9 percentage points, and 11 out of 32 revised values were revised downwards rather than upwards. This suggests that future revisions of the flat 2014 growth rate are likely to keep it well below the average of the past 15 years.

Official coal consumption data for all of 2015 was not available at the time of submission, but data for the first three quarters agree with an ongoing drop in coal consumption. The China Coal Industry Association (CCIA) estimated that coal consumption for January-September 2015 was 2.9 Gt, down 4.6% year-on-year[24]. It is challenging to assess the uncertainty of this estimate, because the CCIA has not published similar partial-year consumption estimates for previous years, and because economic conditions for 2015 are unique. But it is broadly consistent with apparent consumption calculated using official production, import and export statistics and partial stock data (see Methods), which yields 2.89 Gt, or −5.2% change relative to the same calculation for January-September 2014. Recent results from the Global Carbon Project using compatible data project −4.6% to −0.5% growth in fossil CO_2

emissions for China, and −1.6% to +0.5% globally.[13] Output of coal-intensive industrial products from large businesses also matches the trend, and is down much more sharply than in 2014 (Table 1)[25]. Given that coal-derived energy use has typically grown more slowly than these products (Figure 4), a significant negative growth rate looks highly probable. These results do not preclude that total coal consumption for 2015 could grow or drop less relative to 2014, but if so, the last three months of 2015 would need to follow a very different trend relative to 2014 than the first nine.

In conclusion, initial claims that Chinese CO_2 emissions fell in 2014 were likely premature, being based on a preliminary number for coal consumption that did not take into account the energy content of the consumed coal, but later energy data still shows stagnant coal use and a dramatic slowdown in emissions growth. Previous upwards revisions of coal consumption raise the question of whether this trend will vanish in later revisions. However, although uncertainty about absolute consumption remains and future revisions are likely, our analysis shows that a reversal of the trend currently seen in the data is much less likely. We also provide data and uncertainty ranges that may be useful for assessing similar preliminary data in the future. The trend for 2014 is supported by steeper reductions reported for the first three quarters of 2015, which makes it likely that the stagnation in coal use in 2014 was real and the start of at least a short-term trend, rather than an artefact of unreliable preliminary data.

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Author contributions

J.I.K. and G.P.P. designed the research. J.I.K. obtained data and carried out analyses. R.M.A. assisted in obtaining and processing data. All authors contributed to writing the article.

Competing financial interests

The authors declare no competing financial interests.

Figure 1: Comparison of growth rates for different measures of coal use

Growth rates in mass units (solid lines) and energy units (dashed lines), from preliminary estimates in annual Statistical Communiqés (black line)[26] and later energy balance tables in the China Energy Statistical Yearbooks (colored lines)[16,21,27]. Growth rates for mass and energy content for the same quantity have diverged in recent years. **CC** = Total Coal Consumption; **TCDEU** = Total Coal-Derived Energy Use (see Methods). **RCC** = Raw Coal Consumption, including only consumption and inputs to transformation of raw coal. **Stat. Comm.** = coal consumption growth rate from Statistical Communiqués. Only TCDEU and Stat. Comm. are available for 2014.

Figure 2: Revisions of coal use in National Economic Censuses

(a) Total coal-derived energy use and (b) coal consumption in mass units for 1990-2014, before and after each of the National Economic Censuses.[1,10,15–17,21,28–30] Dashed-line segments are extrapolations using growth rates reported in the 2013 and 2014 Statistical Communiqués.

Figure 3: Discrepancies in national and provincial coal consumption statistics

Total Chinese coal consumption from different statistics[16,21,28], which should be identical if there were no data inconsistencies. The differences are greatly reduced in the latest NEC revision. Note that the provincial statistics for 2012 and earlier was not updated in the NEC revision. **National cons.** = National reported consumption, i.e., reported coal use by consuming entities; **Natl. apparent cons.** = Domestic production plus net imports minus net stock increases. (The pre-third NEC version of this series was the energy data adopted by the recent paper by Zhu et al., claiming that Chinese CO_2 emissions were over-estimated by many sources[12].)

Figure 4: Growth rates in total coal-derived energy use and correlated economic quantities

Thick colored lines show growth rates for total coal-derived energy use before and after each National Economic Census, compared to growth rates of GDP, thermal electricity generation, and output of key coal-intensive industrial products[8,16,17,21,27–29]. “Sum provinces” is sum of coal consumption reported for each province, in mass units. The shaded areas show 1 and 2 times the average standard deviation of growth rates in coal energy consumption from the different NECs (see Methods). The impact of revisions on growth rates is smaller than the impact on absolute quantities, cf. Figure 2.

Table 1: Growth rates of quantities presumed to be correlated with coal consumption, 2000-2015 Q3

	2010	**2011**	**2012**	**2013**	**2014**	**2015 Q1-3**
GDP, constant 2010 prices	10.6%	9.5%	7.7%	7.7%	**7.3%**	-
(10^{12} RMB)	(40.9)	(44.8)	(48.2)	(51.9)	(55.7)	
Crude steel	11.4%	7.5%	5.6%	12.3%	**1.1%**	**−2.1%**
(Mt)	(637)	(685)	(724)	(813)	(822)	(609)
Cement	14.5%	11.5%	5.3%	9.5%	**3.0%**	**−4.7%**
(Mt)	(1,882)	(2,099)	(2,210)	(2,419)	(2,492)	(1,723)
Coke	8.2%	12.4%	0.9%	9.9%	**−0.4%**	**−4.7%**
(Mt)	(387)	(434)	(438)	(482)	(480)	(338)
Thermal electricity	11.7%	15.1%	1.5%	9.1%	**−0.3%**	**−2.2%**
(TWh)	(3,332)	(3,834)	(3,893)	(4,247)	(4,234)	(3,153)
Total coal-derived energy	**3.7%**	**8.9%**	**1.4%**	**2.0%**	**0.1%**	-
(Mtce)	(2,496)	(2,717)	(2,755)	(2,810)	(2,812)	

Year-on-year growth rates of selected economic indicators which are thought to correlate with coal use (absolute quantities in parentheses)[10,16,24,25]. Note that the 2013 and 2014 numbers for crude steel and cement were revised between the 2014 Statistical Communiqué in February 2015 and the release of the 2015 China Statistical Yearbook, the latter of which is used here. The 2014 growth rates according to the Statistical Communiqué were +1.2% for crude steel and +2.3% for cement[1]. Total coal derived energy is not available for 2015 Q1-3, but coal consumption in mass units decreased 4.6% year-on-year (to 2.9 Gt).

Methods

Calculation of CO_2 emissions based on total coal-derived energy use

Coal-related CO_2 emissions estimates in this paper are obtained by multiplying total coal-derived energy use by an emission factor in energy units ($kgCO_2$ / TJ) and average oxidation rates[12]. The emission factor is an average for domestically produced coal, and may be inaccurate for imported coal. But imported coal represented only 6.2% of total coal-derived energy use in 2013 (the last year of sufficient data)[16]. The variance for emission factors of coal types in energy units ($kgCO_2$ / TJ) is also quite small compared to emission factors in mass units ($kgCO_2$ / kg coal). The resulting inaccuracy in emission factors is thus much smaller than the uncertainty in the energy consumption data (see main text and further down in the Methods section for further discussion of the emission factors). Emissions from oil and gas are estimated in the same way.

Total coal-derived energy use vs. coal consumption

The term "total coal-derived energy use" in this paper contrasts with "coal consumption" (in energy or mass units). "Coal consumption" without further qualifiers refers to the quantity "Total Coal" used in energy balance tables published by NBS, and includes all final consumption and inputs to transformation of raw coal, washed/rinsed coal products and coal briquettes, but not coke or other derived products directly. The latter are included only through the quantity of coal used in their production. Imports/exports or stock changes of derived products (chiefly coke) are therefore not included. "Total coal-derived energy use", by contrast, includes all energy flows of all coal types and all products derived from coal (in energy units). The difference is small, and mainly due to exports and stock changes for coke. Net coke imports and stock changes accounted for 0.9% of total coal-derived energy use in 2013.[16] Total coal-derived energy use is reported in tables named "Total consumption of energy and its composition" in several NBS publications, and can also be calculated from "standard quantity" (energy units) energy balance tables.

Heuristic error ranges for coal use growth rates based on NEC revisions

Figure 4 shows heuristic 1σ and 2σ error ranges for the growth rate in coal-derived energy use based on the magnitude of revisions in each NEC. The 1σ range is the average over the years 2001-2013 of the standard deviation in year-on-year growth rates over each time series for each year in which data from both before and after at least one NEC revision is available. 2000 and prior years are not included in the averaging, since they contain large revisions which were partly due to considerable under-reporting of coal production from small coal mines that should have been closed per national policy (including these years increase the 1σ range from 0.93 to 1.29 percentage points). Revisions in these years are therefore not representative of what to expect in revisions of the 2013-2014 growth rate. The error ranges are only indicators of typical revisions based on historical experience. There is not enough information about how the revisions are carried out to construct an error model and derive proper confidence intervals.

Estimation of share of coal consumption for thermal power, iron/steel and cement production

We state that "at least 25% of coal is used for other activities than power, iron/steel and cement production". This is based on NBS's data for final energy consumption in the industrial sector and their national energy balance table for 2013[16]. Coal-derived energy use for power generation, iron/steel and cement are estimated by adding together reported total coal-derived energy use for thermal power generation (1264 Mtce), for smelting and pressing of ferrous metals (595 Mtce) as well as coal energy lost in the coking process (24 Mtce), and in manufacture of non-metallic mineral products (234 Mtce). This gives 2118 Mtce out of total coal-derived energy use of 2815 Mtce, though this is a slight overestimate since non-metallic mineral products includes other products than cement (although cement dominates coal usage in that sector). This leaves at least 25% for other uses.

Calculation of apparent consumption of coal for the first three quarters of 2015

The apparent coal consumption of 2.89 Gt for January-September 2015 is calculated by adding domestic production reported by NBS and the China Coal Industry Association (2.72 Gt / −4.3%)[24,25] to total imports (156.36 Mt / −29.8%) and subtracting total exports (4.02 Mt / −7.9%) from official customs data[31,32]. We then add total stock decreases in Chinese coal industry units, key power plants, and major coal ports (11.58 Mt), reported by the China Coal Industry Association.[24] These are the largest stocks in China and the only ones for which detailed statistics are widely available. This stock data is nevertheless incomplete, as it adds up to only 217 Mt (by end of September 2015), while total stocks for all sectors are reported to be "above 300 million tonnes" without further specification.[24]

Sensitivity of emission estimates to uncertainty in emission factors for coal from Liu et al. 2015.

The publication from which we obtain the emission factors (Liu et al. 2015)[12] has been criticized for methodological shortcomings and differences with China's most recent greenhouse gas inventory and other emission estimates, which are claimed to be unjustified[18,19]. However, the differences mainly affect coal consumption and carbon content per unit *mass* of coal, while we use carbon content per unit *energy*, which varies far less. The average carbon content that we adopt from Liu et al. – 26.32 tC/TJ – is less than 0.1% away from that of the reference approach of the greenhouse gas inventory used for China's second National Communication (NC) to the UNFCCC (Table 3 of Teng & Zhu 2015)[19]. The average oxidation rate for coal in Liu et al. is somewhat lower, 92% vs. 94.3%.

To probe the maximum (not necessarily realistic) impact of uncertainties in both the composition of coal and oxidation rates, we redid our calculations using the full range of average carbon contents for different coal types listed by Teng and Zhu (25.4 tC/TJ – 28 tC/TJ), and simultaneously varying the oxidation rate between 92% and 94.3%. The minimum and maximum values obtained for the change in total fossil CO_2 emissions due to the third NEC revisions were from 895 $MtCO_2$ to 1.0 $GtCO_2$ for the 2013 emissions (−3.3% to +8.5% relative to our result of 925 $MtCO_2$) and 7.3 $GtCO_2$ to 8.3 $GtCO_2$ for the cumulative 2000-2013 emissions (−3.4% to +8.9% relative to our result of 7.6 $GtCO_2$). Even though this variation is based on an unrealistically large range in parameters, it is not greater than the uncertainty in existing estimates of Chinese CO_2 emissions.

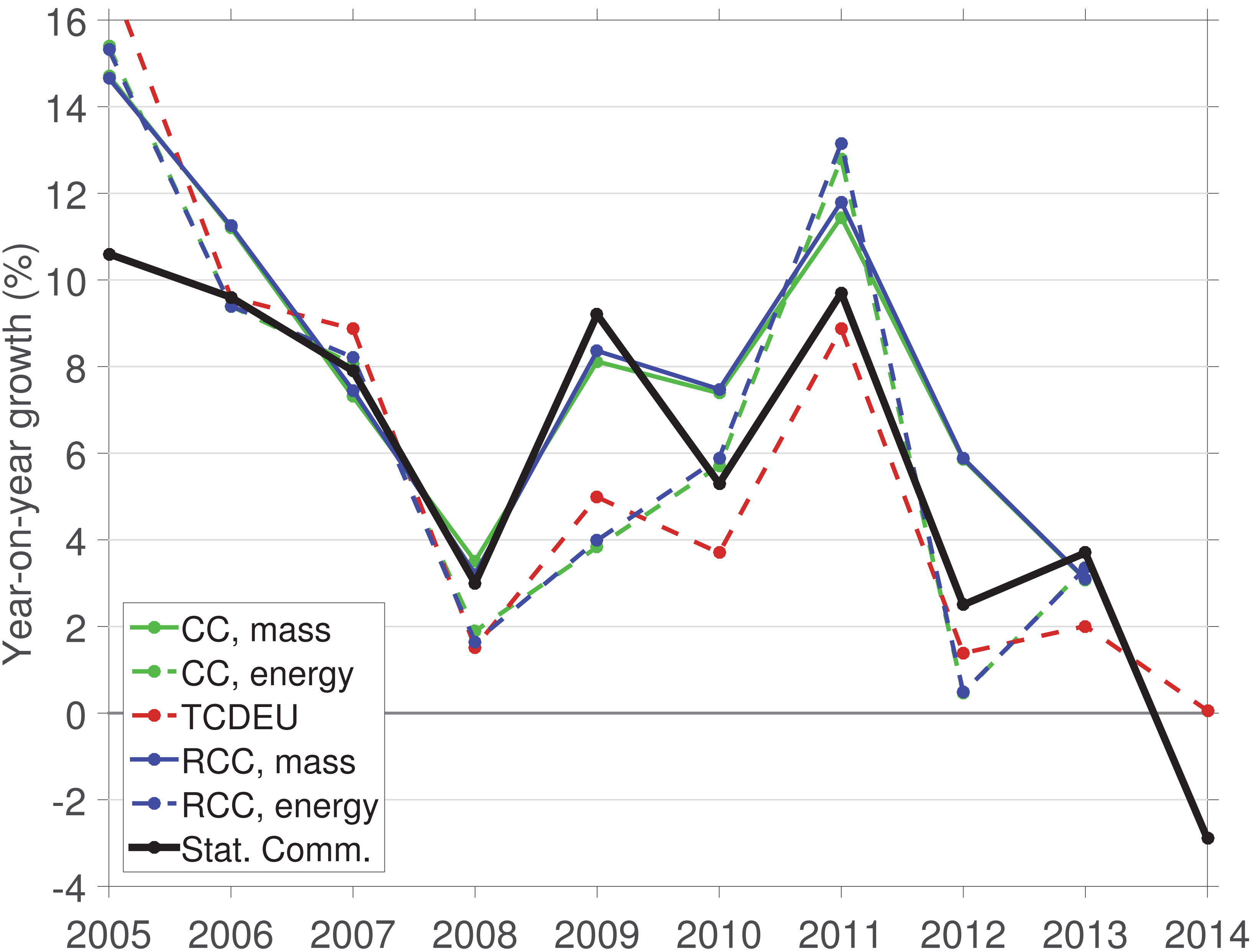
Varying the parameters affects the absolute level of emissions and the absolute changes in emissions, but it has little effect on the relative changes, since the same factors are applied both to pre-revision and post-revision energy data. The maximum variation in relative changes ranges from 0.06 percentage points below to 0.15 percentage points above our results for both the 2013 emissions (+11.2%) and the cumulative 2000-2013 emissions (+9.2%). For similar reasons, the estimated growth rate in total fossil CO_2 emissions from 2013 to 2014 (0.8%) changes from 0.06 percentage points below to 0.01 percentage points above our main estimate. These slight variations come about because changing the carbon content and oxidation rates for coal changes the weighting of coal relative to petroleum and natural gas in the total emissions. If looking only at emissions from coal combustion, changing these parameters would not affect the relative changes at all.

Both Liu et al. and NC are based only on 2005 data, and any change in carbon content or oxidation rates over time could potentially affect our results. We assessed this additional uncertainty by letting carbon content and oxidation rates increase or decrease linearly from 2000 to 2013 (which should have the greatest effect on the relative impact of revisions on cumulative emissions) and also let them vary randomly for each year. For the change in CO_2 emissions due to the third NEC revisions, this did not result in any greater variation than that produced by using constant maximum or minimum carbon content and oxidation rates. For the 2014 emissions growth rate, the effect can be larger if it is unrealistically assumed that there is little or no correlation between parameters in adjacent years. For more realistic, small year-to-year variations in parameters, the growth rate varies by about 0.8 percentage points for each percent change in either the carbon content or the oxidation rate. Note that 1% change in either of the parameters is a large variation for a single year, given the vast size of China's coal consumption.

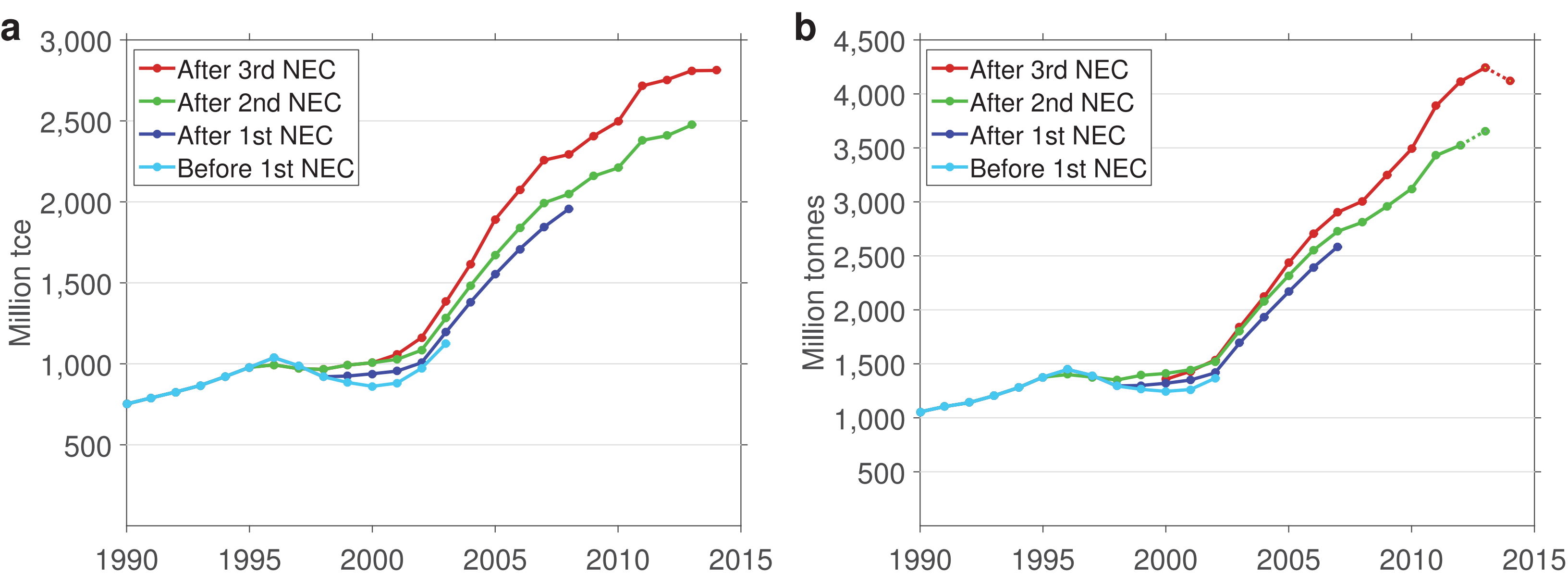
References

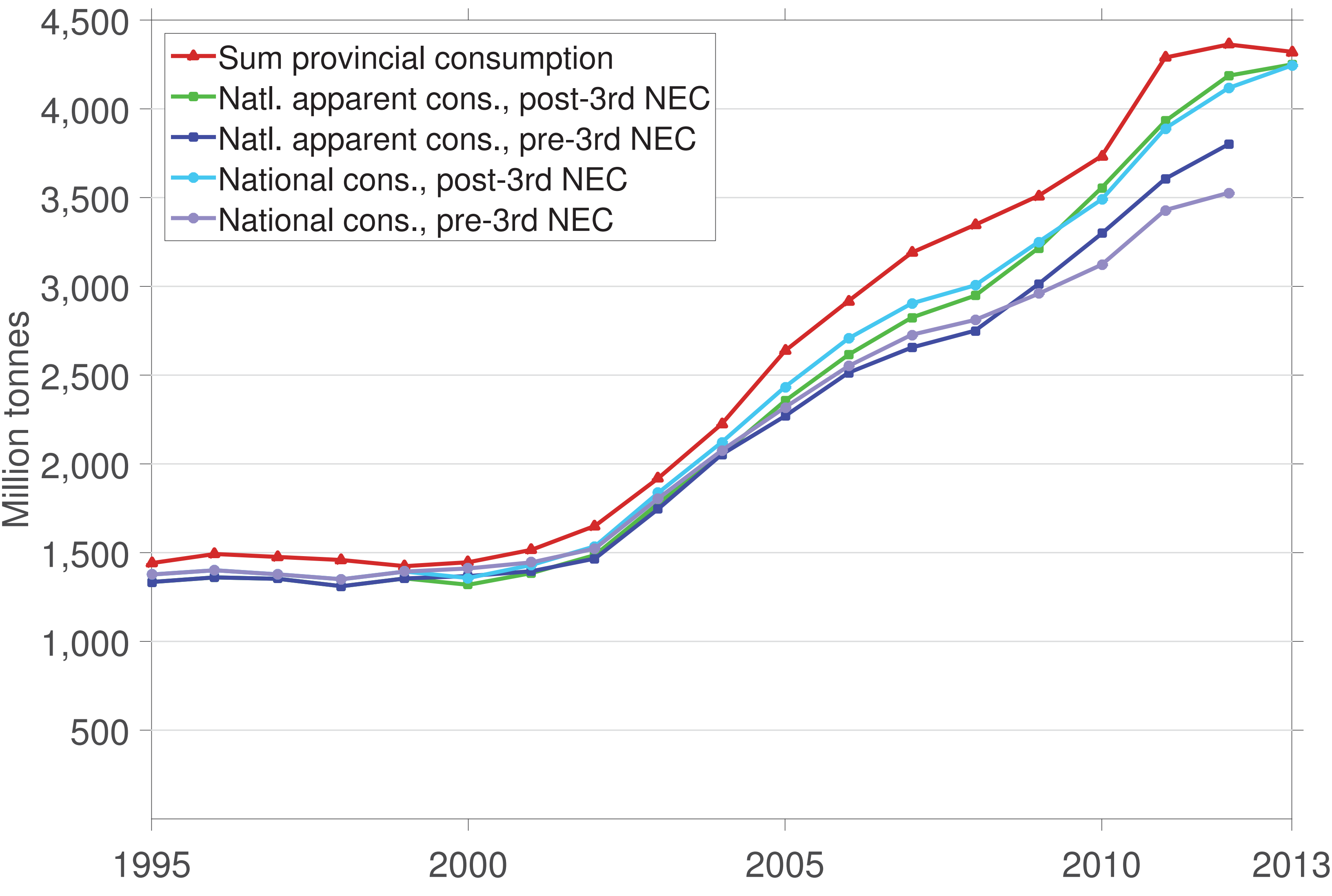
31. General Administration of Customs People's Republic of China. China's major imports by quantity and RMB value, September 2015 (2015年9月全国进口重点商品量值表（人民币值）). (2015). at <http://www.customs.gov.cn/publish/portal0/tab49666/info774876.htm>

32. General Administration of Customs People's Republic of China. China's major exports by quantity and RMB value, September 2015 (2015年9月全国出口重点商品量值表（人民币值）).

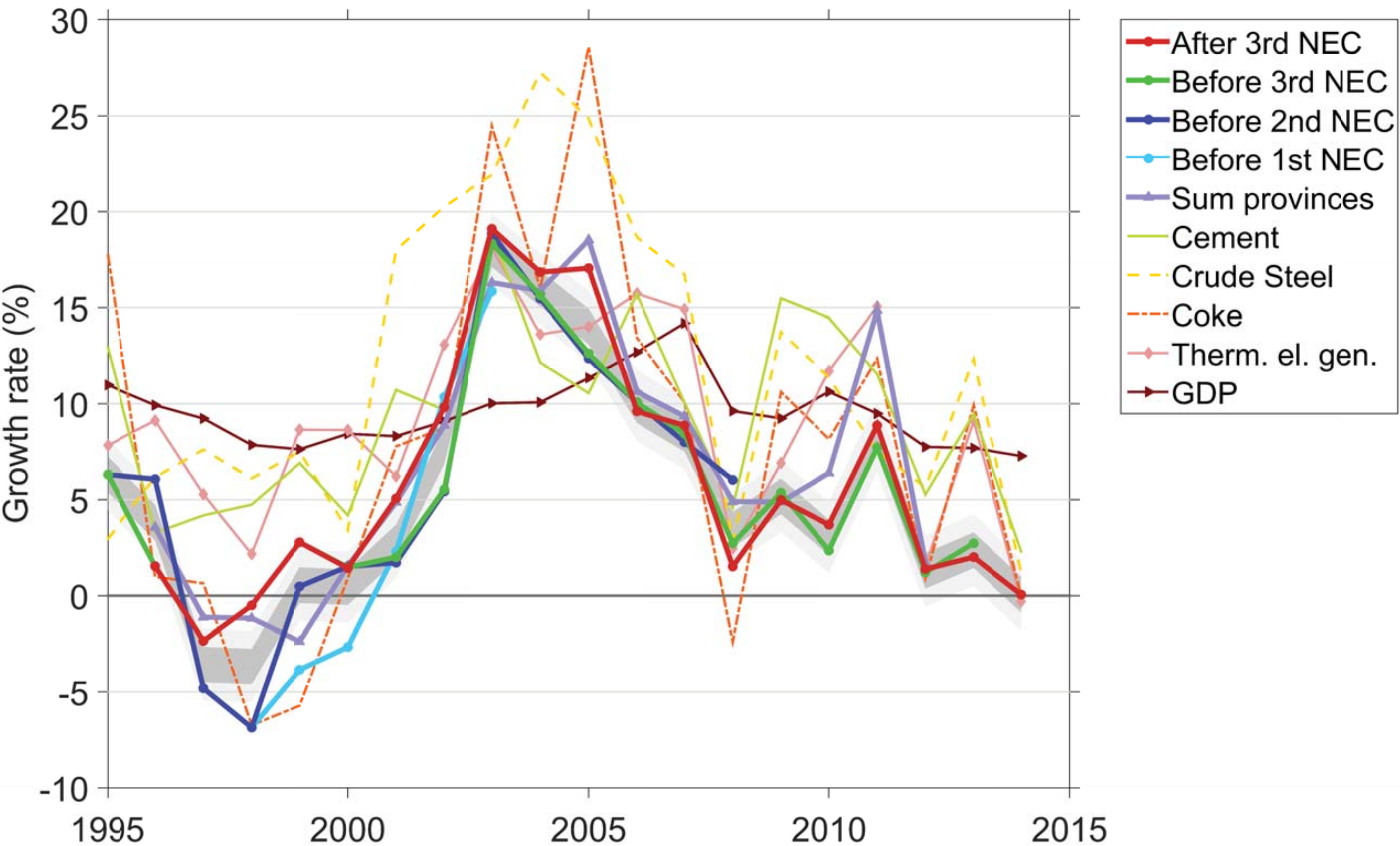


Year-on-year growth (%)
16
14
12
10
8
6
4
2
0
-2
-4
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
CC, mass
CC, energy
TCDEU
RCC, mass
RCC, energy
Stat. Comm.


a
b
3,000
2,500
2,000
1,500
1,000
500
Million tce
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
Million tonnes
After 3rd NEC
After 2nd NEC
After 1st NEC
Before 1st NEC
1990
1995
2000
2005
2010
2015



Sum provincial consumption
Natl. apparent cons., post-3rd NEC
Natl. apparent cons., pre-3rd NEC
National cons., post-3rd NEC
National cons., pre-3rd NEC
Million tonnes
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
1995
2000
2005
2010
2013



Growth rate (%)
30
25
20
15
10
5
0
-5
-10
1995
2000
2005
2010
2015
After 3rd NEC
Before 3rd NEC
Before 2nd NEC
Before 1st NEC
Sum provinces
Cement
Crude Steel
Coke
Therm. el. gen.
GDP