Supplementary Information

Timely estimates of India's annual and monthly fossil CO_2 emissions

Contents

1. Coal production

National, revised monthly coal production data are reported by the Indian Bureau of Mines with a lag of more than six months, and at time of writing over 12 months (Indian Bureau of Mines, 2019). Provisional national coal and lignite production data were published with a lag of less than two months via press release by the Ministry of Mines until mid-2017 (Ministry of Mines, 2017), but these were not released for about 18 months, reappearing in March 2020 with provisional data for January 2020, although these data are of low precision (Ministry of Mines, 2020). The Coal Controller's Organisation (CCO) at the Ministry of Coal produces an annual report called Provisional Coal Statistics (PCS) that include monthly national coal production, with a lag of about 7-9 months (Ministry of Coal, various years-c). The CCO also publishes revised statistics in the Coal Directory, with a lag of about 12-16 months (Ministry of Coal, various years-b). Lastly, the United Nations Statistics Division's 'Monthly Bulletin of Statistics Online' also includes monthly coal production for India (UN Statistics Division, 2020). These five datasets are compared and their availability by month shown in Figure 1 (the datasets are so similar that mostly they lie atop one another in the figure). While all figures here are for hard coal, all five of the data sources also report lignite production.

While national coal production data are lacking in recent months, the two largest coal mining companies, Coal India Limited (CIL) and Singareni Collieries Company Limited (SCCL), release their provisional monthly production and offtake data in the first days of the following month (CIL, various years; SCCL, various years). These two companies represent about 90% of Indian coal production.

Reporting of data on production at captive mines has recently been introduced in the Ministry of Coal's Monthly Summary to Cabinet (Ministry of Coal, various years-a). In the two months for which all data are available (Sep 2017 and Jan 2020), the sum of provisional production data from CIL, SCCL and captive mines is within 2% of the provisional national production figure, demonstrating that this sum is suitable to fill the gap in provisional national production.

Revised coal production data are available from CIL both in their provisional production reports, which compare to the same (revised) month in the previous year, and in their more recent quarterly reports. In the available data, CIL's revisions are generally within 0.25% of provisional statistics, except for one anomalous data point in 2016 that was revised by 0.7% (Figure 2). For SCCL, available data show that revisions are also within 0.25% of provisional data (Figure 3). No revised data for captive production are available. When the sum of provisional data from CIL, SCCL and captive mines are compared with revised national production, the latter is always higher in the period where data are available, although always less than 2.5% higher (Figure 4), suggesting either that captive mine production is always revised upwards, or that some minor production is missing. This could for example be from small mines, or an estimate for theft.

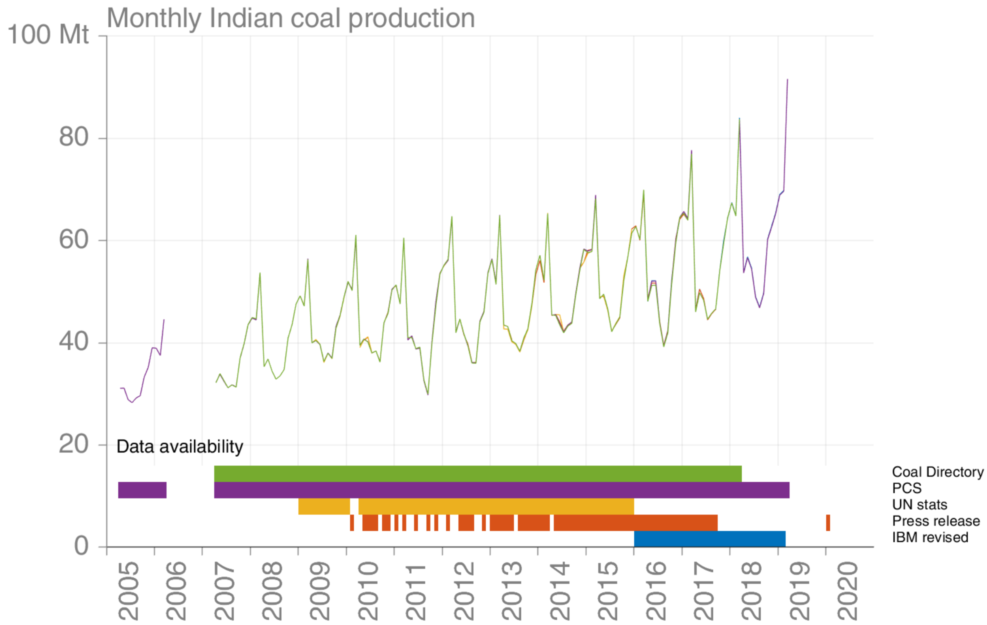

Figure 1: Comparison and availability of the four datasets of monthly national coal production. Sources: Provisional Coal Statistics (PCS), UN Statistics, Ministry of Mines press releases, Indian Bureau of Mines.

In this analysis revised data are always used where available. To close the gap between provisional and revised national coal production statistics, which exhibits no trend (Figure 4), I use the average of this residual, about 1.6% of national production and apply this when revised data are not available.

When looking at each dataset for which both provisional and revised data are available, there are no apparent biases across the full periods, although production of raw coal has mostly been revised downwards in the last five years (Figure 6).

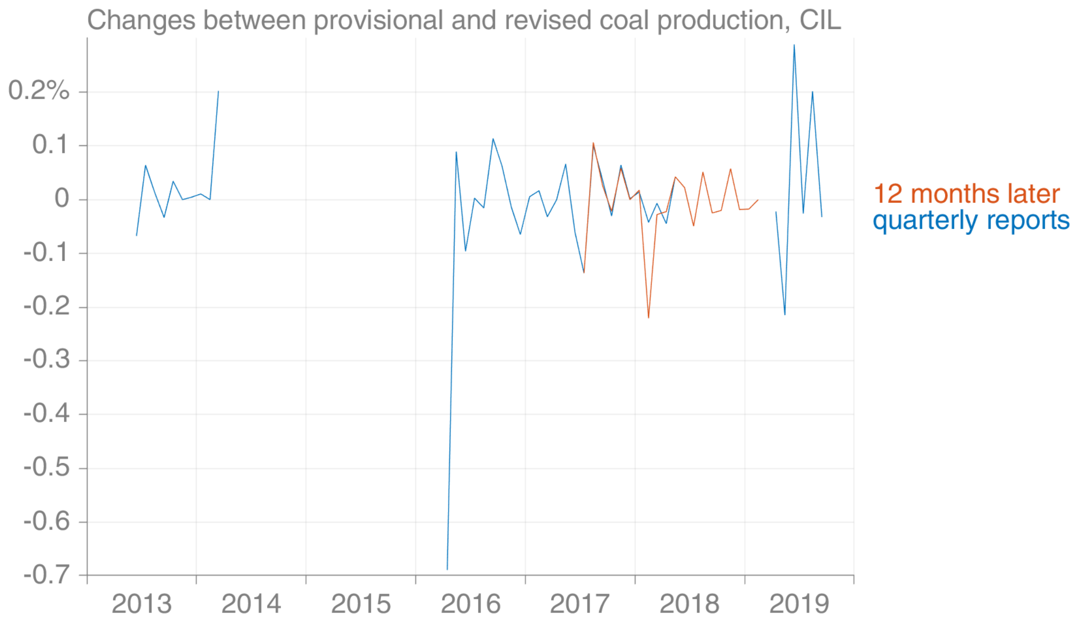

Figure 2: Relative magnitude of revisions reported by CIL to provisional monthly coal production data. Source: CIL.

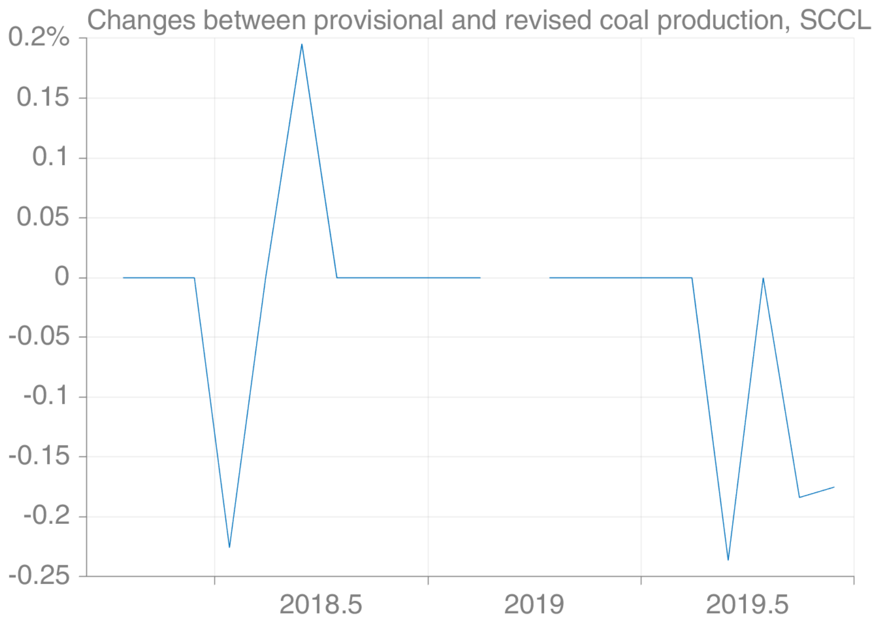

Figure 3: Relative magnitude of revisions reported by SCCL to provisional monthly coal production data. Source: SCCL.

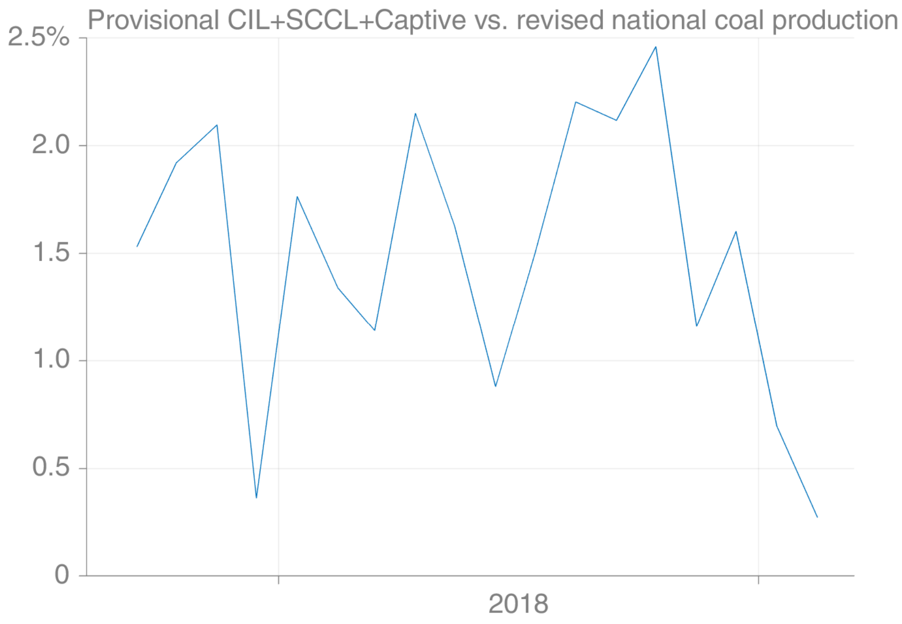

Figure 4: Relative magnitude of revised monthly national coal production and provisional production data from CIL, SCCL, and Captive mines. Source: CIL, SCCL, Ministry of Mines, Indian Bureau of Mines.

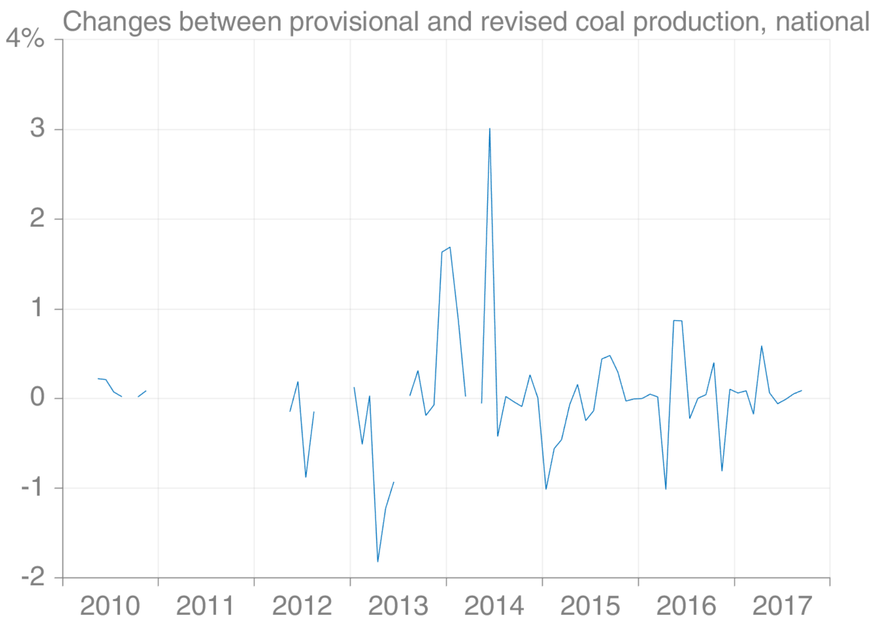

Figure 5: Relative magnitude of revisions. Source: Ministry of Mines, Indian Bureau of Mines, UN Statistics.

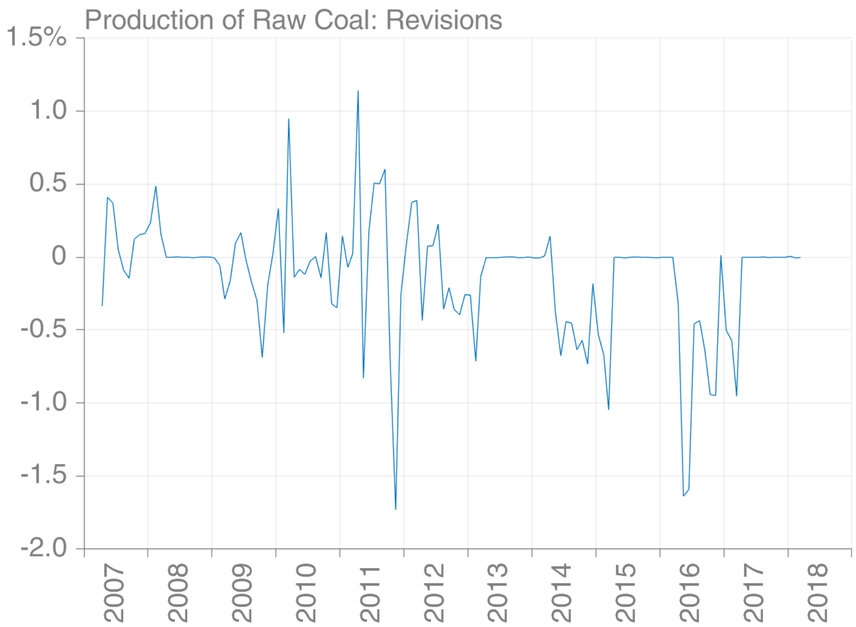

Figure 6: Magnitude of revisions to monthly raw coal production statistics between the Provisional Coal Statistics and Coal Directory reports from the Ministry of Coal.

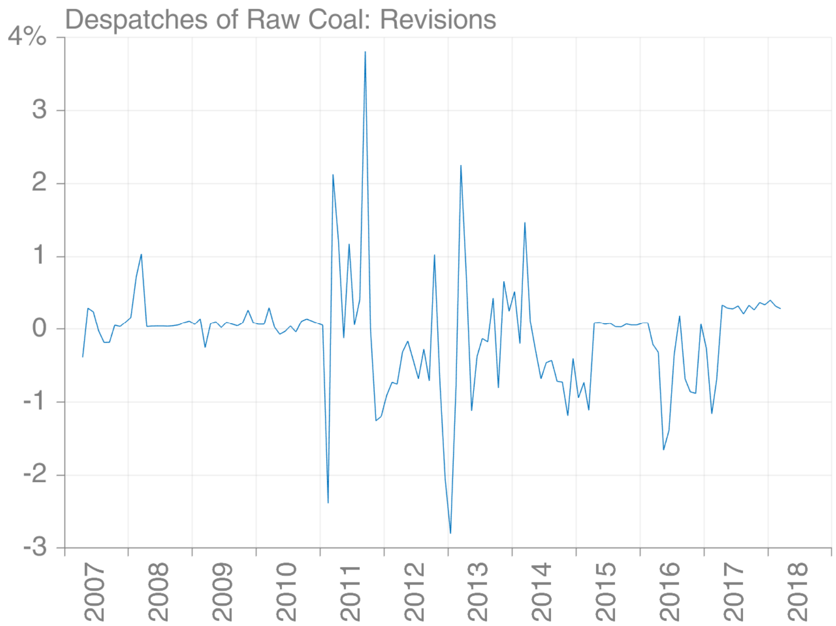

Figure 7: Magnitude of revisions to monthly raw coal despatch statistics between the Provisional Coal Statistics and Coal Directory reports from the Ministry of Coal.

2. Coal stocks

Stocks information are available at mines and power stations, but are unavailable for other users of coal such as steel and cement manufacturers, non-grid power generators, and also at ports. Their omission here amounts to assuming there are no changes of stocks in these categories. Stocks levels follow a strongly seasonal pattern due largely to the monsoon season, where stocks are built up before the heavy rains make both mining and transport of coal significantly more difficult.

Coal mines

Changes in coal stocks are available for CIL and SCCL, calculated as the difference between monthly production and deliveries (SCCL, various years; CIL, various years). The sum of stock changes from the two mining companies matches very closely the monthly data reported in the annual Coal Directory and Provisional Coal Statistics reports (Figure 8), except for a period in 2016-17 that appears to be incorrect in the official estimates, suggesting an unlikely build-up of stocks during the monsoon period. To avoid this anomaly, I use mine companies' data in preference, with Coal Directory and Provisional Coal Statistics data for earlier periods.

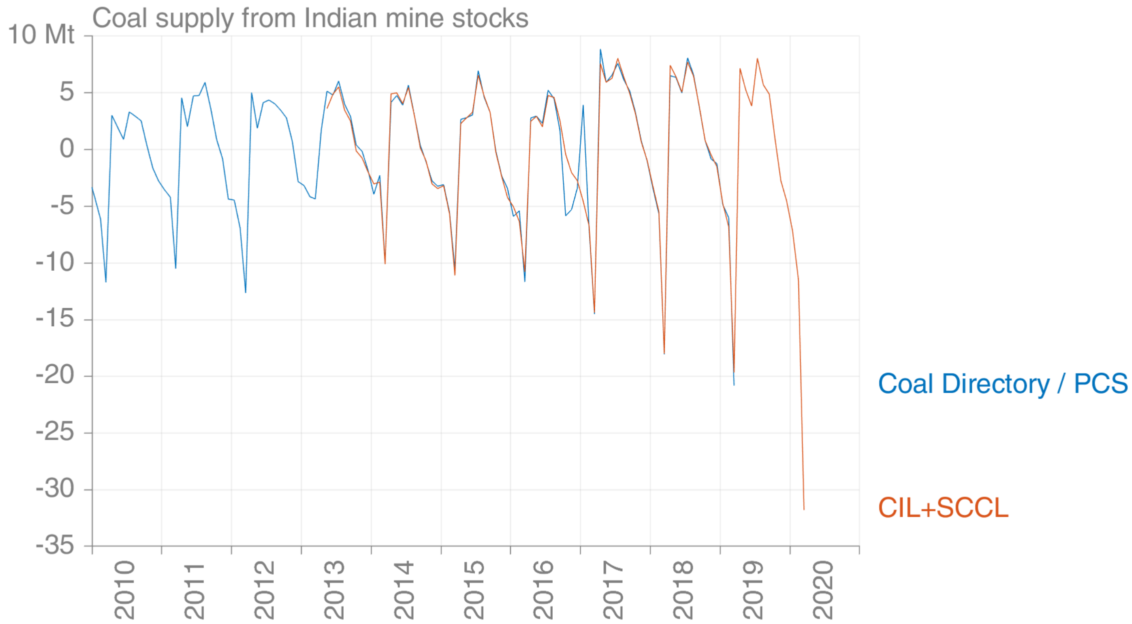

Figure 8: Comparison of reported 'stock changes' in the Provisional Coal Statistics (PCS) with the sum of stock changes at CIL and SCCL mines. Source: Ministry of Coal, CIL, SCCL.

Power stations

Daily data for coal stocks at so-called 'linkage' power stations are available from the CEA (various years-a). Linkage stations are those that are enrolled in the government's linkage scheme whereby assistance is provided to ensure sufficient supply of coal, and as part of that there are specific data requirements. Some of these data have been made public since 2008.

The earliest data are in CSV format, the middle period in PDF, and the later data (from mid-2018) in Excel format, with some temporal overlap between these three formats. These data were read in and assembled to a single data file.

These raw data show many gaps, especially weekends during 2014–2017, and a number of significant one- or two-day spikes that appear to be spurious (Figure 9); the data improve markedly from 2018. To process these data, I have first removed data prior to 31 July 2008, which are extremely noisy. Then spurious spikes are removed by comparing the signal to a median-filtered (window size 9 days) version and using a threshold (300 kt) to identify significant deviations from the smoothed signal, with these deviations removed from the data. Then the resulting signal is interpolated using a shape-preserving piecewise cubic interpolation without extrapolation. The resulting processed dataset (Figure 10) permits the extraction of reliable estimates of month-end stocks and thence stock changes.

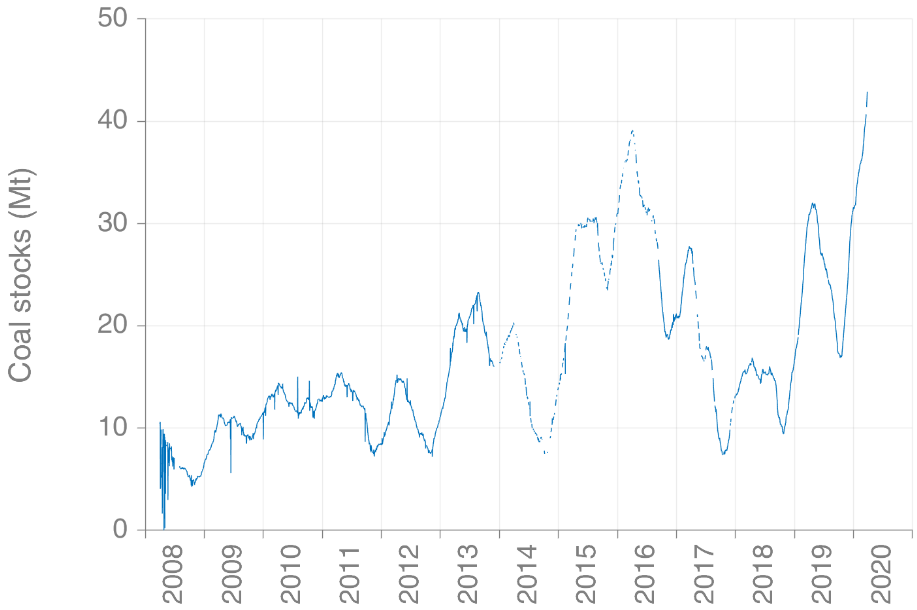

Figure 9: Raw linkage power station coal stocks data collated from CEA.

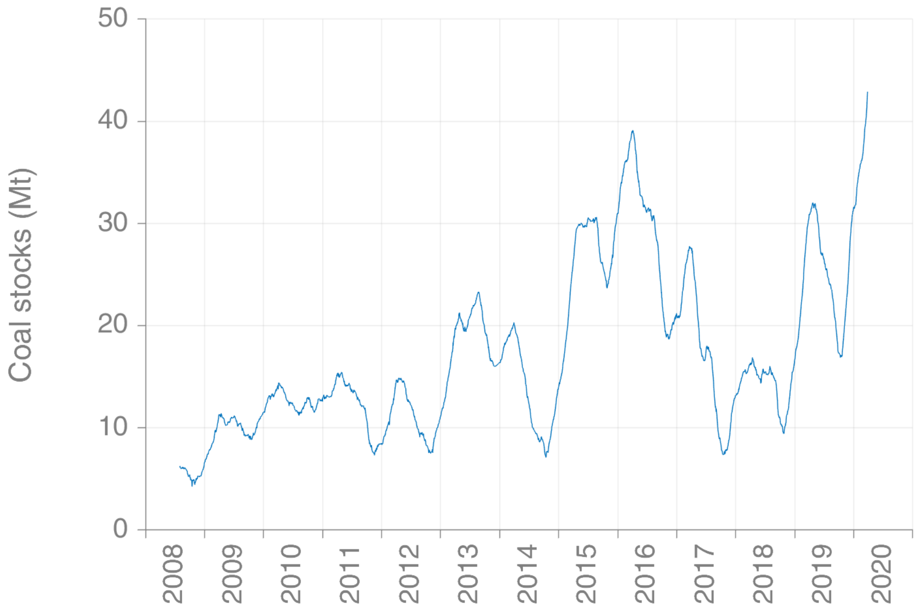

Figure 10: Processed linkage power station coal stocks data.

Because of the unreliability of coal supply in India, most power stations are linkage stations, but not all. Monthly data of coal stocks at all stations are also available, but only beginning in April 2014, and generally with a slight greater lag than linkage station stocks data (CEA, various years-b). Here I have used a simple approach of using linear regression to determine a simple, time-independent relationship between the two series, and using this to extrapolate the all-station data to fill the entire period (Figure 11). This method obviously assumes the relationship holds outside of the period where both data are available, and in particular the share of linkage stations to all stations might have been different in earlier years. However, because the goal is stock changes month to month, and the major swings in the linkage station data are clearly reflected in the all-station data, it is expected that the stock changes (a first-order differential) are less affected by this assumption.

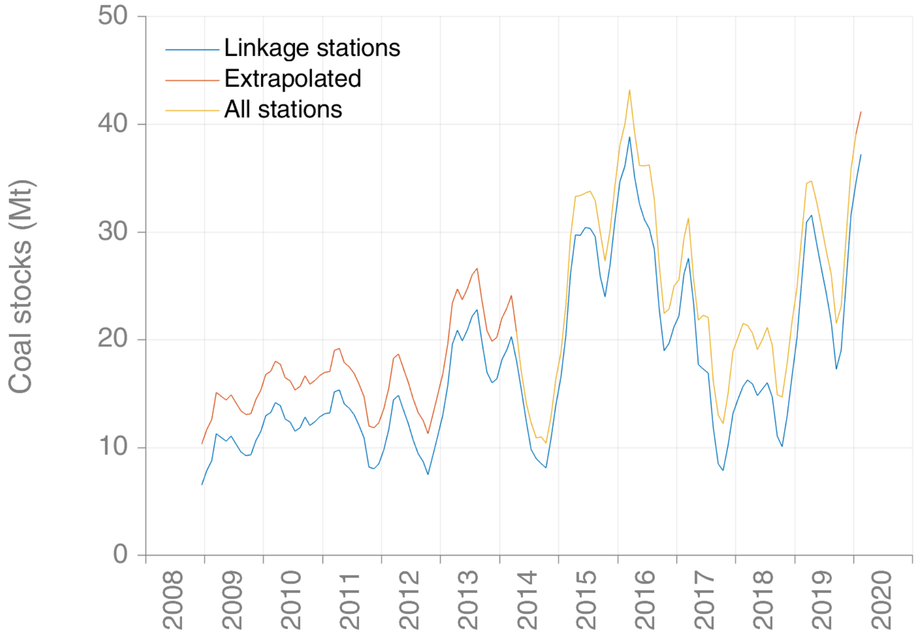

Figure 11: Monthly coal stocks at linkage power stations, all power stations, and the simple extrapolated series for all power stations based on the relationship between the two.

Comparison with IEA data

The IEA derives annual raw coal stock changes from the closing stocks presented in Table 5.2 of the Coal Directory (pers. comm., IEA, April 2020). Figure 12 compares stock changes reported by IEA in the World Energy Statistics 2019 edition with the data presented in two editions of the Coal Directory and with the most recent Provisional Coal Statistics report. Monthly data are estimated from production and despatches from these same Indian reports and should be lower than annual stock changes because they exclude use of collieries. There are four points to make here.

First, the IEA is using a figure for closing stocks for non-coking coal in 2008-09 that has been revised since the 2016-17 Coal Directory, and this results in a difference in calculated stock changes for 2009-10. Approximate stock changes derived from both the monthly and annual data reported in the 2009-10 Coal Directory appear to agree with the later estimate for stock changes of non-coking coal in that year. It seems likely that an error in reported stocks in Table 5.2 in the 2009-10 coal directory was propagated for several years, and finally corrected in the 2016-17 Coal Directory.

Second, the IEA reports exactly zero stock changes for non-coking coal in 2017-18, contrary to the almost 10 Mt stock change reported in the Coal Directory 2017-18. At the time the IEA collated these data, no figure for non-coking coal stock changes in that year were available (pers. comm., IEA, April 2020).

Third, the IEA reports stock changes for both coking and non-coking coal that are at significant variance with those reported in the Provisional Coal Statistics 2018-19, the latter matching provisional production and despatch statistics. While the IEA statistics report a build-up of stocks of non-coking coal of over 20 Mt in 2018-19 (based on information from CIL; pers. comm., IEA, April 2020), the PCS reports a draw down from stocks of about 2 Mt.

Fourth, the IEA's reported stock changes only include stocks at mines, and exclude power stations, ports, and other industrial facilities.

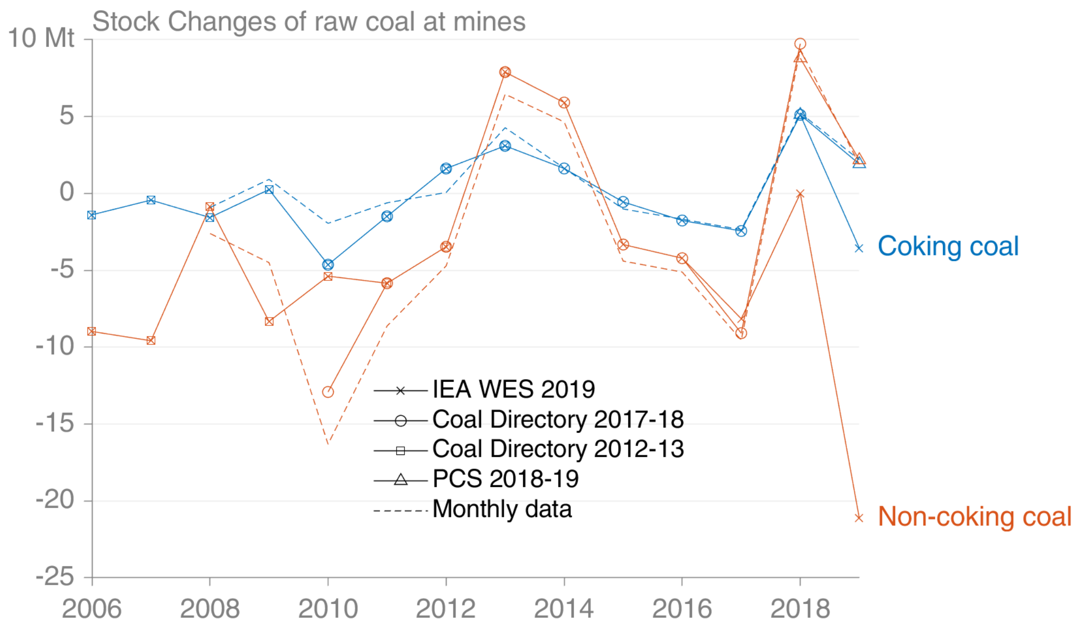

Figure 12: Comparison of raw coal stock changes at mines. Source: IEA, CCO, own calculations.

3. Coal trade

International coal trade data are readily available from the Directorate General of Commercial Intelligence and Statistics (DGCIS) from June 2015 onwards for the principal commodity category 'Coal, coke and briquittes [sic] etc', with a lag of up to two months (DGCIS, 2020). This category includes more than just coal, but the other products, which are very minor in quantity, are derivatives of coal and will also be oxidized when used.

Because of the lag in official reporting, the most recent 1–2 months of coal imports are taken from media reports based on information from mjunction, a company that tracks ships' movements. Given the wide interest in this information, these are regularly reported by a number of media outlets.

More detailed trade data, with a breakdown by coal types, are available from the Department of Commerce (DOC, 2020), but while the lag has recently reduced somewhat, these still become available at least a month later than those from DGCIS.

Coal exports are minor, peaking in the available data at 2.0% of imports in February 2017, and I report net imports henceforth. Monthly imports amount to between 20% and 40% of domestic hard coal production.

The IEA states that India's reported imports of coal until and including the year 2014-15 are significantly below the reports of the same trade from countries exporting to India, and use exporters' data in preference in this period (IEA, 2019b). Here I use IEA's annual import data to scale up the monthly data from DGCIS in that period; in later years IEA data match very closely the data reported by DGCIS, and no adjustment is required (Figure 13).

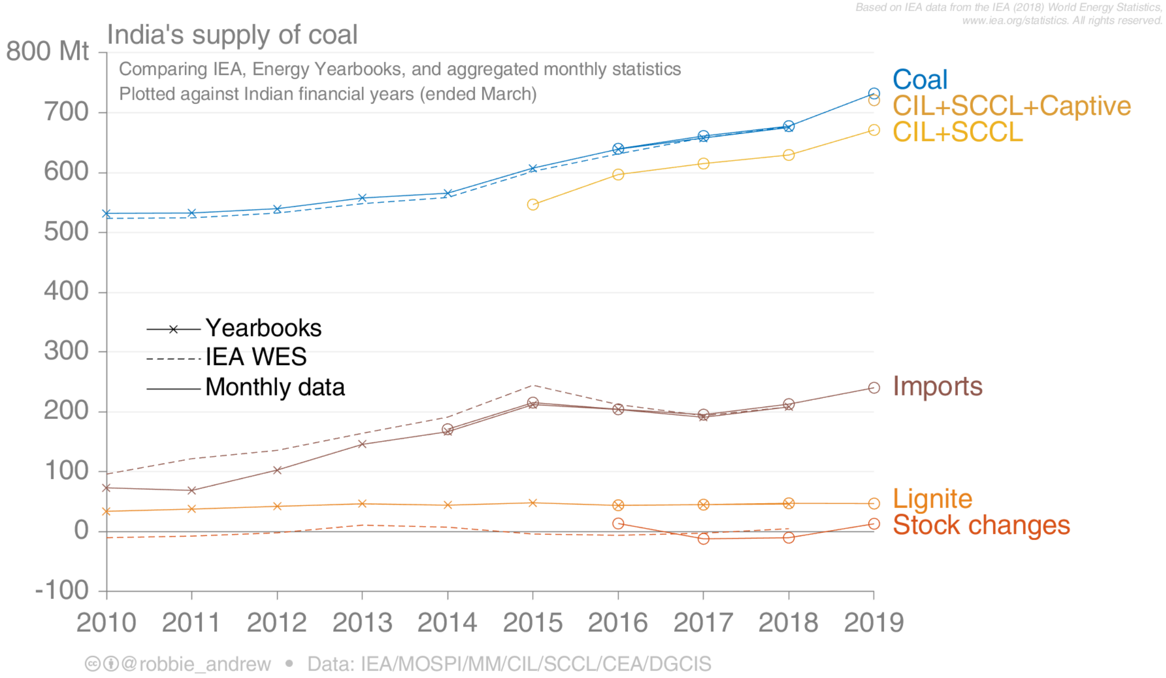

Figure 13: India's supply of coal. Source: IEA, MoSPI Yearbooks, monthly data assembled herein.

For some countries, imports of coal-derived non-energy products such as carbon anodes used in aluminium smelting are significant (Andrew, *in review*), but no data was found to suggest this in India.

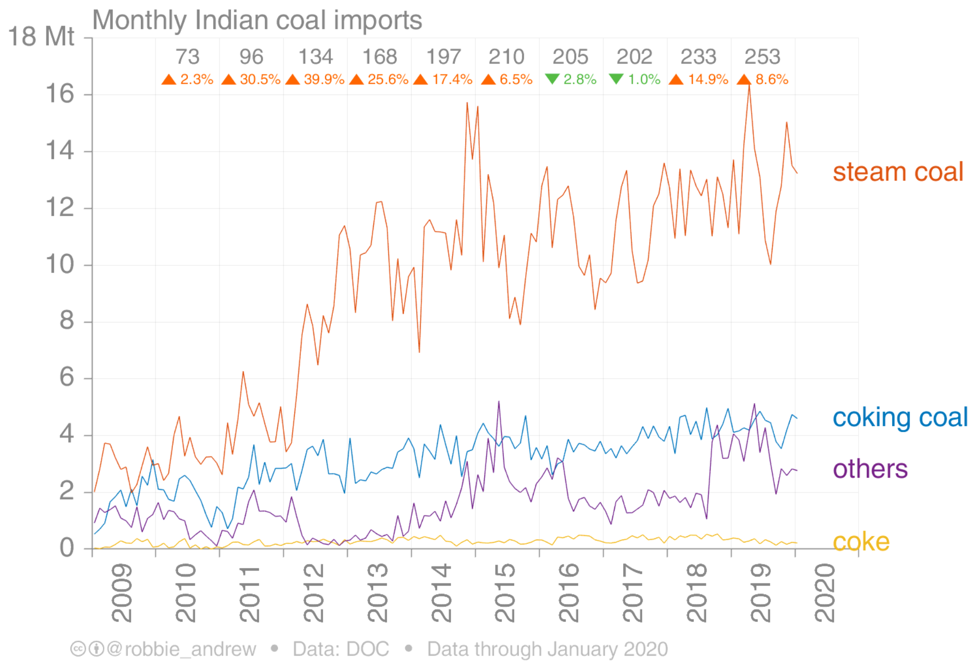

Figure 14: Monthly imports of coal by type. Source: Department of Commerce

4. Extrapolation

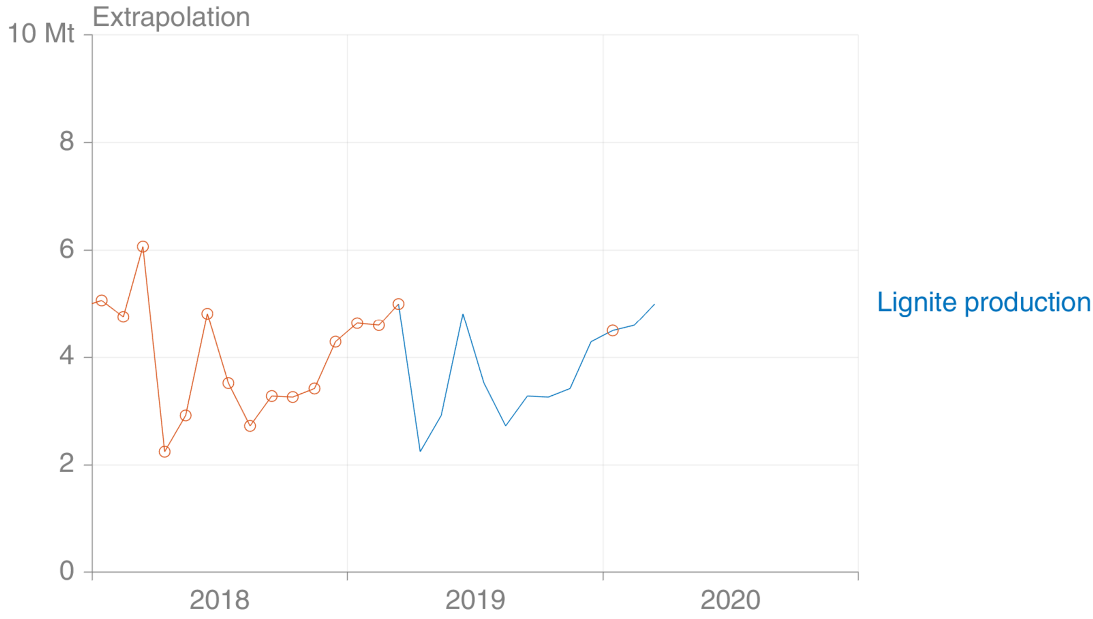

Figure 15: Extrapolation of lignite production. Line with circle markers shows reported values, while line without markers shows interpolation/extrapolation.

5. Coal energy content

The Indian Government introduced quality sampling of coal from 2016 (ETEnergyWorld, 2016), but while these data are collected throughout the year, they are only available on a cumulative basis. India's Energy Yearbook provides tables of annual production and imports in both physical and energy units, but these deviate significantly from those used by the IEA (Figure 16). Here I choose to use the energy contents from the IEA (2019c, 2019d), assuming its information is more reliable, particularly for earlier years.

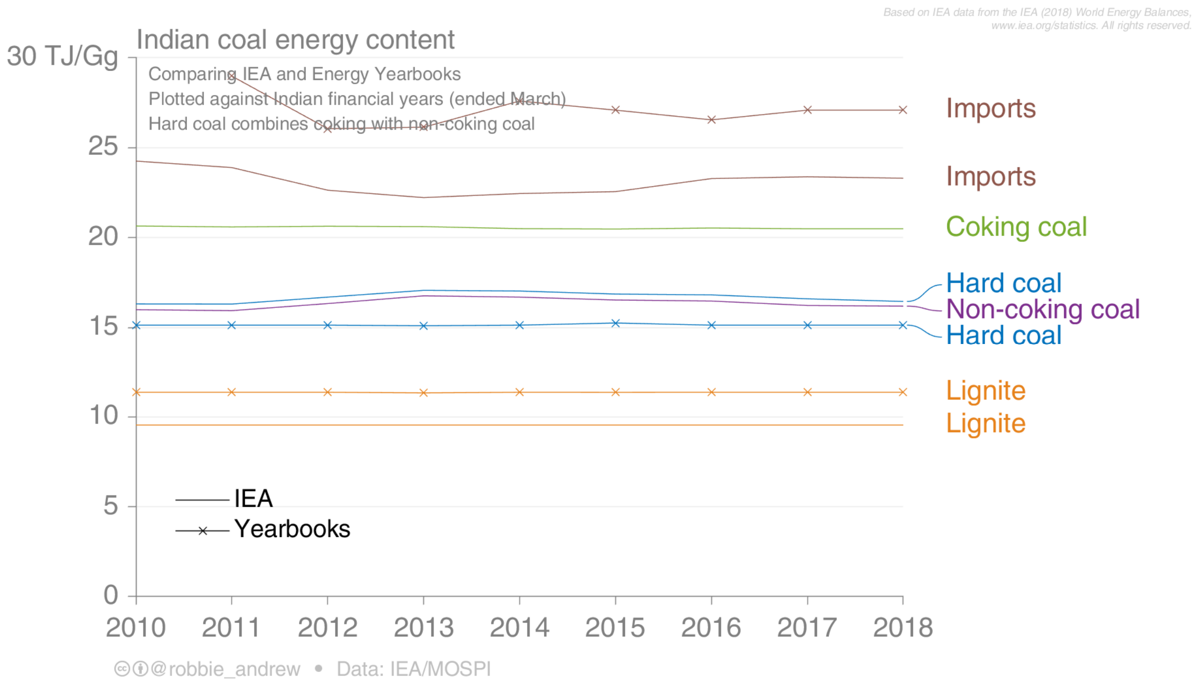

Figure 16: Comparison of energy content of coal from IEA (2019c, 2019d) and India's Energy Yearbooks (MOSPI, various years).

6. Coal CO_2 emissions

I calculate apparent hard coal and lignite consumption separately as production + net imports + net withdrawal from stocks. These are then converted to CO_2 emissions using default factors from the IPCC's guidelines (Gómez et al., 2006). Resulting monthly emissions estimates are shown in Figure 17.

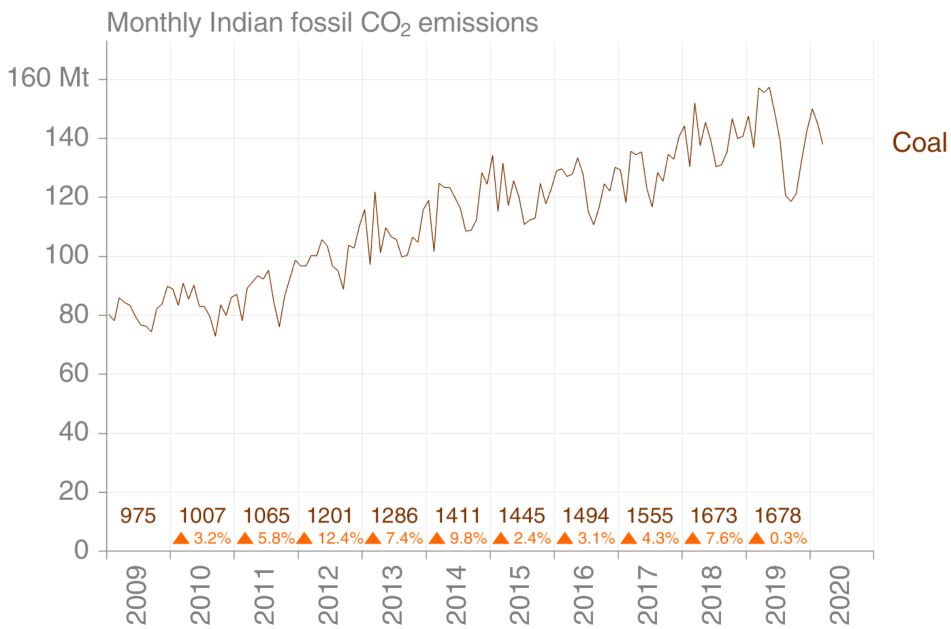

Figure 17: Final monthly estimates of CO_2 emissions from oxidation of coal in India.

7. Petroleum production and consumption

Consumption data by mass are available for 12 different petroleum products including non-energy uses such as bitumen, starting in April 1998 (Figure 18)(PPAC, various years-a). These data are most likely in fact sales data rather than actual consumption, a distinction that gains more significance when looking at monthly as opposed to annual data.

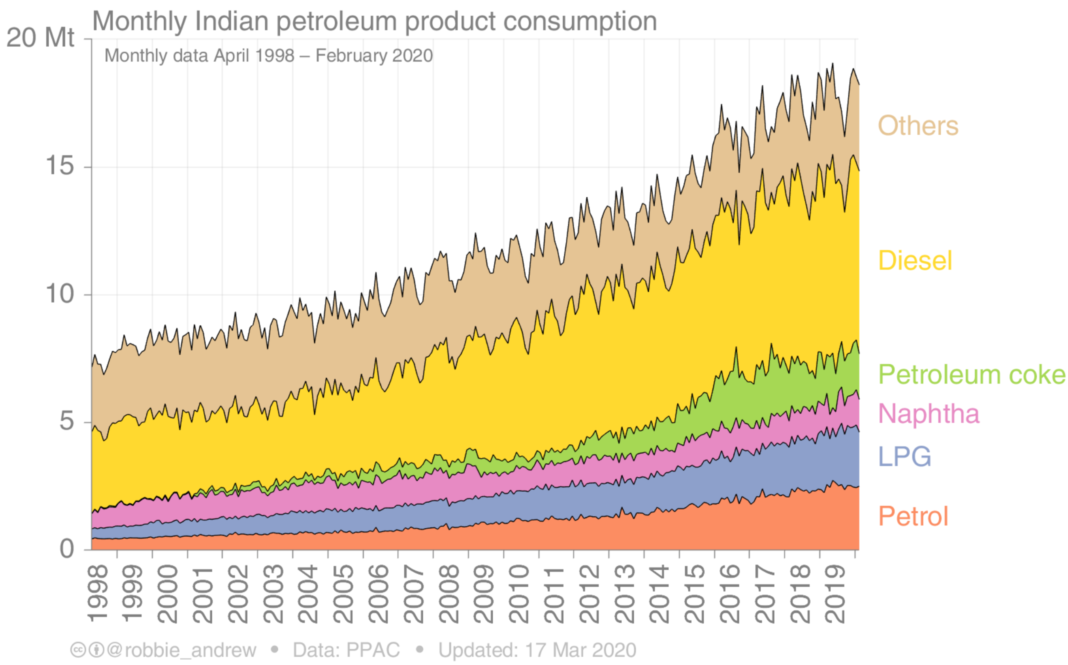

Figure 18: Consumption of petroleum products from April 1998 in physical units. Source: PPAC.

To convert to units of energy I again use factors from the IEA (2018b), which are similar but not identical to the IPCC default factors (Gómez et al., 2006).

Since this analysis focusses on India's domestic emissions, fuel consumption by international aviation and navigation (bunkers) are excluded. The consumption data from PPAC exclude marine bunker fuels but include aviation bunker fuels, the same convention used by the IEA in its Oil Demand tables (IEA, 2019a). I use the annual ratio of bunker to non-bunker consumption from IEA (2018a) to estimate and remove monthly aviation bunker fuels. This effectively assumes, for example, that the proportion of jet kerosene supplying international flights is constant through the year.

The resulting consumption data in energy units are shown in Figure 19.

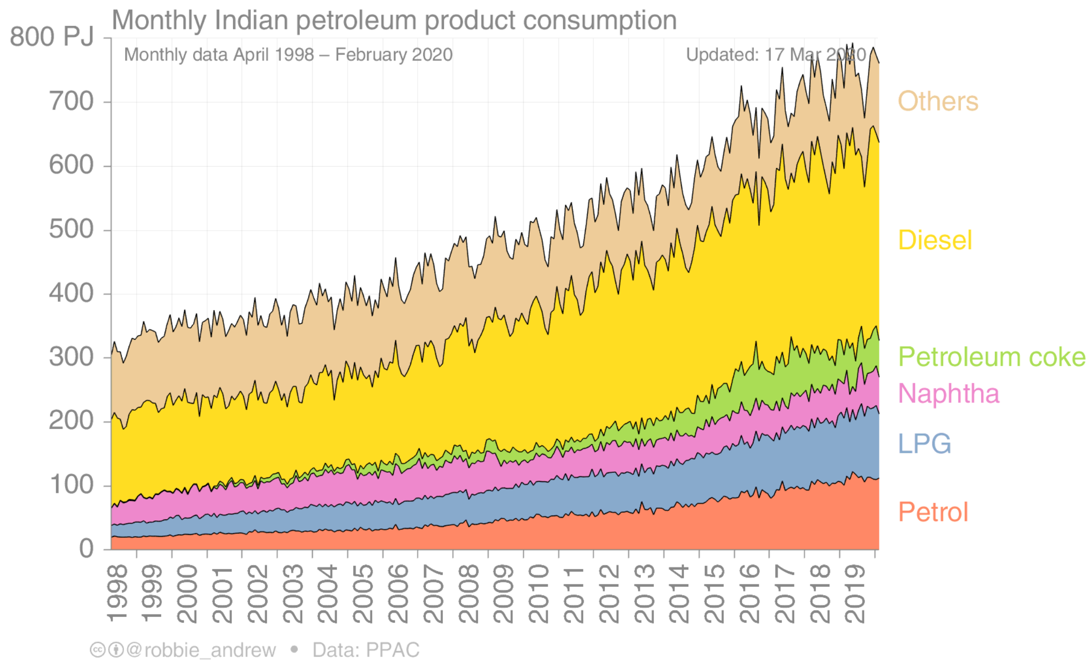

Figure 19: Consumption of petroleum production from April 1998 in energy units. Source: Own calculations.

To determine combustion emissions, non-energy uses of petroleum products must be removed. IEA data also indicate non-energy use by fuel type; these vary gradually over time, and I assume the fractions in the final year of the IEA data also apply for the years immediately following. For oxidation, I assume that both bitumen and lubricants are never oxidised, but that all other fuels are. This is likely to be a small overestimate because some naphtha and other petroleum products are used as feedstocks to produce commodities that might never oxidise. The resulting energy dataset is converted to CO_2 emissions using default IPCC factors (Gómez et al., 2006).

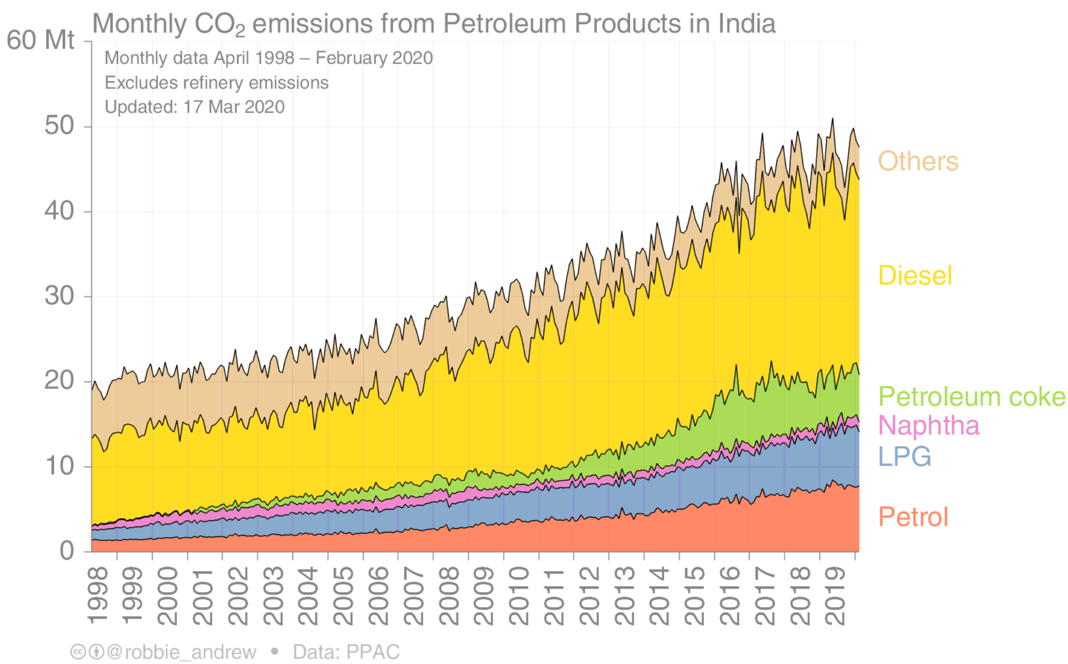

Figure 20: Emissions from combustion of petroleum products. Source: Own calculations.

Lastly, emissions from refineries' own use of energy are added by scaling annual refinery energy use in the form of petroleum products from IEA (2018a) to monthly production data available from April 2010 (PPAC, various years-b). The IEA indicate that energy use from petroleum products by refineries is entirely refinery gas (IEA, 2019c), and emissions are therefore determined using the default IPCC emission factor for refinery gas (Gómez et al., 2006). Where monthly production data are not available, annual production data are used to estimate refinery emissions. This assumption introduces a small month-to-month error, but refinery emissions are small compared to total petroleum emissions.

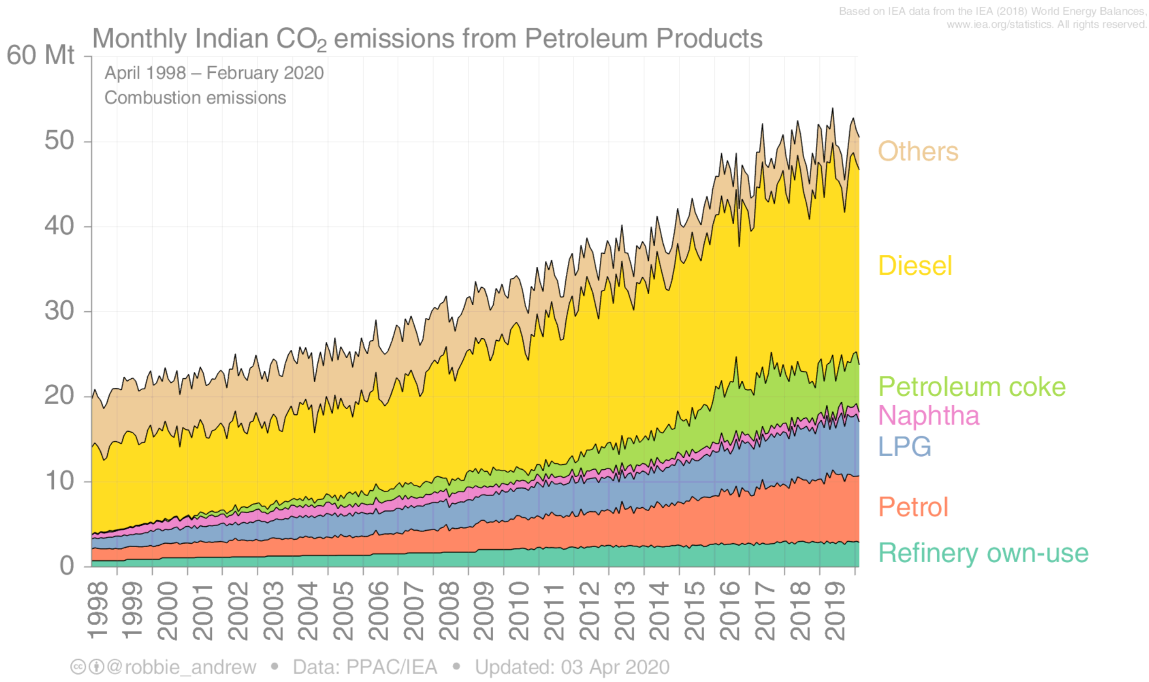

Figure 21: Emissions from combusted petroleum products: Source: Own calculations.

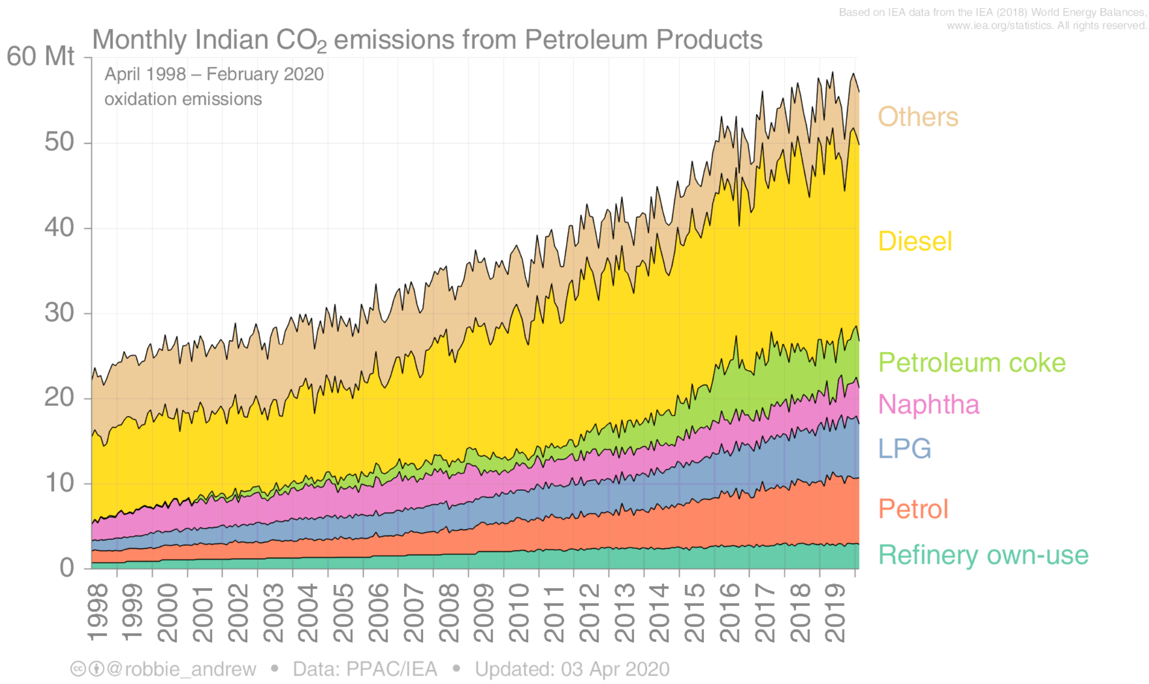

Figure 22: Emissions from oxidised petroleum products: Source: Own calculations.

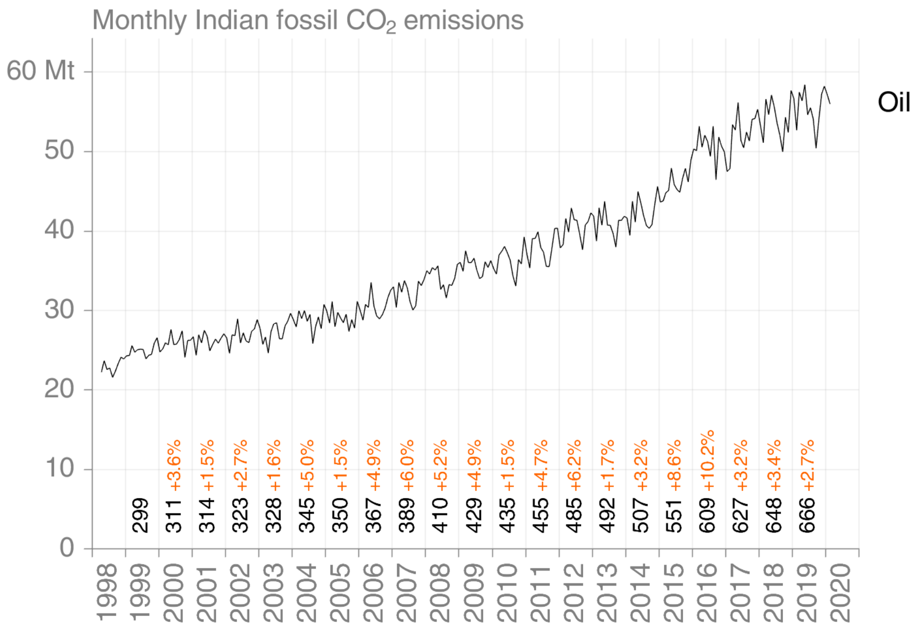

Figure 23: Final monthly estimates of CO_2 emissions from oxidation of oil and oil products in India.

The Joint Organisations Data Initiative (JODI) publishes monthly data on oil and gas production and consumption for a large number of countries, but when comparing India's total oil demand with the official, revised data series from PPAC, some considerable deviations are evident (Figure 24).

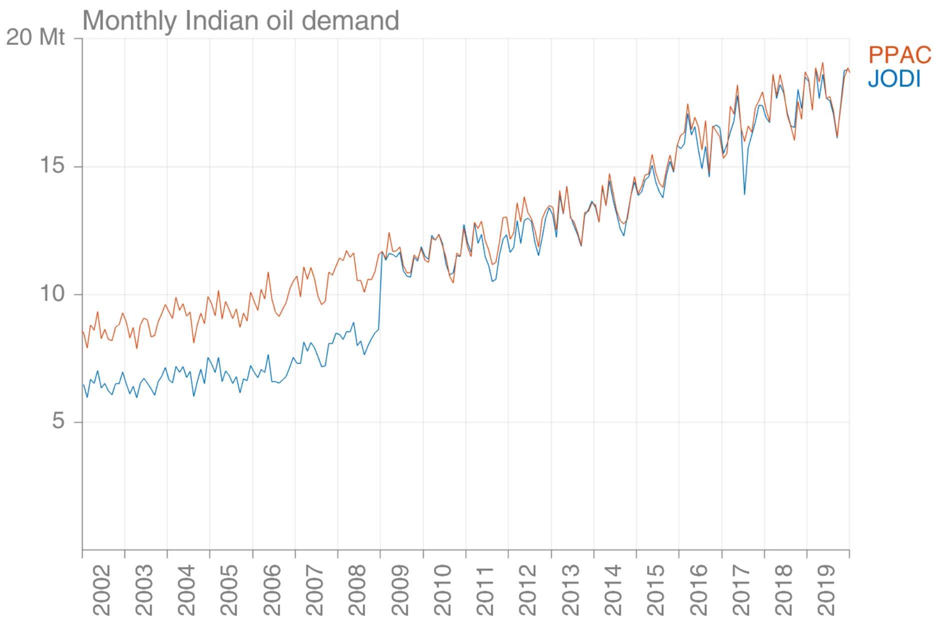

Figure 24: Comparison of monthly oil demand from PPAC and JODI.

Comparison with IEA annual consumption data

The following figures demonstrate that the monthly consumption data as used match very closely the annual data provided by the IEA.

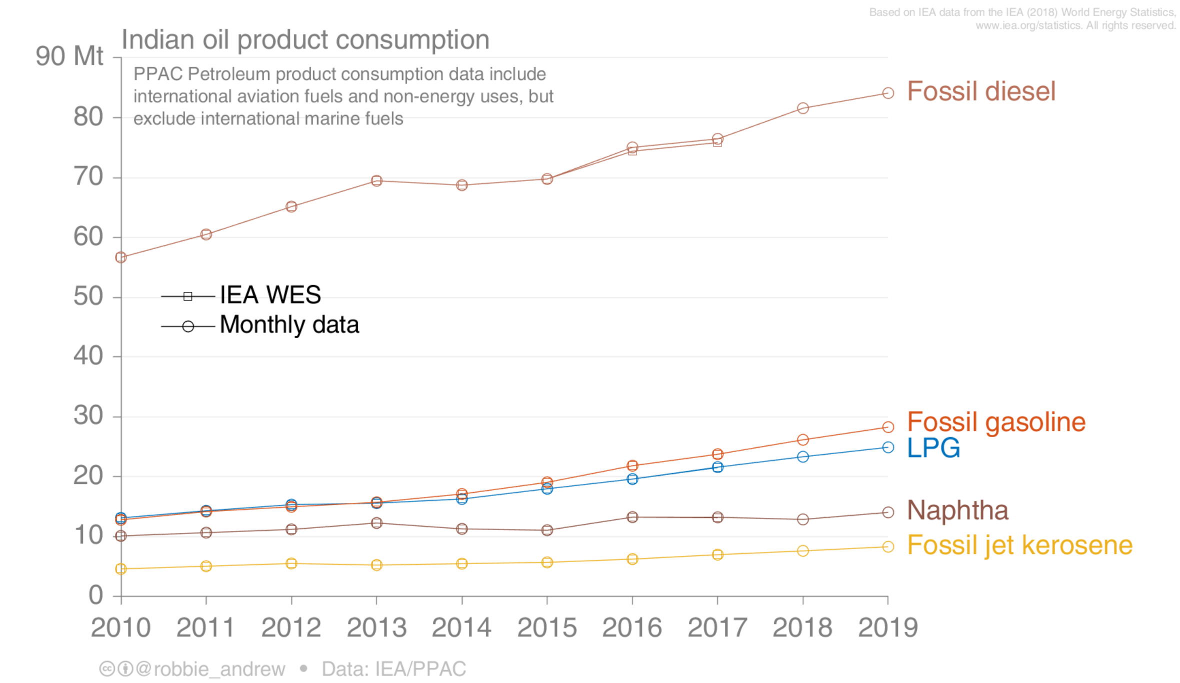

Figure 25: Comparison of consumption of diesel, gasoline, LPG, naphtha, and jet kerosene in physical units between aggregated monthly data from PPAC and annual data from IEA.

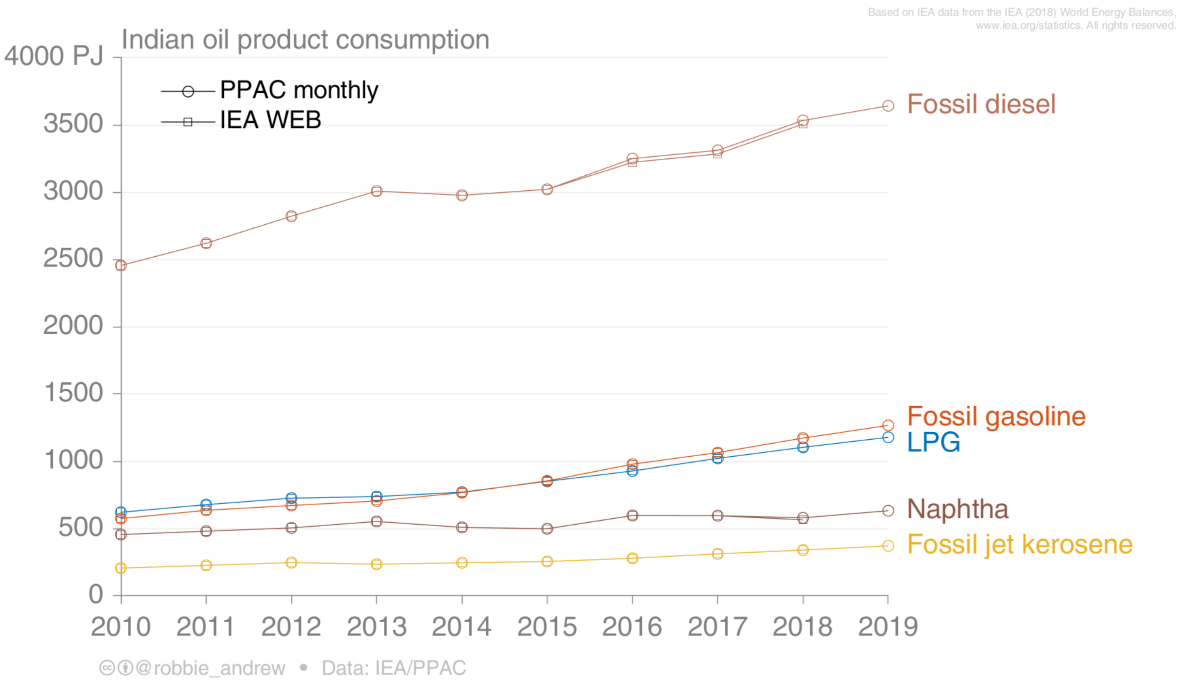

Figure 26: Comparison of consumption of diesel, gasoline, LPG, naphtha, and jet kerosene in energy units between aggregated monthly data from PPAC and annual data from IEA.

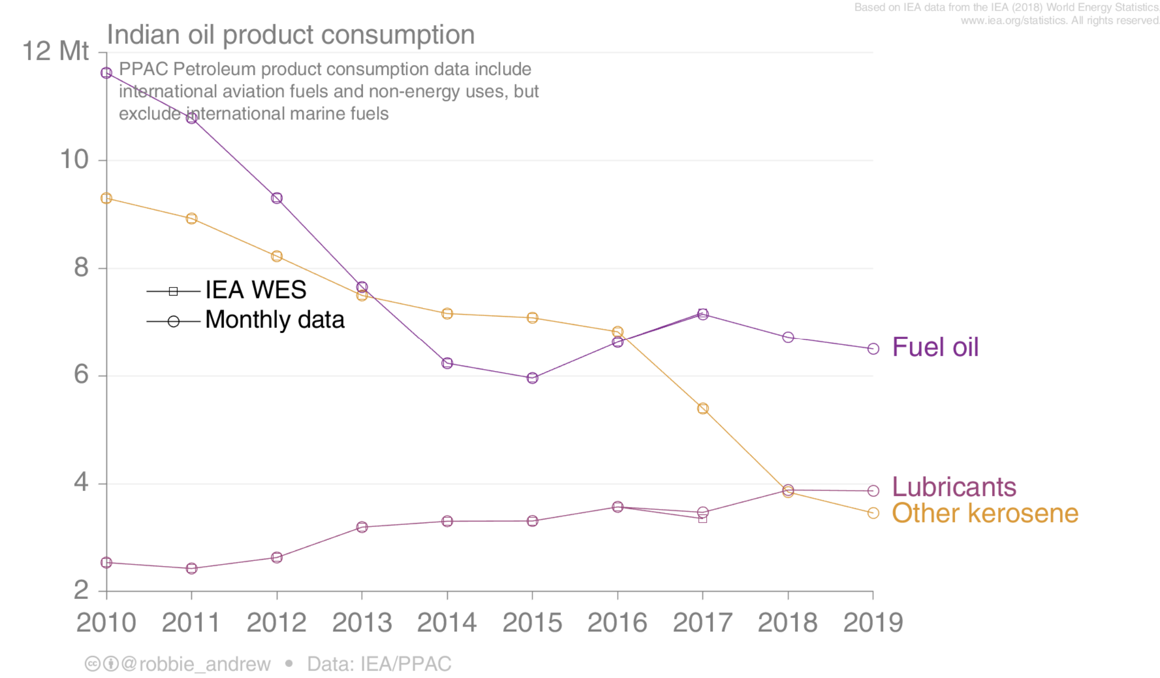

Figure 27: Comparison of consumption of fuel oil, lubricants, and other kerosene in physical units between aggregated monthly data from PPAC and annual data from IEA.

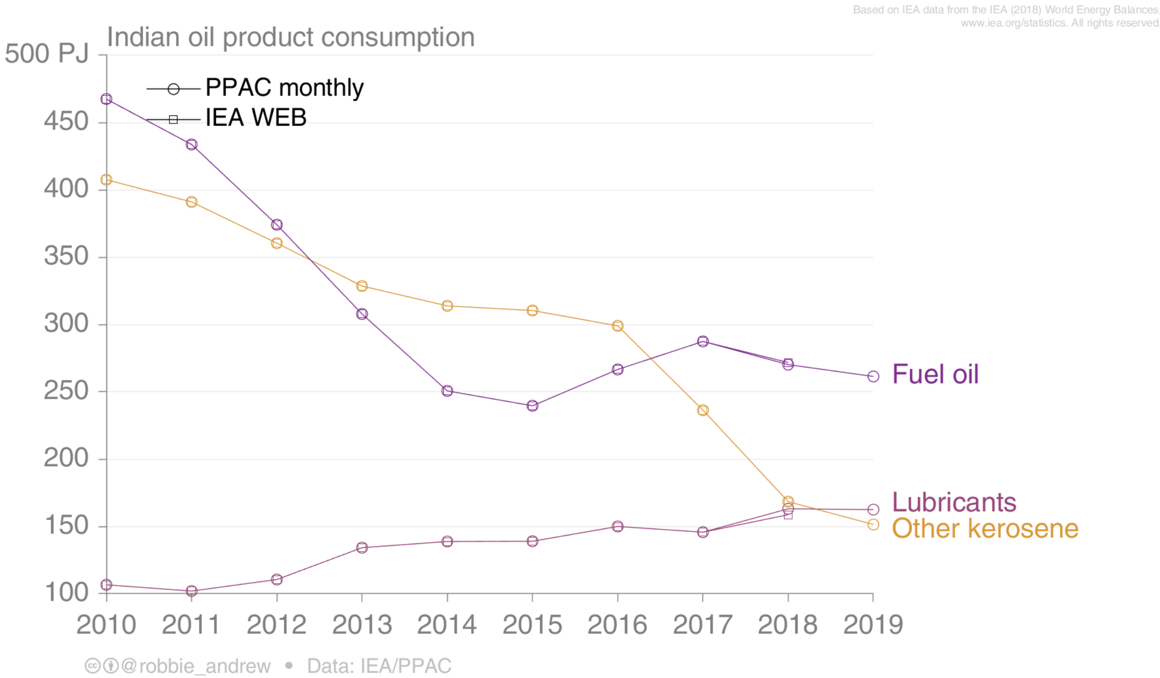

Figure 28: Comparison of consumption of fuel oil, lubricants, and other kerosene in energy units between aggregated monthly data from PPAC and annual data from IEA.

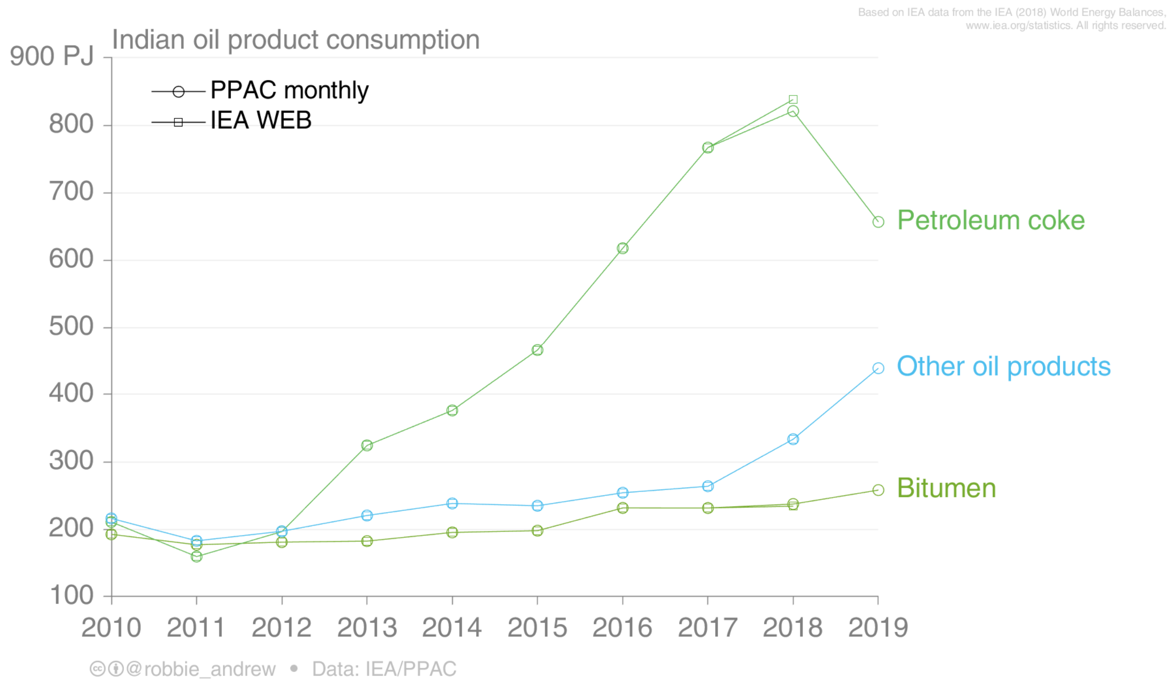

Figure 29: Comparison of consumption of petroleum coke, bitumen, and other oil products in physical units between aggregated monthly data from PPAC and annual data from IEA.

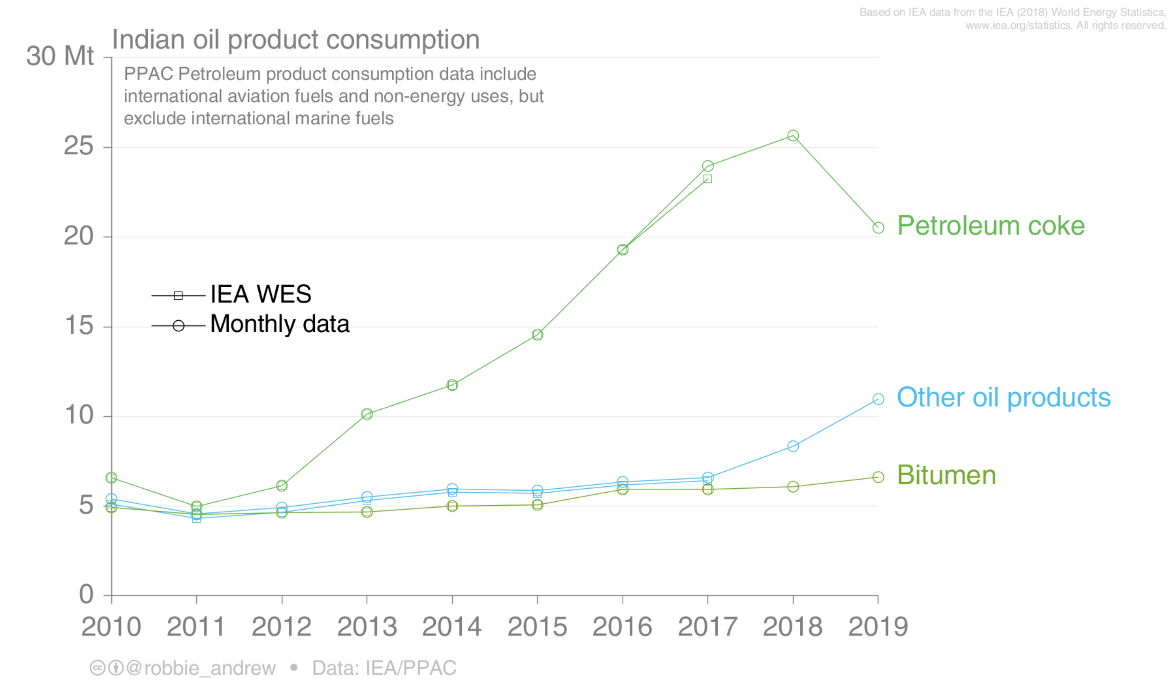

Figure 30: Comparison of consumption of petroleum coke, bitumen, and other oil products in energy units between aggregated monthly data from PPAC and annual data from IEA.

8. Natural Gas

Monthly data for natural gas are available from the Petroleum Planning & Analysis Cell (PPAC) of the Ministry of Petroleum & Natural Gas in four separate reports, all available from the PPAC website: www.ppac.gov.in. Table 1 shows the format and lag between the end of the month for which data are available and the publication of the report.

Table 1: Publication lags of reports that provide data on natural gas production and consumption in India.

Report	Format	Lag
Snapshot of India's Oil & Gas data (Abridged Ready Reckoner)	PDF	~3 weeks
Monthly report on Natural Gas Production, Availability and Consumption	PDF	~5 weeks
Gas Consumption Current	Excel	~5 weeks
Gas Production Current	Excel	~5 weeks

PPAC reports total extracted natural gas as 'Gross production', and variously 'Net availability' or 'Net production' when flaring and losses are removed, noting that the Yearbook indicates that reported losses are very minor. None of the monthly reports explicitly report internal consumption by the gas industry itself, but once this is removed the resulting amount is referred to as 'Net production for sale'. Total supply to the market consists of this net production from domestic production plus LNG imports, and the resulting total supply is called 'Total consumption', noting that this excludes both flaring/losses and internal use by the gas industry. Table 2 shows which reports include each term, and what they are called. India does not export natural gas.

Table 2: Use of natural gas terms across reports on natural gas.

Energy Yearbook (annual data)	Snapshot	Monthly report	Gas Consumption Current	Gas Production Current
Gross production	Gross production	Gross production		Gross production
Flared				
Losses				
Net availability *and* Net Production (for consumption)[1]	Net production		Net production	Net production
Internal use/Consumption				
Net production (sales)		Net production for sale		
LNG imports	LNG imports	LNG imports	LNG imports	
	Total consumption		Total consumption	

[1] Two different terms are used in the Yearbook in different tables.

Data from these sources are available back to April 2012, with some spot data for gross production before that. The UN Statistics Monthly Bulletin of Statistics Online reports monthly production back to January 2009, and these match exactly the net production values from PPAC in the overlapping period until 2016, from which point they match exactly the gross production values from PPAC (except for the very final data point). The assembled data from these sources are shown in Figure 31, For the purposes of a continuous series, the two-month data gap in domestic production in early 2010 is filled with simple linear interpolation.

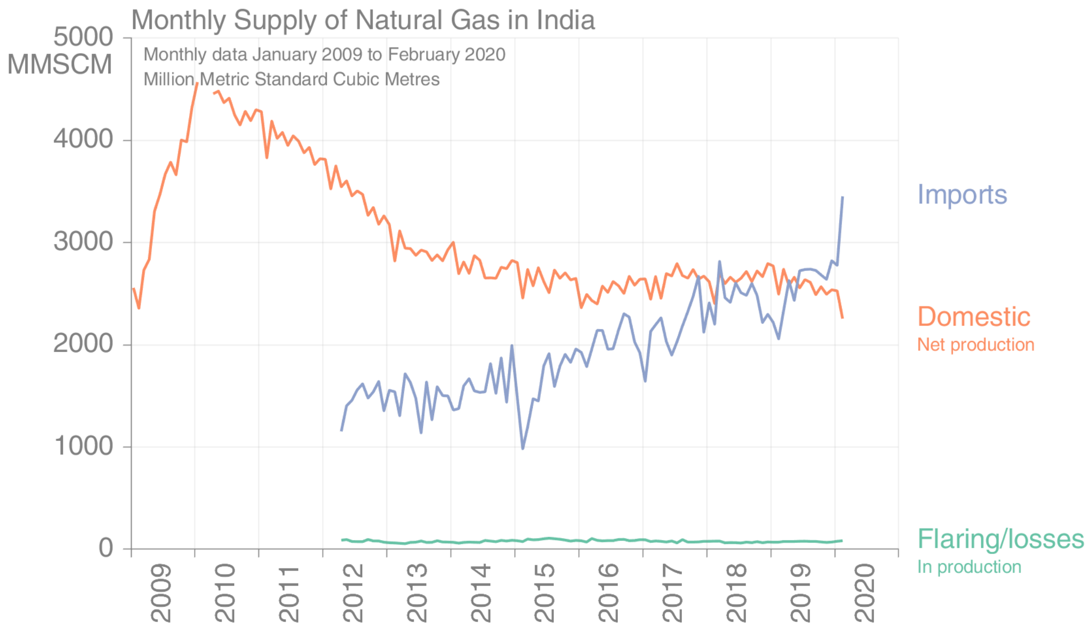

Figure 31: Monthly supply of natural gas in India. Source: PPAC, UN Statistics.

Imports are also available directly from the Department of Commerce (DOC), from January 2007. These data are in units of kilotonnes, and do not match particularly well the data from PPAC when converted using PPAC's conversion factor of 1325 MMSCM (million metric standard cubic metres) per MMT (million metric tonnes), as shown in Figure 32. However, the variation of DOC data does approximately follow that of the PPAC data, and I therefore use the annual totals from the Energy Yearbook spread across months using the DOC dataset to extend monthly imports back to April 2007. Because the period of overlap between domestic production and use of DOC imports data coincides with the lowest proportion of imports in supply in the entire series, the error introduced by this approach is relatively small.

The large spike in imports of natural gas in February 2020 resulted from low international prices because the Covid-19 situation in China reduced demand.

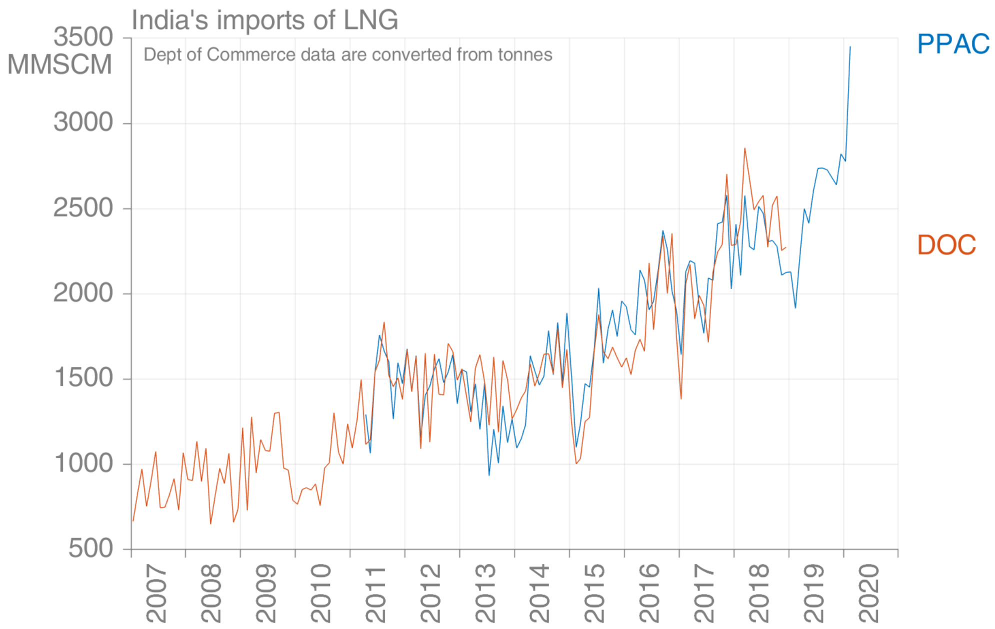

Figure 32: Comparison of LNG import statistics: Source: Petroleum Planning & Analysis Cell (PPAC) of the Ministry of Petroleum and Natural Gas and the Department of Commerce (DOC).

No information is available on stock changes, but there is a considerable supply shortage of natural gas in India, evidenced by gas-fired power stations averaging 20% utilisation factor, so an assumption of zero stock changes is not likely to be far from the truth.

For the purposes of estimating CO_2 emissions from oxidation of natural gas, flaring and internal use should be included in the total, I have used Gross production plus LNG imports, and adjusted that total for an estimated share that is oxidised.

Note that own use in extraction has been mislabelled as 'reinjection' in some editions of the yearbook. The 2013 Yearbook gives very low values for reinjected natural gas, and zero from 1995/96 (Table 3.6 in that book), while the values labelled as reinjection in the 2016 edition (Table 3.5) are identical to those labelled 'internal consumption' in the 2019 edition (Table 3.5).

The "Monthly report" also includes a breakdown of sales by sector (Figure 33). This time series is relatively short, and the 'Others' category includes both oxidised and non-oxidised uses of natural gas, such that this series is not very helpful for determining the share of oxidised gas over time.

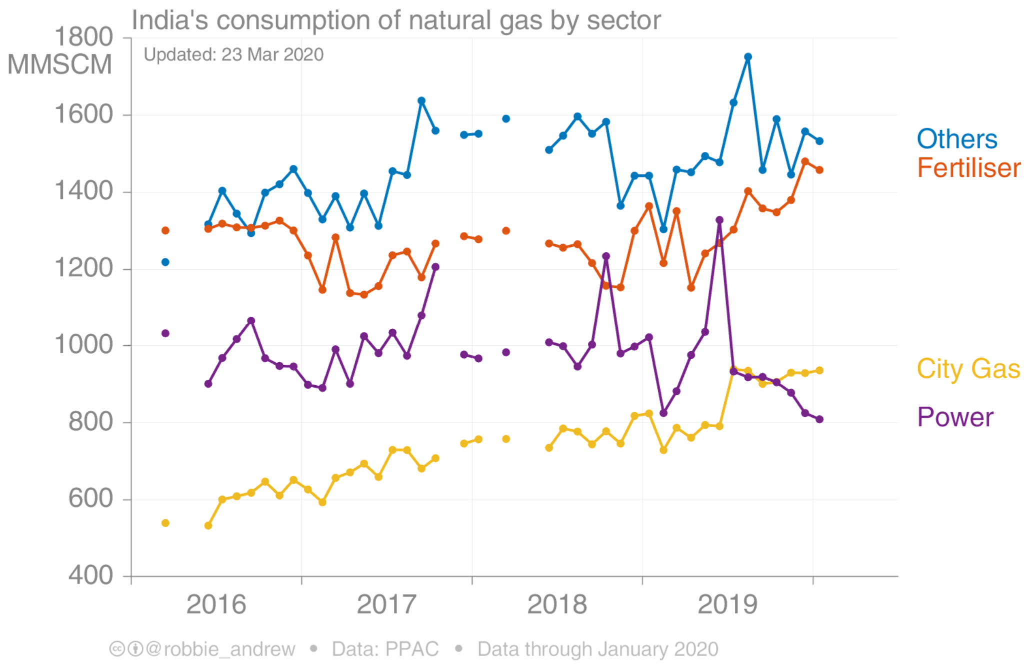

Figure 33: Consumption of natural gas by sector. Reports for missing months were probably produced but have not been located for this analysis. Source: PPAC.

Combustion emissions can be estimated using non-energy use shares either from IEA or India's Energy Yearbooks (MOSPI, various years), and these show considerably lower emissions than if all natural gas were oxidised.

Using information in the Yearbooks on sectoral consumption it is possible to approximate actual oxidation by adding to energy use the non-energy use by the fertiliser and sponge iron industries, along with gas 'shrinkage' (evaporative losses from liquified gas). Some of the natural gas used in the petrochemical industry will also be oxidised, when products are later incinerated, but no data were found from which estimate this fraction. The share of the petrochemical industry grew from about 3% in 2011-12 to about 8% in 2015-16, but has been relatively stable since, and the 2017-18 value is used for later periods until the next yearbook is published.

To convert from physical units to energy units I use the conversion factors provided by PPAC, with 0.90 NCV/GCV and 10000 Kcal/GCV (PPAC, no date). CO_2 emissions factors are taken from the IPCC guidelines (Gómez et al., 2006), resulting in the monthly emissions shown in Figure 34.

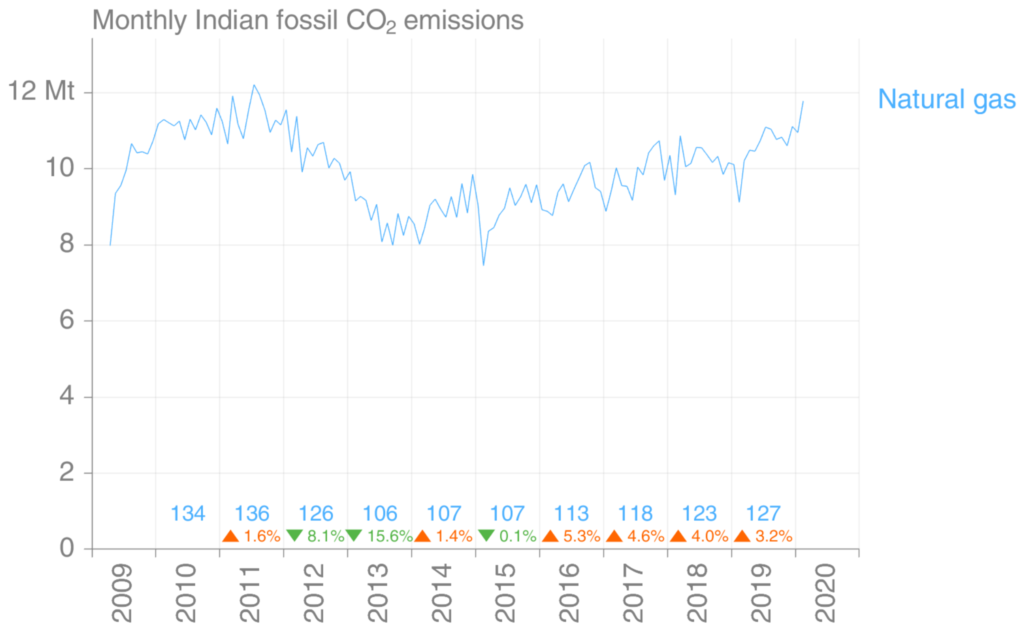

Figure 34: Final monthly estimates of CO_2 emissions from oxidation of natural gas in India.

9. Cement production

Cement production has two major sources of emissions. The first is the use of fossil energy, largely coal, and this is already covered in the estimates of total emissions by fuel category. The second is the chemical reaction that decomposes calcium carbonate into calcium oxide and CO_2 (Andrew, 2019). To accurately estimate these process emissions requires clinker production data, but these have not been published in India since 2012 as a result of a court case against the industry (CCI, 2016). Monthly cement production data are available from the Office of the Economic Advisor (OEA, 2019), and these are used to update the emissions are calculated by Andrew (2019).

I extrapolate the annual clinker data from Andrew (2019) by replicating the final data point forward one to two years, and clinker ratio is calculated from these data and the annualised cement production data from OEA. Then the annual clinker ratio series is interpolated to give a monthly series by placing each annual clinker ratio at the midpoint in each year, and interpolating with a shape-preserving piecewise cubic interpolation, which is then passed through a 36-month moving average filter to reduce potentially spurious volatility (Figure 35). This clinker ratio series is then applied to the entire OEA cement production series to give estimated monthly clinker production, and this is in turn multiplied by the emissions factors used by Andrew (2019) to give monthly process emissions (Figure 36).

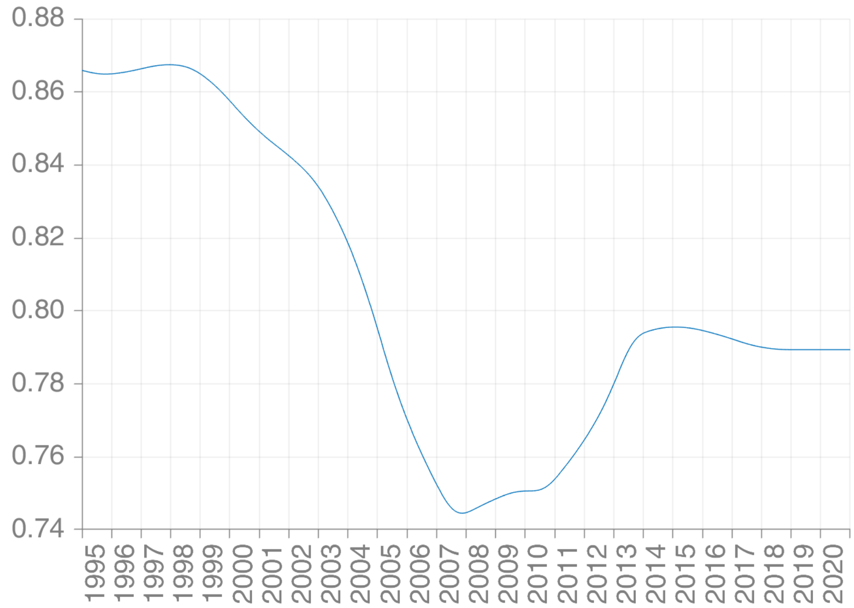

Figure 35: Interpolated/extrapolated monthly Indian clinker-cement ratio.

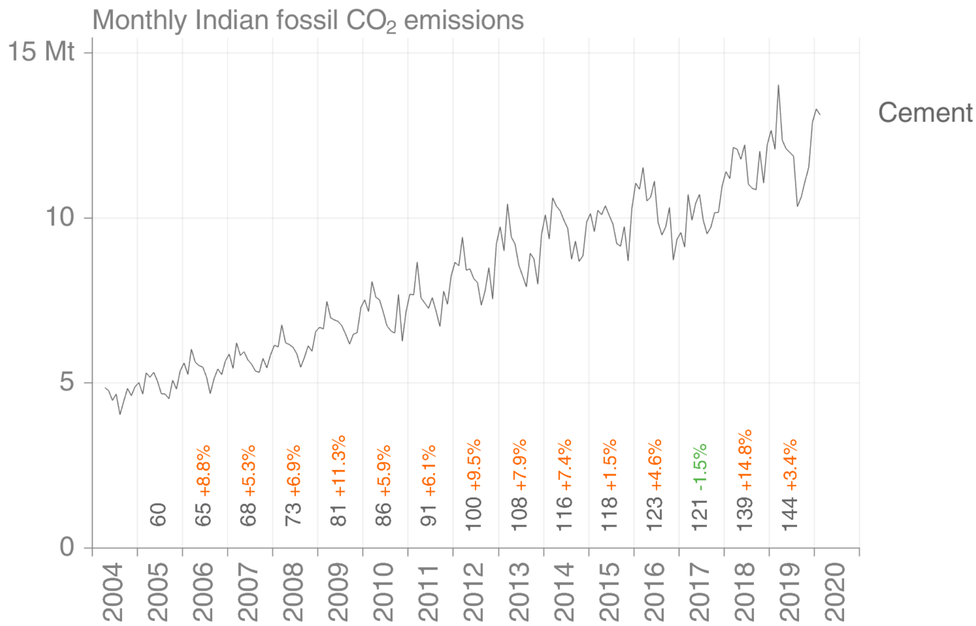

Figure 36: Final monthly estimates of CO2 process emissions from cement production in India.

10. Electricity generation capacity

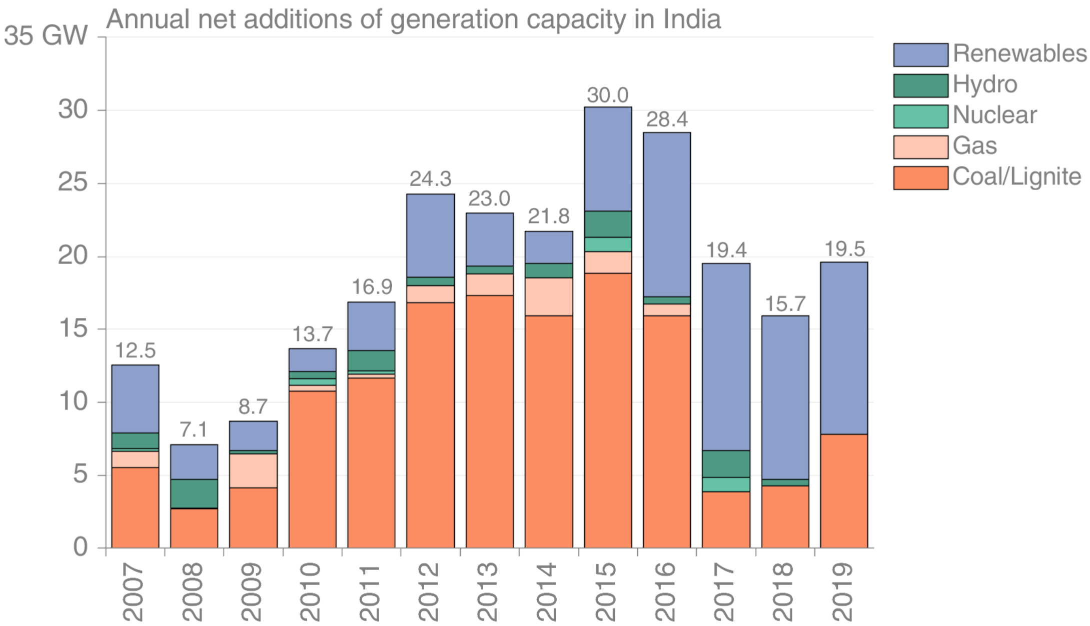

Figure 37: Annual net additions of electricity generation capacity in India. Source: CEA.

11. Quarterly GDP growth

Figure 38 shows official estimates of India's quarterly growth in gross domestic product from 2012, the values published in March 2020 shown in red. This version reveals substantial revisions compared to the previous version from December 2019, resulting from changed estimates of the "informal" sector, largely operating with cash and therefore less visible to data collection efforts.

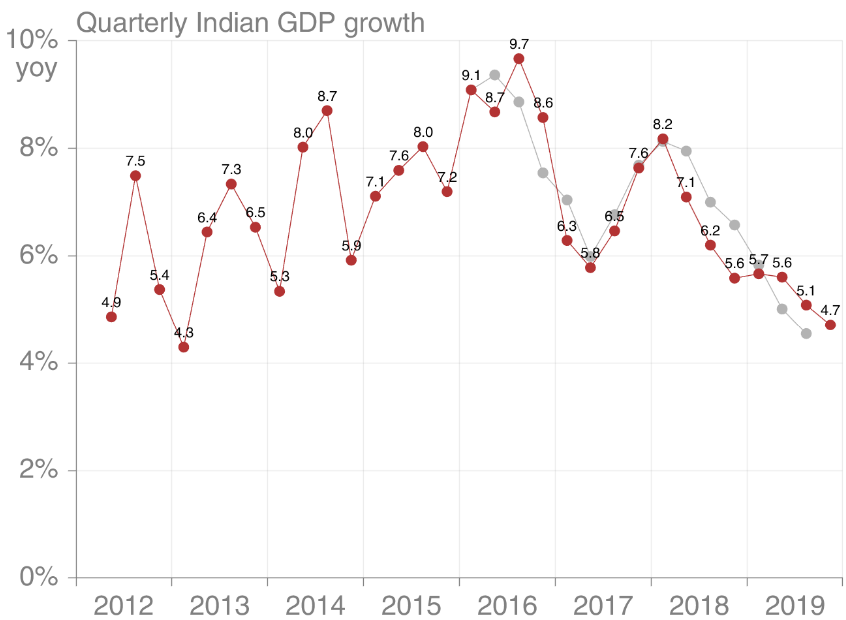

Figure 38: India's Quarterly GDP growth. Latest revision in red, estimates from December 2019 in grey. Source: MOSPI.

12. Total monthly electricity demand

Total electricity demand exhibits summer peaks and winter troughs, reflecting the higher demand for cooling than for heating in India.

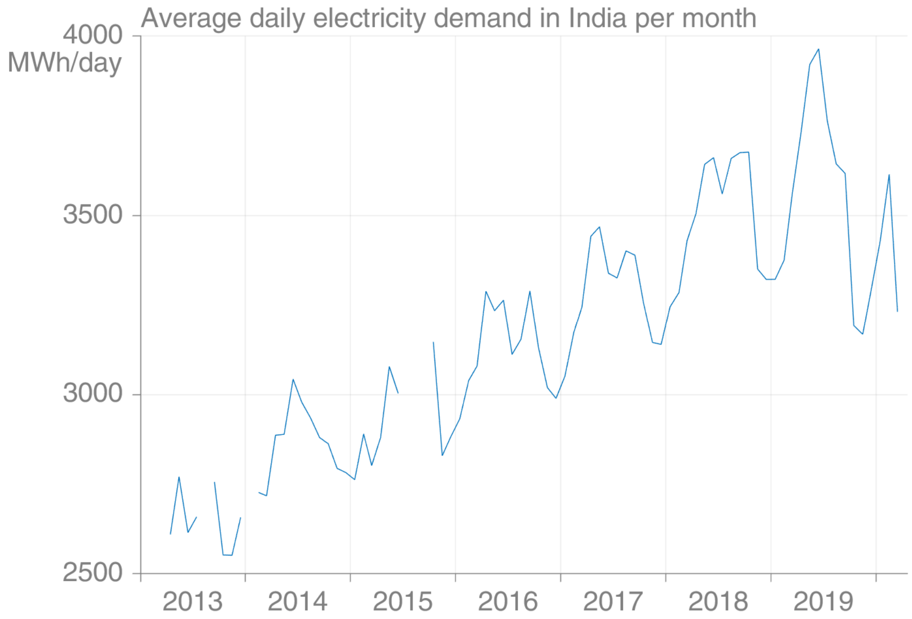

Figure 39: Monthly total electricity demand in India, adjusted for the number of days in the month. Source: (POSOCO, 2020).

13. Summary of X-11 deseasonalisation method

The following is a brief summary of the method (Eurostat, 2013):

1. Derive an initial estimate of the trend-cycle by applying a moving average to the raw data
2. Subtract this estimate from the raw data to obtain an initial estimate of the seasonal-irregular (SI) and apply a moving average to the SIs for each type of period (month) separately to obtain initial estimates of the seasonal component
3. Subtract the initial seasonal factors from the raw data to obtain an initial estimate of the seasonally adjusted series (i.e. the trend-cycle/irregular) and apply a Henderson moving average to obtain a second estimate of the trend-cycle
4. Subtract the second estimate of the trend-cycle from the raw data to obtain a second estimate of the SIs, and apply a moving average for each type of quarter separately to obtain final estimates of the seasonal component
5. Subtract the seasonal factors from the raw data to obtain a final estimate of the seasonally adjusted series and apply a Henderson moving average to obtain a final estimate of the trend-cycle

14. Imports of urea from China

India imported 2.4 Mt of urea from China in 2019 (Roache, 2020). The IPCC's default factor is 0.20 tonnes of carbon emitter per tonne of urea (De Klein et al., 2006), or 0.73 tCO_2 per tonne. These imports would then lead to emissions of 1.76 Mt CO_2 when used in Indian agriculture.

References

Andrew, R.: A comparison of estimates of global carbon dioxide emissions from fossil carbon sources, Earth System Science Data, DOI: 10.5194/essd-2020-34, *in review*.

Andrew, R. M.: Global CO_2 emissions from cement production, 1928–2018, Earth System Science Data, 11, 1675–1710, DOI: 10.5194/essd-11-1675-2019, 2019.

CCI: Case No. 29 of 2010, Competition Commission of India, 2016. https://www.cci.gov.in/sites/default/files/Final%20Order%2029%20of%202010%2031.08.2016%20.pdf (Last access: 8 April 2020).

CEA: Daily Coal Report, various years-a. https://npp.gov.in/publishedReports (Last access: 17 April 2020).

CEA: Coal Statement, various years-b. http://cea.nic.in/monthlycoal.html (Last access: 17 April 2020).

CIL: Provisional Production and offtake performances of CIL and its subsidiaries companies, Coal India Limited, various years. https://www.coalindia.in/en-us/performance/physical.aspx (Last access: 17 April 2020).

De Klein, C., Novoa, R. S. A., Ogle, S., Smith, K. A., Rochette, P., Wirth, T. C., McConkey, B. G., Mosier, A., Rypdal, K., Walsh, M., and Williams, S. A.: N_2O Emissions From Managed Soils, and CO_2 Emissions From Lime and Urea Application, in: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, edited by: Eggleston, S., Buendia, L., Miwa, K., Ngara, T., and Tanabe, K., IGES, Japan, 2006. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (Last access: 21 May 2017).

DGCIS: Foreign Trade Data Dissemination Portal, Directorate General of Commercial Intelligence and Statistics, 2020. http://14.98.253.4/ (Last access: 6 April 2020).

DOC: System on India's Monthly Trade, Department of Commerce, 2020. http://commerce-app.gov.in/meidb/brcq.asp?ie=i (Last access: 7 April 2020).

Eurostat: Handbook on quarterly national accounts: 2013 edition, Luxembourg, ISBN 978-92-79-33081-0, 2013. https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/KS-GQ-13-004 (Last access: 6 April 2020).

Gómez, D. R., Watterson, J. D., Americano, B. B., Ha, C., Marland, G., Matsika, E., Namayanga, L. N., Osman-Elasha, B., Saka, J. D. K., Treanton, K., and Quadrelli, R.: Stationary Combustion, in: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, edited by: Eggleston, S., Buendia, L., Miwa, K., Ngara, T., and Tanabe, K., IGES, Japan, 2006. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (Last access: 21 May 2017).

IEA: World Energy Balances (2018 Edition), International Energy Agency, Paris, 2018a. www.iea.org (Last access: 19 February 2019).

IEA: World Energy Statistics (2018 Edition), International Energy Agency, Paris, 2018b. www.iea.org (Last access:

IEA: World Energy Balances 2019 Edition: Database Documentation, International Energy Agency, Paris, 2019a. www.iea.org (Last access: 29 August 2019).

IEA: World Energy Statistics 2019 Edition: Database Documentation, International Energy Agency, Paris, 2019b. www.iea.org (Last access: 29 August 2019).

IEA: World Energy Balances 2019 Edition, International Energy Agency, Paris, 2019c. www.iea.org (Last access: 29 August 2019).

IEA: World Energy Statistics 2019 Edition, International Energy Agency, Paris, 2019d. www.iea.org (Last access: 29 August 2019).

Indian Bureau of Mines: Monthly Statistics of Mineral Production, 2019. http://ibm.nic.in/index.php?c=pages&m=index&id=497 (Last access: 26 November 2019).

Ministry of Coal: Monthly Summary for Cabinet, various years-a. https://coal.nic.in/content/monthly-summary-cabinet (Last access: 26 November 2019).

Ministry of Coal: Coal Directory of India, Coal Controller's Organisation, Ministry of Coal, Kolkata, various years-b. http://www.coalcontroller.gov.in/pages/display/16-coal-directory (Last access: 17 April 2020).

Ministry of Coal: Provisional Coal Statistics, Coal Controller's Organization, Ministry of Coal, Kolkata, various years-c. http://www.coalcontroller.gov.in/pages/display/20-provisional-coal-statistics (Last access: 17 April 2020).

Ministry of Mines: Mineral Production during August 2017 (Provisional), 2017. https://pib.gov.in/newsite/PrintRelease.aspx?relid=172036 (Last access: 28 October 2019).

Ministry of Mines: Mineral Production during January 2020 (Provisional), 2020. https://pib.gov.in/newsite/PrintRelease.aspx?relid=200538 (Last access: 31 March 2020).

MOSPI: Energy Statistics, Central Statistics Office, Ministry of Statistics and Programme Implementation, various years. http://www.mospi.gov.in/recent-reports (Last access: 26 August 2019).

OEA: Eight Core Industries, Office Of The Economic Adviser, Department For Promotion Of Industry And Internal Trade, 2019. https://eaindustry.nic.in/ (Last access: 26 August 2019).

POSOCO: National Load Despatch Centre: Daily Reports, Power System Operation Corporation Limited, 2020. https://posoco.in/reports/daily-reports/ (Last access: 16 April 2020).

PPAC: Conversion Factors, Petroleum Planning & Analysis Cell, Ministry of Petroleum and Natural Gas, no date. https://www.ppac.gov.in/content/232_2_Others.aspx (Last access: 17 April 2020).

PPAC: Consumption of Petroleum Products, Petroleum Planning & Analysis Cell, Ministry of Petroleum & Natural Gas, various years-a. https://www.ppac.gov.in/content/146_1_ProductionPetroleum.aspx (Last access: 20 April 2020).

PPAC: Production of Petroleum Products by Refineries & Fractionators, Petroleum Planning & Analysis Cell, Ministry of Petroleum & Natural Gas, various years-b. https://www.ppac.gov.in/content/146_1_ProductionPetroleum.aspx (Last access: 20 April 2020).

SCCL: Provisional Production and Dispatches Performance of SCCL, The Singareni Collieries Company Limited, various years. https://scclmines.com/scclnew/performance_production.asp (Last access: 17 April 2020).

UN Statistics Division: Monthly Bulletin of Statistics Online, United Nations Statistics Division, 2020. https://unstats.un.org/unsd/mbs/app/DataSearchTable.aspx (Last access: 17 April 2020).