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Supplement of

Timely estimates of India’s annual and monthly fossil CO₂ emissions

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Supplementary Information

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S1. Coal production

The landscape for Indian activity data is composed of historical data sources, stable ongoing data sources, and unstable sources for low-lag data. National, revised monthly coal production data are reported by the Indian Bureau of Mines with a lag of more than six 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, and their publication remains unreliable (Ministry of Mines, 2020). The Ministry of Coal has recently begun publishing total provisional fiscal-

year-to-date national hard coal production, broken down by CIL, SCCL, Captive, and Other (Ministry of Coal, no date), and with regular access, these can be converted to monthly production values. 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). The United Nations Statistics Division's 'Monthly Bulletin of Statistics Online' also includes monthly coal production for India (UN Statistics Division, 2020). Lastly, the now-discontinued Monthly Abstract of Statistics was published by the Central Statistics Organisation (now Ministry of Statistics and Programme Implementation) (CSO/MoSPI, various years). This last dataset appears to be available for earlier years going back several decades, but the author has not been able to obtain access to these editions. These datasets are compared and their availability by month shown in Figure S1 (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 provisional production at captive mines has recently been introduced in the Ministry of Coal's Monthly Summary to Cabinet (Ministry of Coal, various years-a) and also on the Ministry's website as year-to-date data, which also reports the provisional small production from other mines (Ministry of Coal, no date). 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 when production from other mines is not available.

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 S2). For SCCL, available data show that revisions are also within 0.25% of provisional data (Figure S3). 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 S4), representing the production of a small number of other mines.

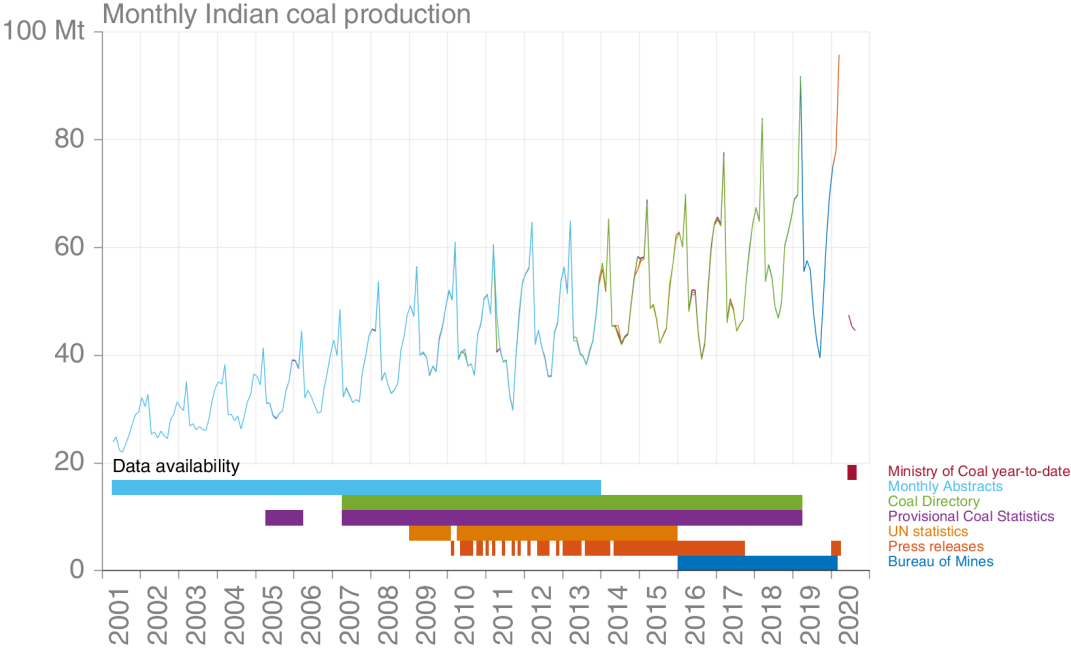


Figure S1: Comparison and availability of the datasets of India’s monthly national coal production. Sources: Monthly Abstracts of Statistics, Coal Directories, Provisional Coal Statistics, UN Statistics, Ministry of Mines press releases, Indian Bureau of Mines, Ministry of Coal.

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 S4), 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 S6).

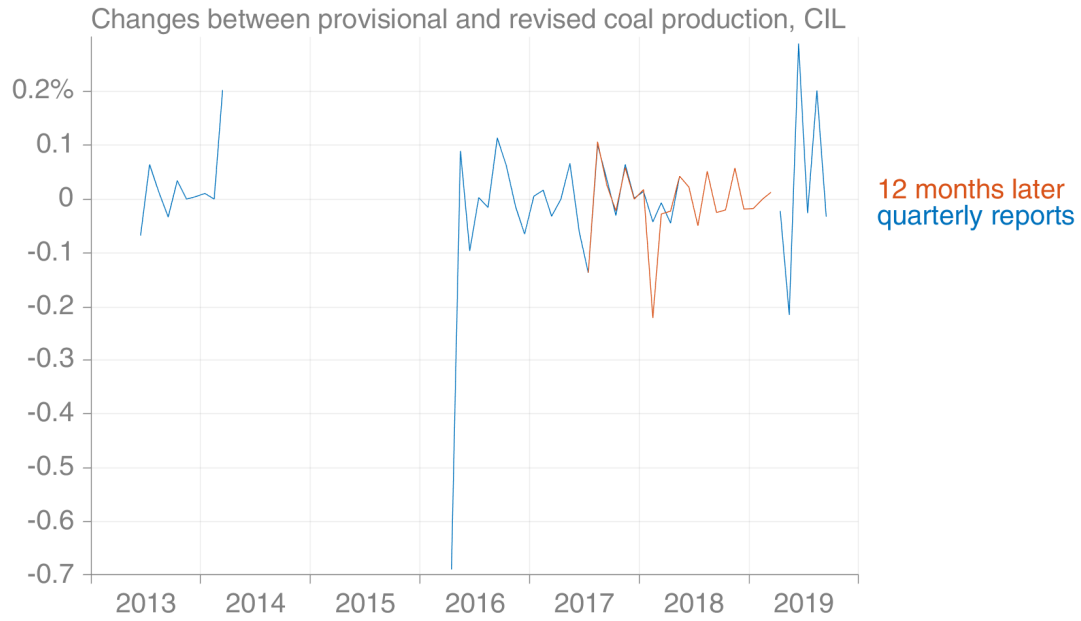


Figure S2: Relative magnitude of revisions reported by CIL to provisional monthly coal production data. Source: CIL.

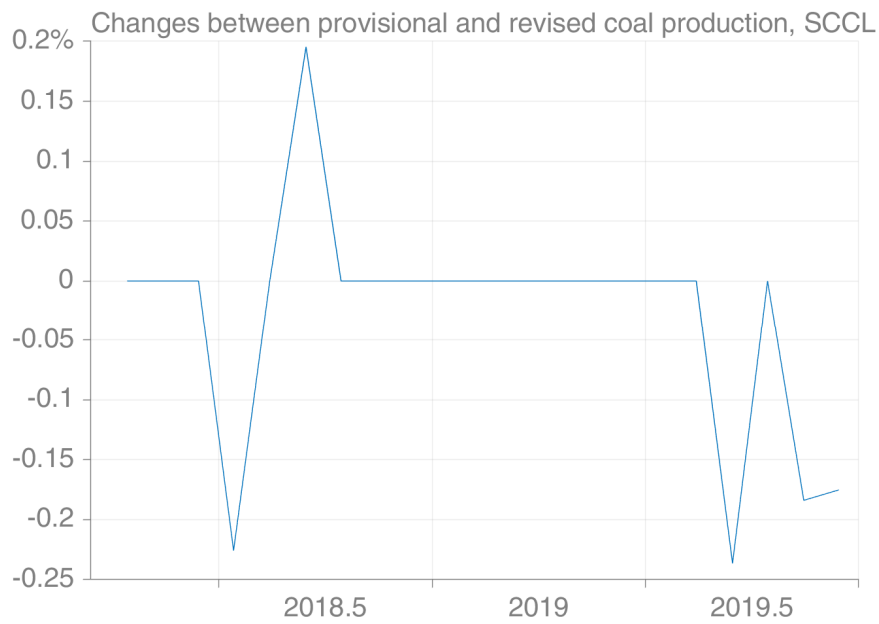


Figure S3: Relative magnitude of revisions reported by SCCL to provisional monthly coal production data. Source: SCCL.

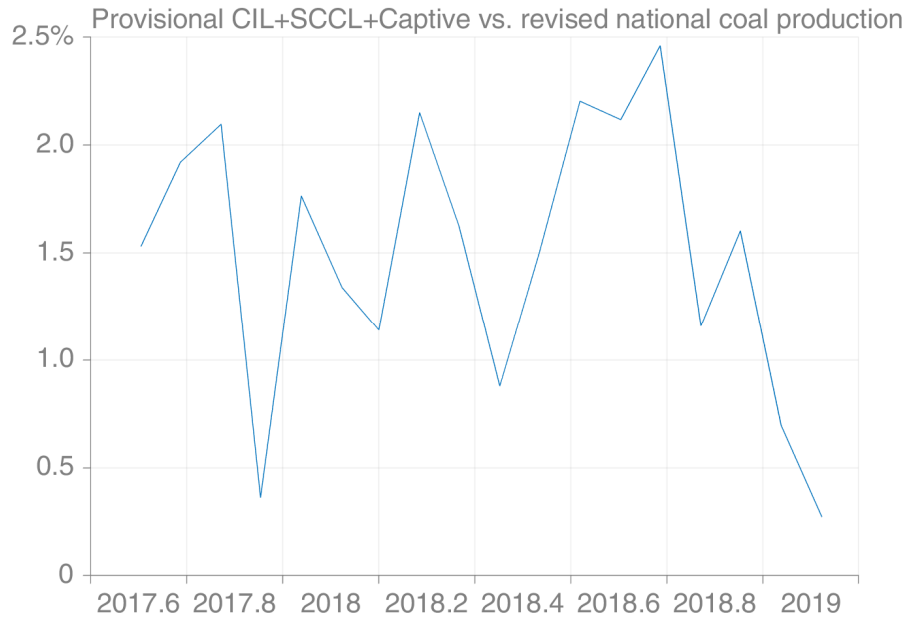


Figure S4: Relative magnitude of revised monthly national coal production and provisional production data from CIL, SCCL, and Captive mines. Source: CIL, SCCL, Ministry of Mines, Indian Bureau of Mines.

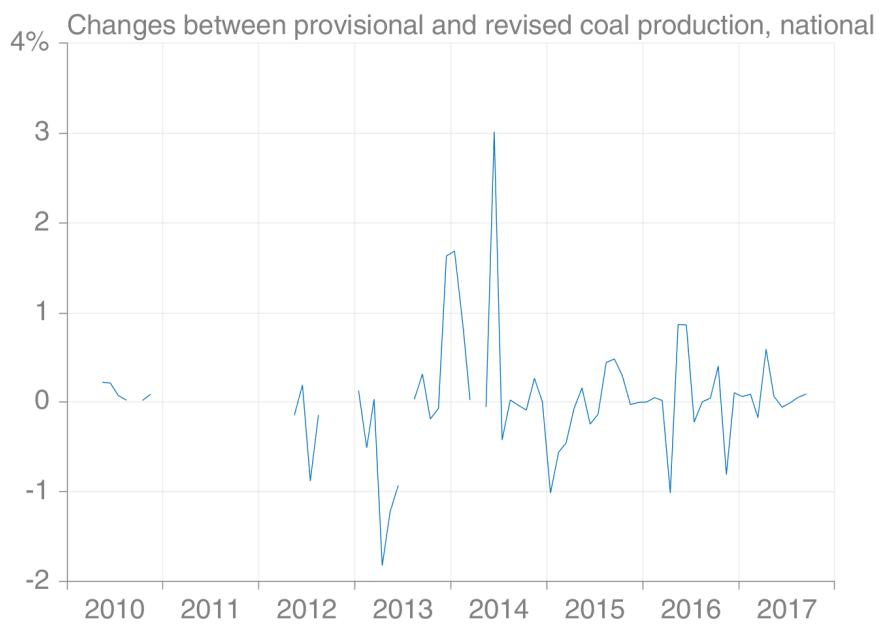


Figure S5: Relative magnitude of revisions. Source: Ministry of Mines, Indian Bureau of Mines, UN Statistics.

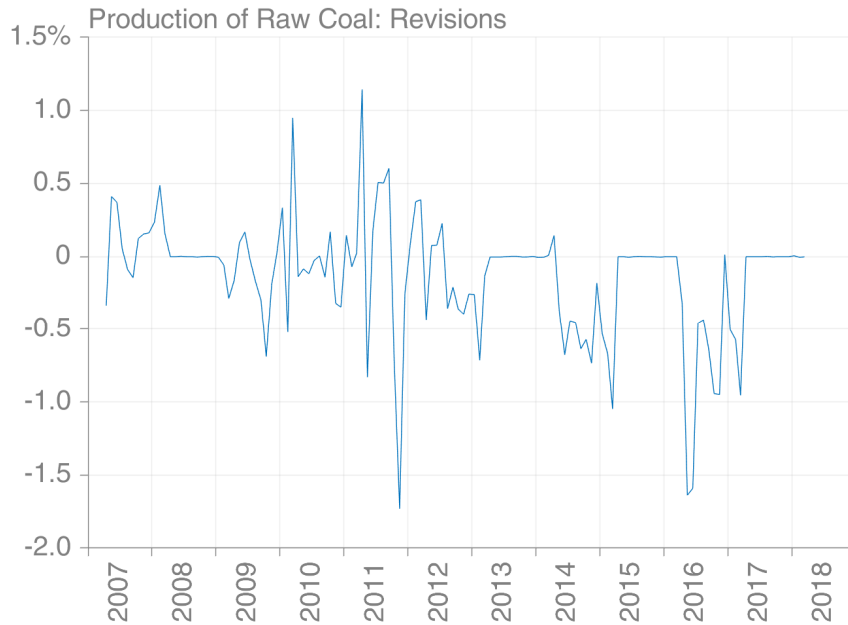


Figure S6: Magnitude of revisions to monthly raw coal production statistics between the Provisional Coal Statistics and Coal Directory reports from the Ministry of Coal.

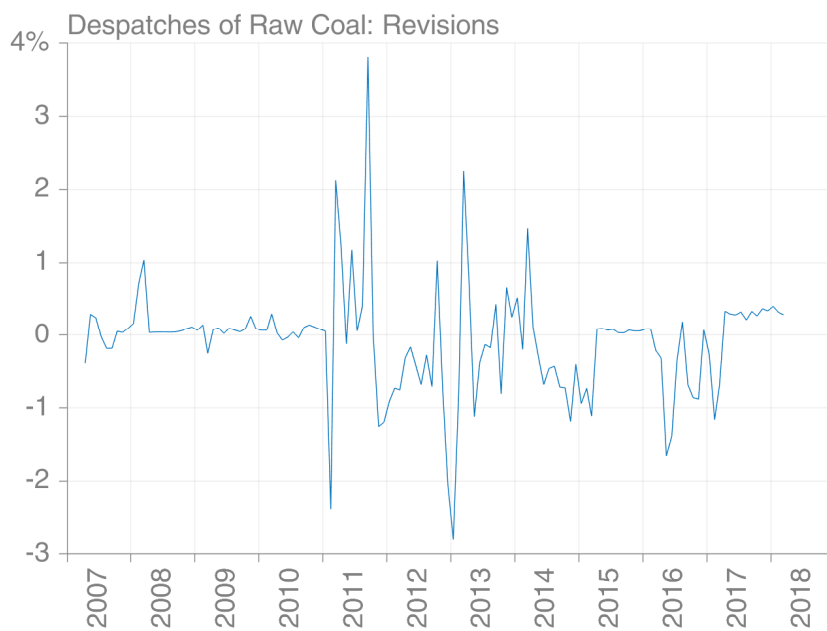


Figure S7: Magnitude of revisions to monthly raw coal despatch statistics between the Provisional Coal Statistics and Coal Directory reports from the Ministry of Coal.

S2. 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 S8), 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.

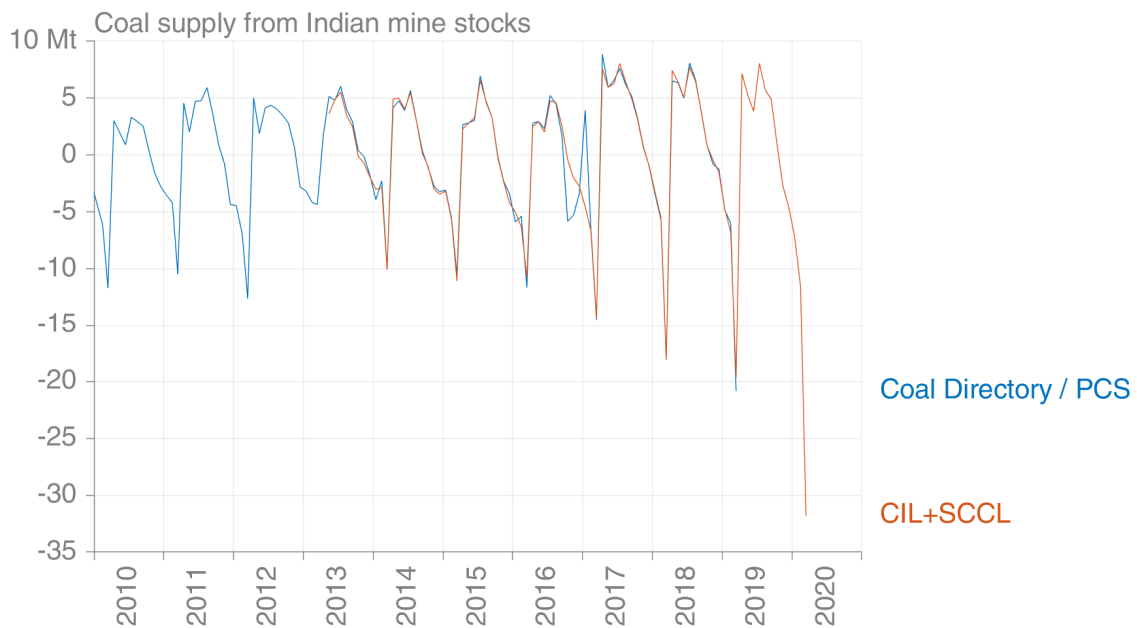


Figure S8: Comparison of reported 'stock changes' in the Coal Directories and Provisional Coal Statistics (PCS) with the sum of stock changes at CIL and SCCL mines. Source: Ministry of Coal, CIL, SCCL.

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 S9); 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 S10) permits the extraction of reliable estimates of month-end stocks and thence stock changes.

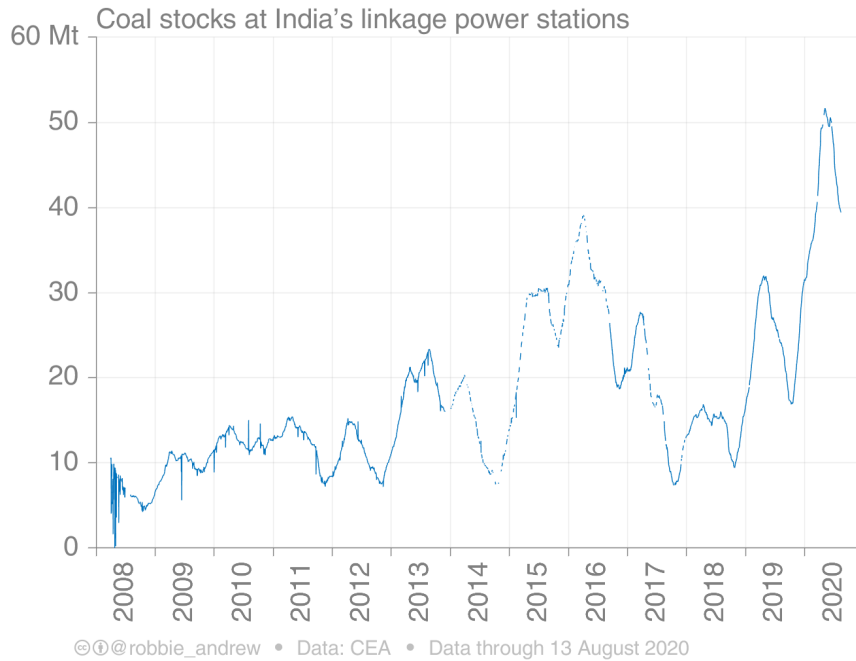


Figure S9: Raw linkage power station coal stocks data collated from CEA.

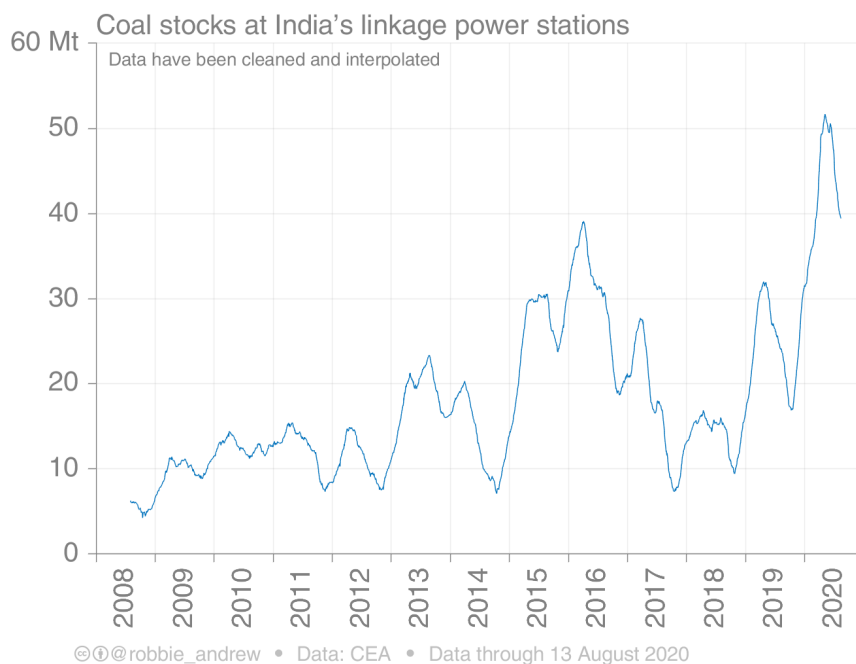


Figure S10: Processed linkage power station coal stocks data.

Because of the unreliability of coal supply in India, most utility 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 S11). 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.

Note that coal stocks at captive power stations are not included in these data.

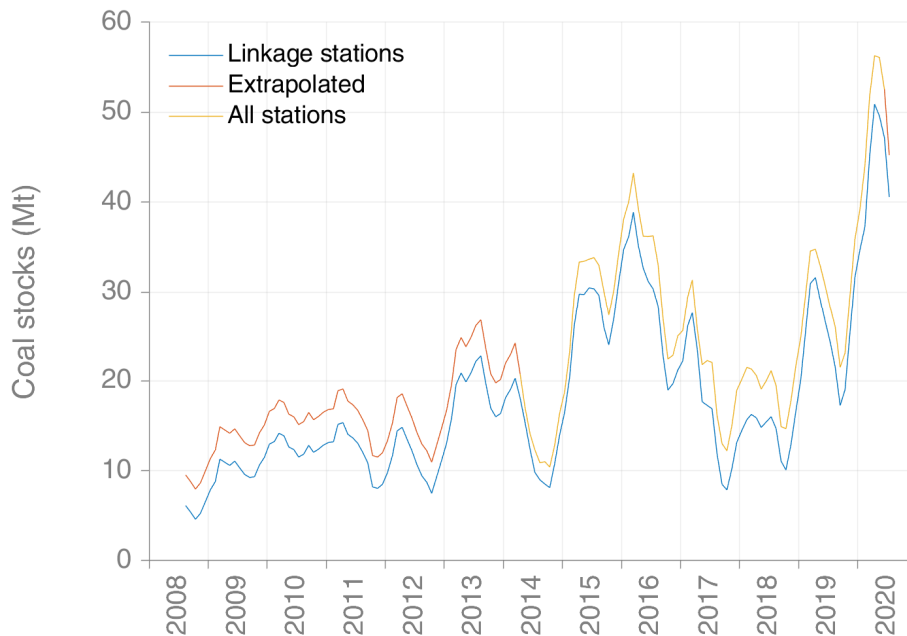


Figure S11: Monthly coal stocks at linkage power stations, all power stations, and the simple extrapolated series for all power stations based on the relationship between the two.

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 S12 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.

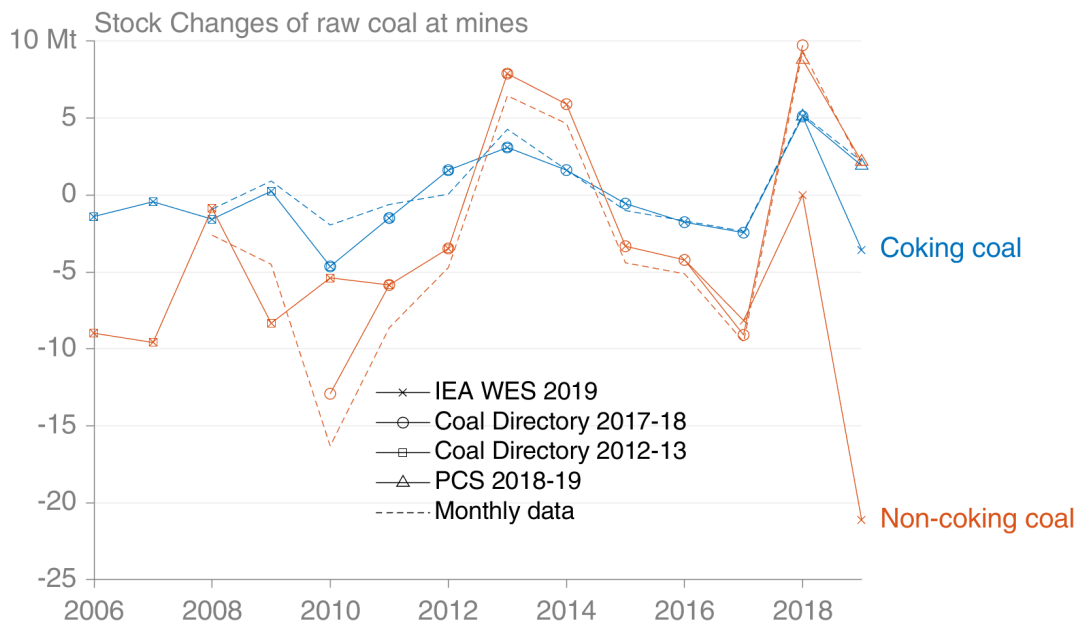


Figure S12: Comparison of raw coal stock changes at mines. Source: IEA, CCO, own calculations.

S3. 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 briquettes [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 S13).

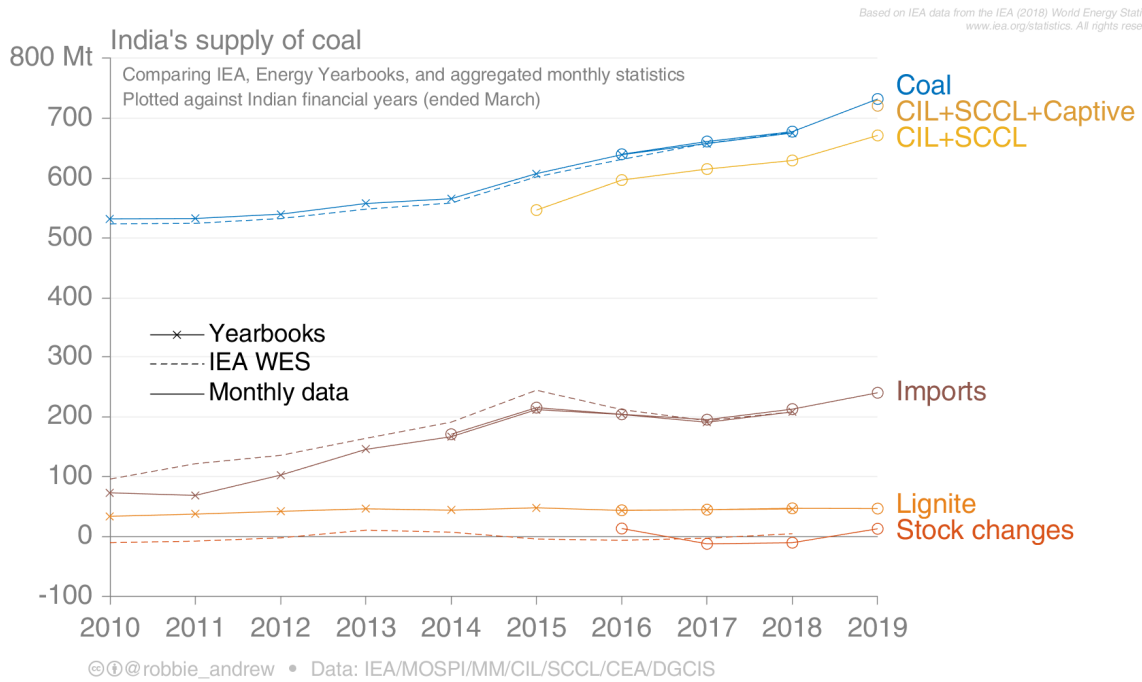


Figure S13: India's supply of coal. Source: IEA, MoSPI Yearbooks, monthly data assembled herein.

For some countries, imports of coal-derived non-energy products such as carbon anodes used in aluminium smelting are significant (Andrew, 2020), but no data was found to suggest this in India.

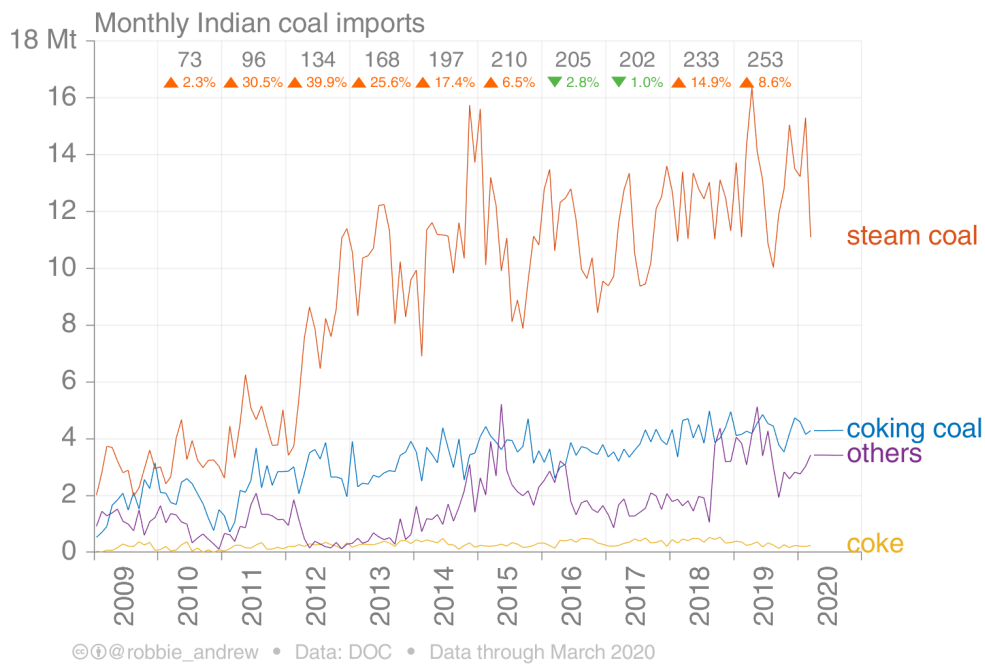


Figure S14: Monthly imports of coal by type. Source: Department of Commerce

S4. Extrapolation

Lignite production data lag behind data on production of hard coal and must be extrapolated.

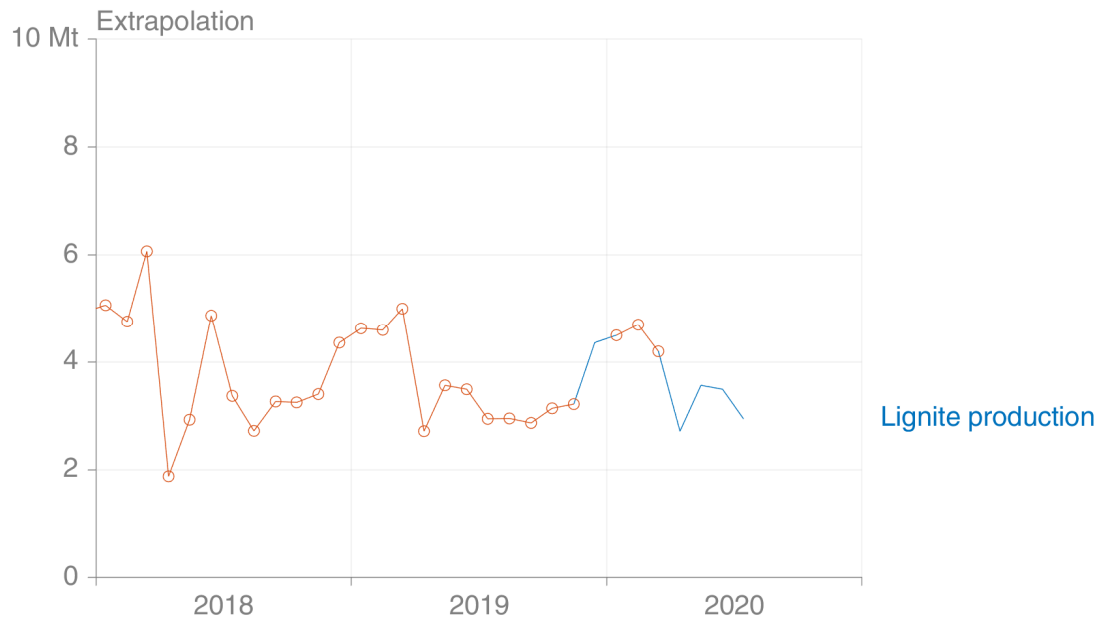


Figure S15: Extrapolation of lignite production. Line with circle markers shows reported values, while line without markers shows interpolation/extrapolation.

S5. 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 S16). Here I choose to use the energy contents from the IEA (2019c, 2019d), assuming its information is more reliable, particularly for earlier years.

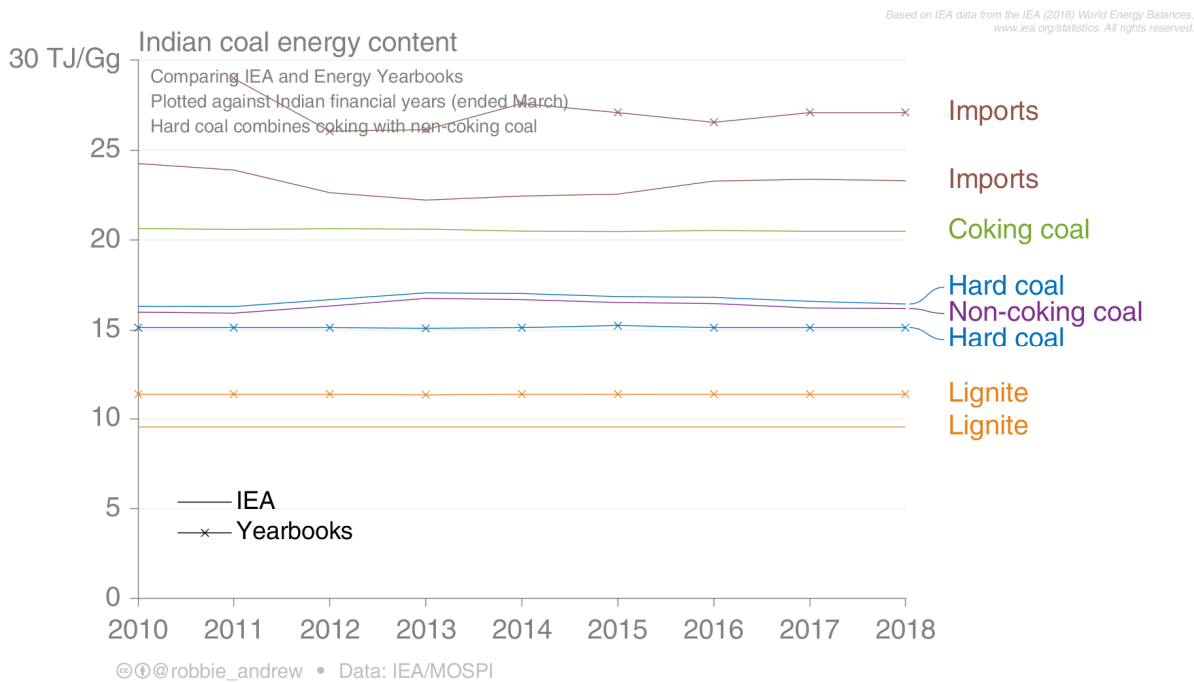


Figure S16: Comparison of energy content of coal from IEA (2019c, 2019d) and India's Energy Yearbooks (MOSPI, various years).

Focusing on hard coal, Figure S17 compares a number of different datasets, demonstrating wide divergence in reported coal quality. It seems clear that coal quality overall has declined in the last 50 years, partly as a result of the significant increase in the share of lower-cost production from open-cast mines (77% in 1998/99 to 94% in 2018/19, according to the Coal Directories), but the IEA's figures in the 1970s and 1980s are markedly different from those reported in all but the most recent Energy Statistics yearbooks.

It is unclear how the Energy Statistics derives average coal quality, but it appears that the IEA has used the annual data on production by coal grade, combined with average energy contents for each grade. This supposition is based on the author doing exactly that with the data provided by the Coal Directories: from 2013, estimates made this way match very closely to those of the IEA. Before 2013, India used a less-detailed grading system. The author's estimates for that earlier period assume that the average energy content did not jump dramatically upwards from 2012 to 2013, something that seems unlikely, and this leads to a difference with the IEA's estimates in that period.

In 2016, Coal India introduced quality assurance routines, sending samples to third-party laboratories for assessment of energy content, a scheme called 'Unlocking Transparency by Third Party Assessment of Mined Coal' (UTTAM). This scheme was introduced after repeated complaints by power station operators that received coal was of lower than the declared (and paid-for) energy content. With 51% sampling coverage in the 2017-18 year, UTTAM results showed that the average analysed energy content was 6% lower than the average declared energy content. Back-calculation of energy content from hard coal production in both energy and mass terms suggests that the Energy Statistics report has subsequently simply used this much lower average for the entire period reported (2006-07 through 2018-19 in the 2020 edition).

The UN Statistics Division's Energy Yearbooks report much higher energy contents in 2012 and 2013, with these numbers having been reported to them by Indian officials; subsequent values are taken from IEA reports (pers. comm., Leonardo Rocha Souza, 16 July 2020). This sharp drop in the UN data

for India's energy content translates directly into a sharp drop in production from 2012-13 to 2013-14, which propagates directly to CDIAC's estimates of emissions from solid fuels for India.

Given the insufficient sampling until the introduction of the UTTAM scheme in 2016, it is impossible to say with any uncertainty what the energy content of India's hard coal was before then, **but it is unlikely that the constant low value used by the Energy Statistics yearbook is correct.**

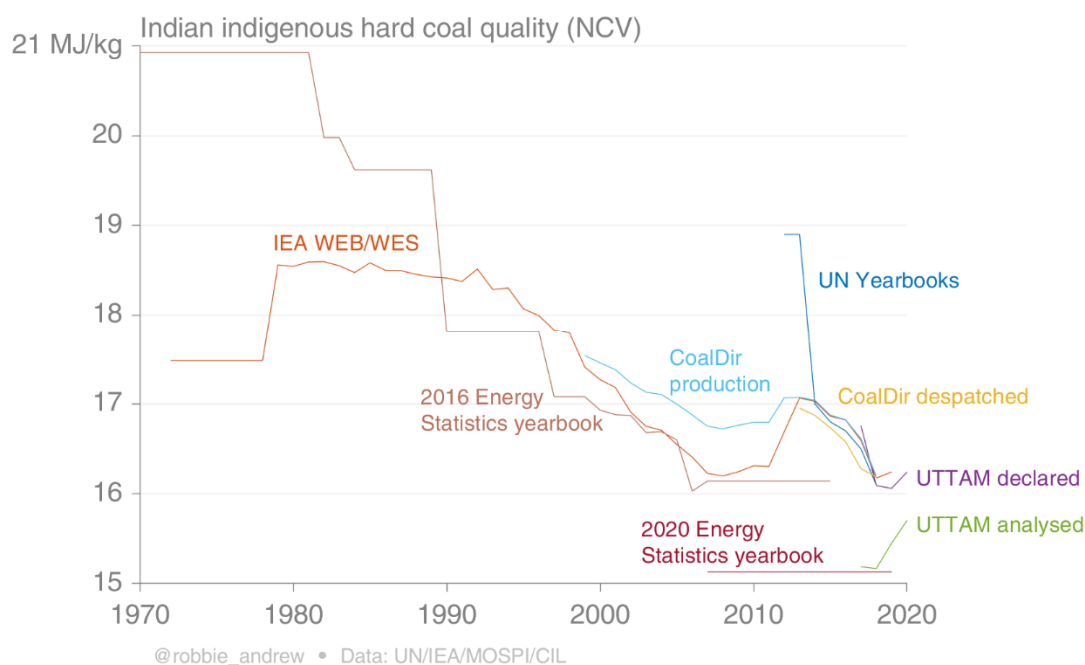


Figure S17: Comparison of energy content of Indian hard coal from various datasets. Data plotted for the Coal Directory ('CoalDir') are the author's estimates derived from data on production by grade. IEA WEB/WES is the World Energy Balances (energy units) and World Energy Statistics (mass units).

Emissions from coal in India's Second Biennial Update Report (BUR) are derived using country-specific energy contents and emission factors (GOI, 2018). The Report is unclear as to whether these factors, reported in tables 2.3 and 2.4, are only used for domestic coal, or whether they are averages for total coal supply, including imports. Imported coal is of higher quality than India's domestic coal, and this likely explains why the energy contents provided in table 2.3 for coking and non-coking coal (23.66 and 18.26 MJ/kg, respectively) are somewhat higher than those reported by the IEA for domestic coal (20.50 and 16.69 MJ/kg). The BUR's reported energy content of lignite, which is entirely domestic, is 9.80 MJ/kg, very similar to the IEA's 9.55 MJ/kg, and somewhat lower than the Energy Statistics' value of 11.37 MJ/kg.

S6. Coal CO₂ emissions

I calculate apparent hard coal and lignite consumption in energy terms separately as production + net imports + net withdrawal from stocks. These are then converted to CO₂ emissions using default factors from the IPCC's guidelines (Gómez et al., 2006). Resulting monthly emissions estimates are shown in Figure S18.

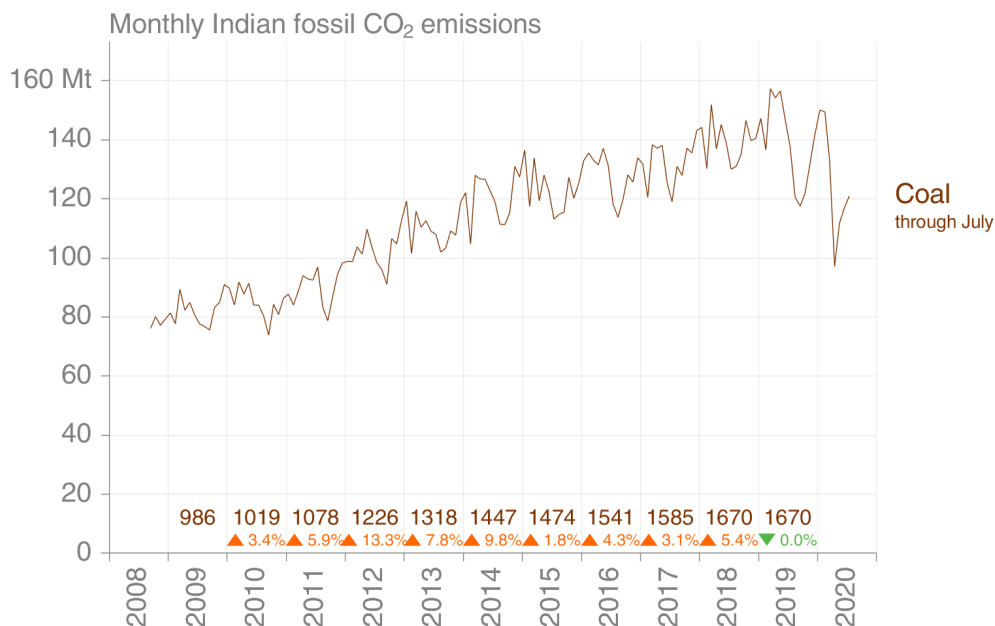


Figure S18: Final monthly estimates of CO₂ emissions from oxidation of coal in India.

S7. Coal ‘consumption’

Two official Indian reports provide data on coal consumption by the electricity sector. But the numbers they report disagree significantly. The problem is the absence of any definition of ‘consumption’ in the *Energy Statistics*.

MoSPI’s *Energy Statistics* publication presents coal consumption by the electricity sector (table 6.4 in the 2020 edition), with a footnote indicating the source is “Office of the Coal Controller, Ministry of Coal). Since 2010, these data are identical to the numbers in the Coal Controller’s *Coal Directory* reports (table 4.20 in the 2018-19 edition), except for the final year, which comes from the *Provisional Coal Statistics*. Importantly, these data represent despatches of domestic coal to both utility and captive power generators, not consumption at all, despite the title of both the chapter and table in *Energy Statistics*. It seems imported coal used by power stations is included in the ‘Others plus import non-coking’ column, partly explaining why this column has such large values. The supply data they use from the Coal Controller do not allow disaggregation of non-coking coal imports by using sector. Nor does this table account for stock changes at power stations. Meanwhile, the Central Electricity Authority’s monthly *Coal Statements* only include consumption by utility generation, not captive generation. Therefore, to reconcile the data in these tables one must take the utility despatch data from the *Coal Directory* (or *PCS*) and the total coal receipts less imports from the *Coal Statements*. These two are approximately the same, with some residual as is common with comparison of supply and use data from different sources.

S8. 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 S19)(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.

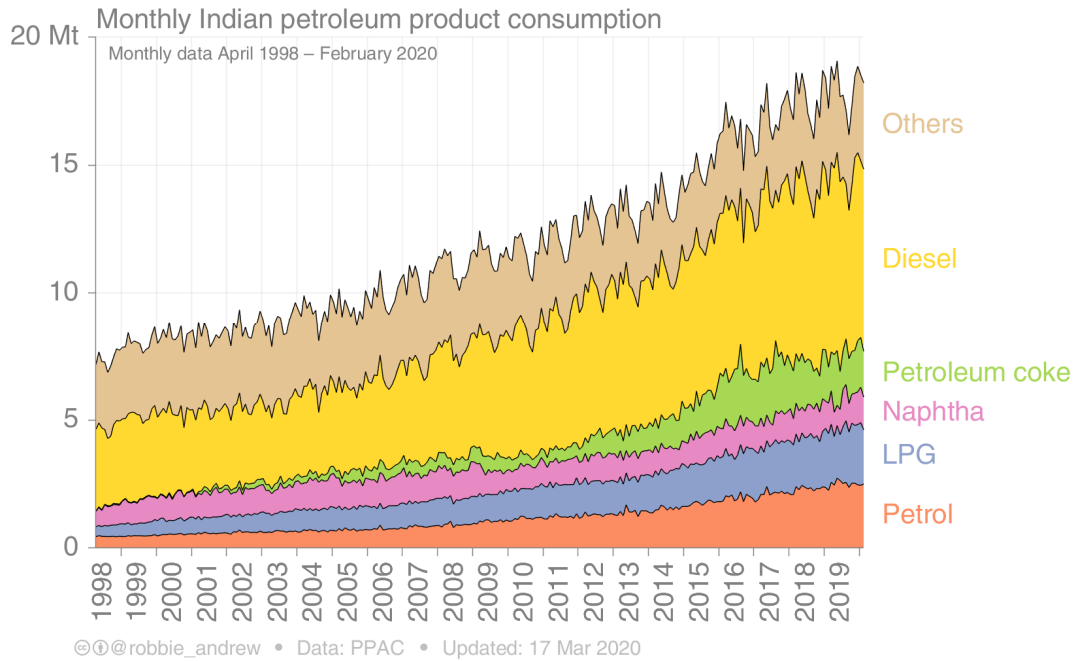


Figure S19: Consumption of petroleum products from April 1998 in physical units. Source: PPAC.

To convert to units of energy I 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 (i.e. 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 S20.

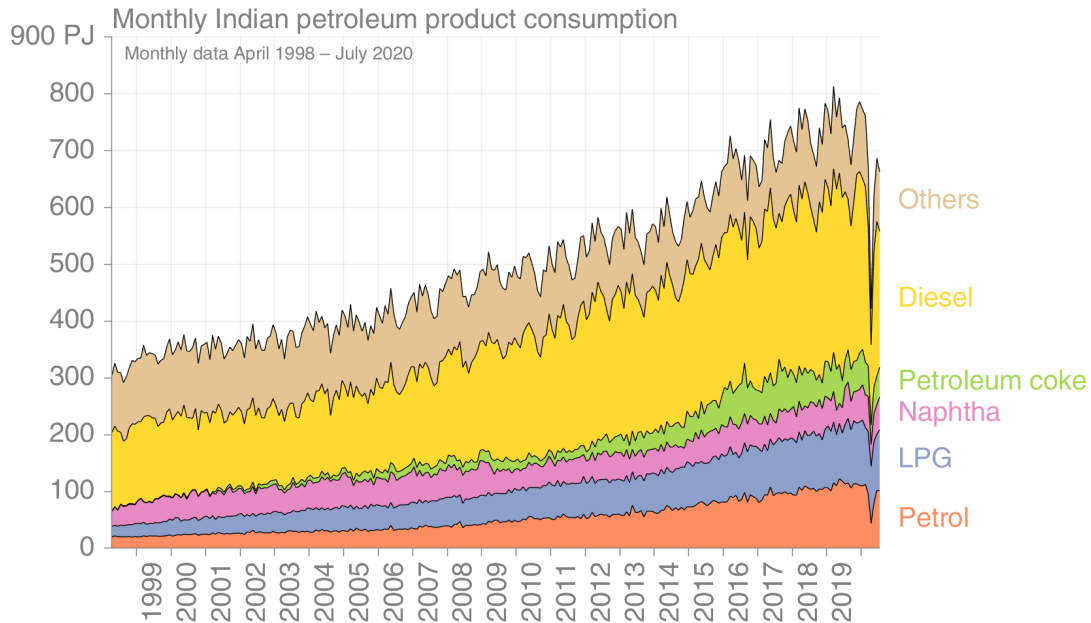


Figure S20: Consumption of petroleum production from April 1998 in energy units. Source: Own calculations.

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 CO₂ emissions using default IPCC factors (Gómez et al., 2006).

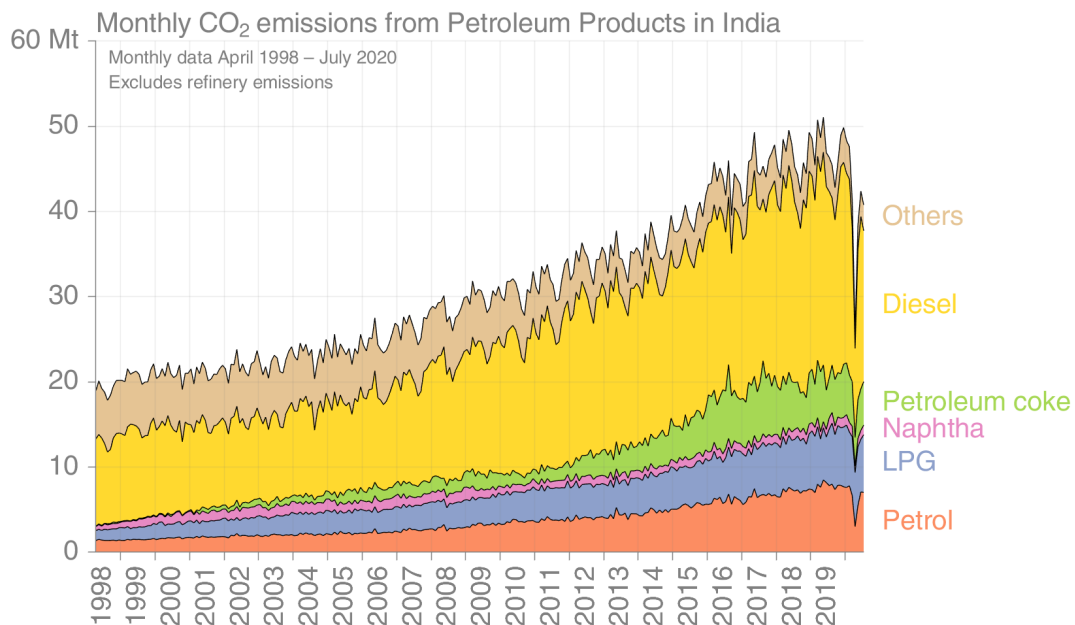


Figure S21: Emissions from combustion of petroleum products, excluding refinery emissions. Source: Own calculations.

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.

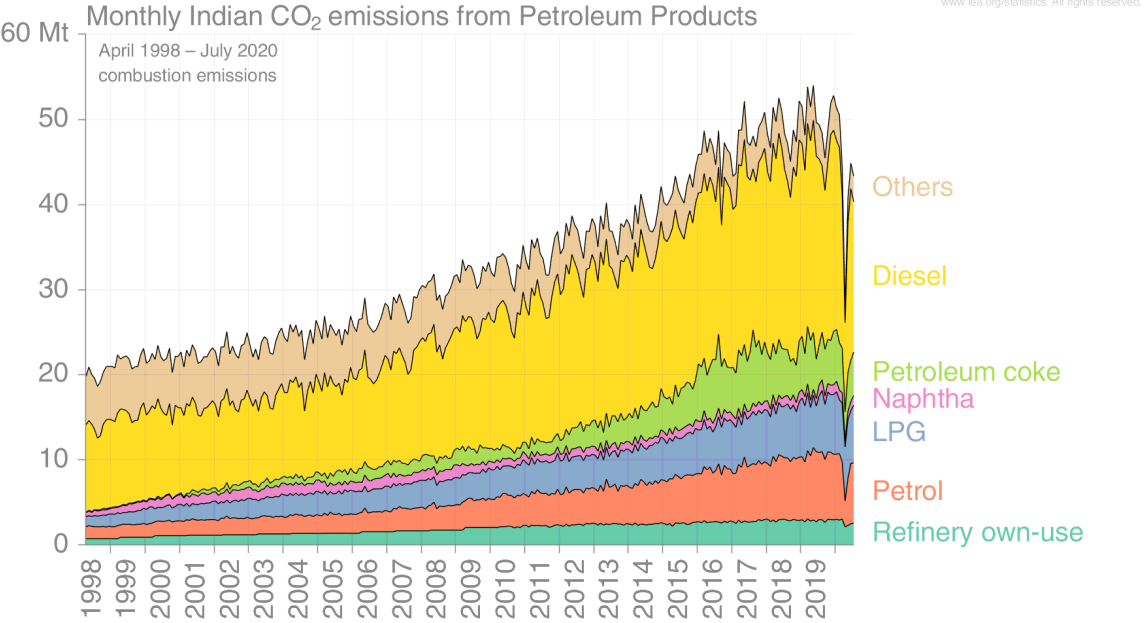


Figure S22: Emissions from combusted petroleum products: Source: Own calculations.

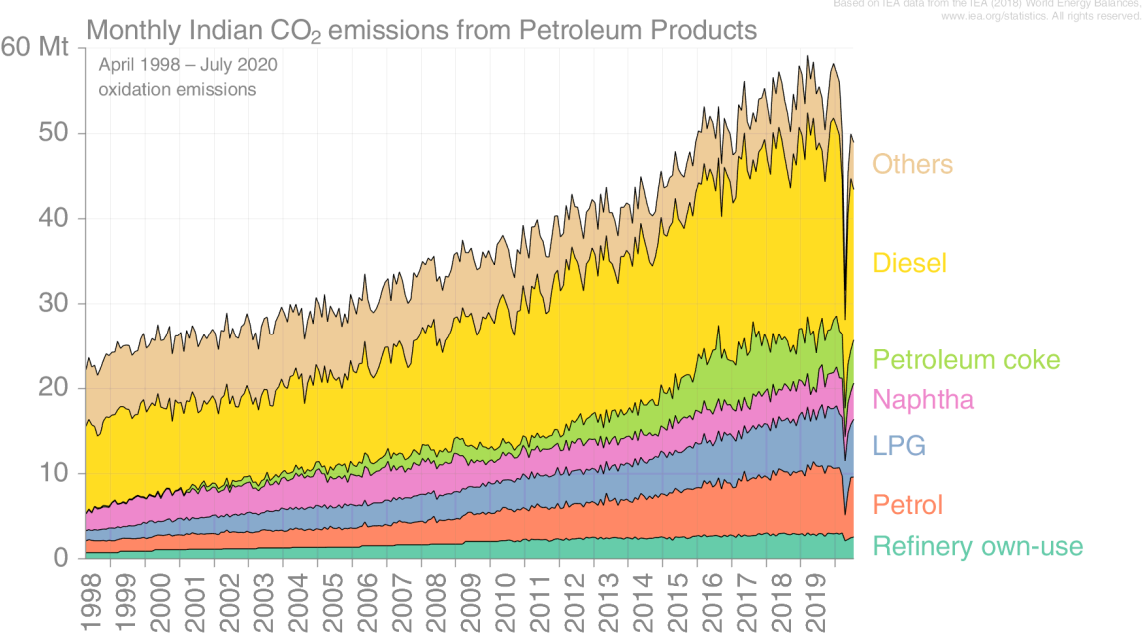


Figure S23: Emissions from oxidised petroleum products: Source: Own calculations.

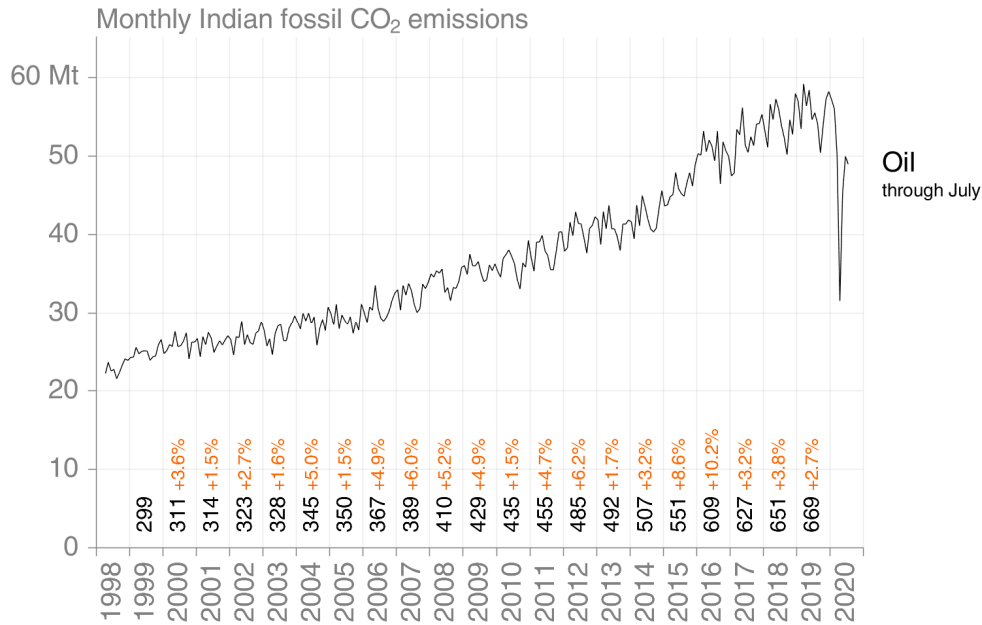


Figure S24: Final monthly estimates of CO₂ emissions from oxidation of oil and oil products in India.

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 S25).

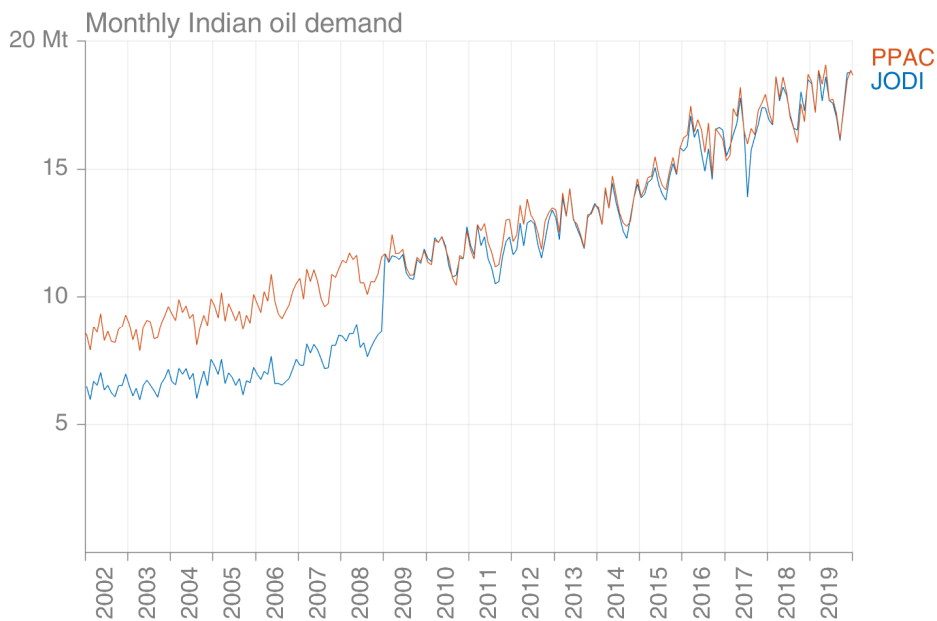


Figure S25: Comparison of monthly oil demand from PPAC and JODI.

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.

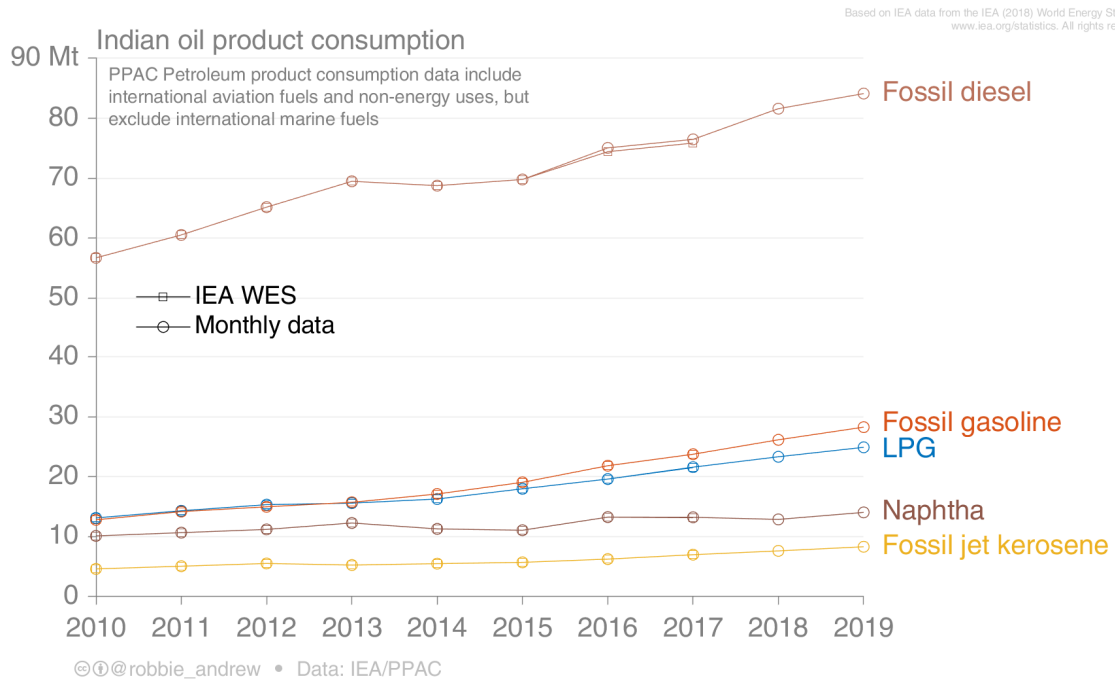


Figure S26: Comparison of consumption of diesel, gasoline, LPG, naphtha, and jet kerosene in physical units between aggregated monthly data from PPAC and annual data from IEA.

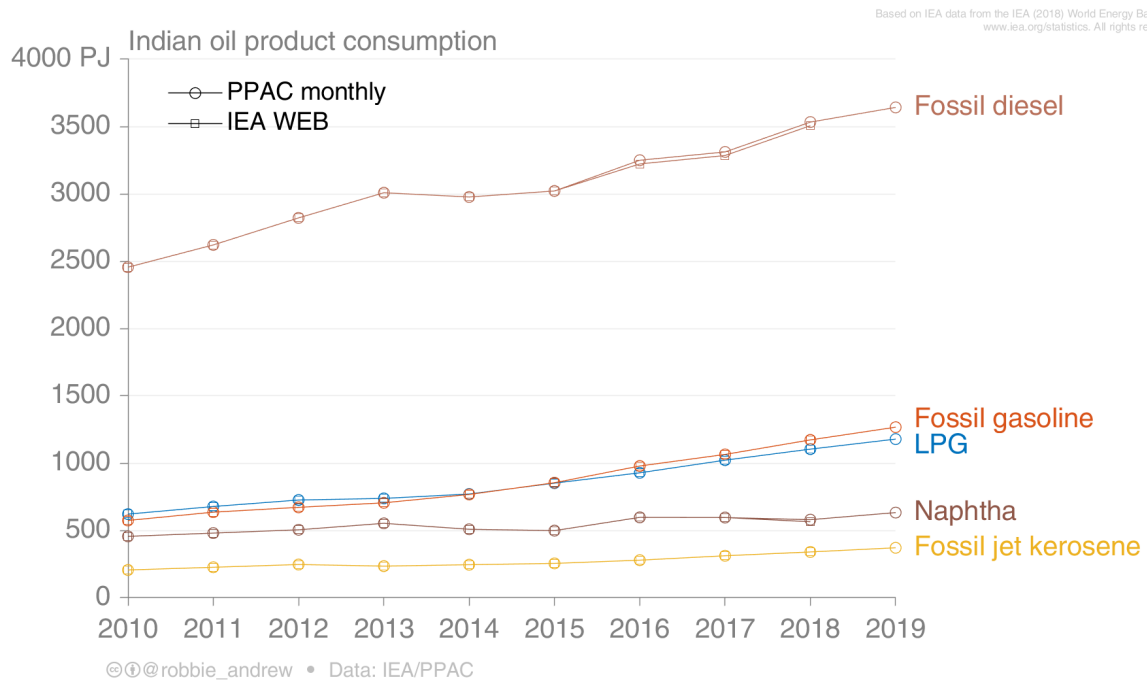


Figure S27: Comparison of consumption of diesel, gasoline, LPG, naphtha, and jet kerosene in energy units between aggregated monthly data from PPAC and annual data from IEA.

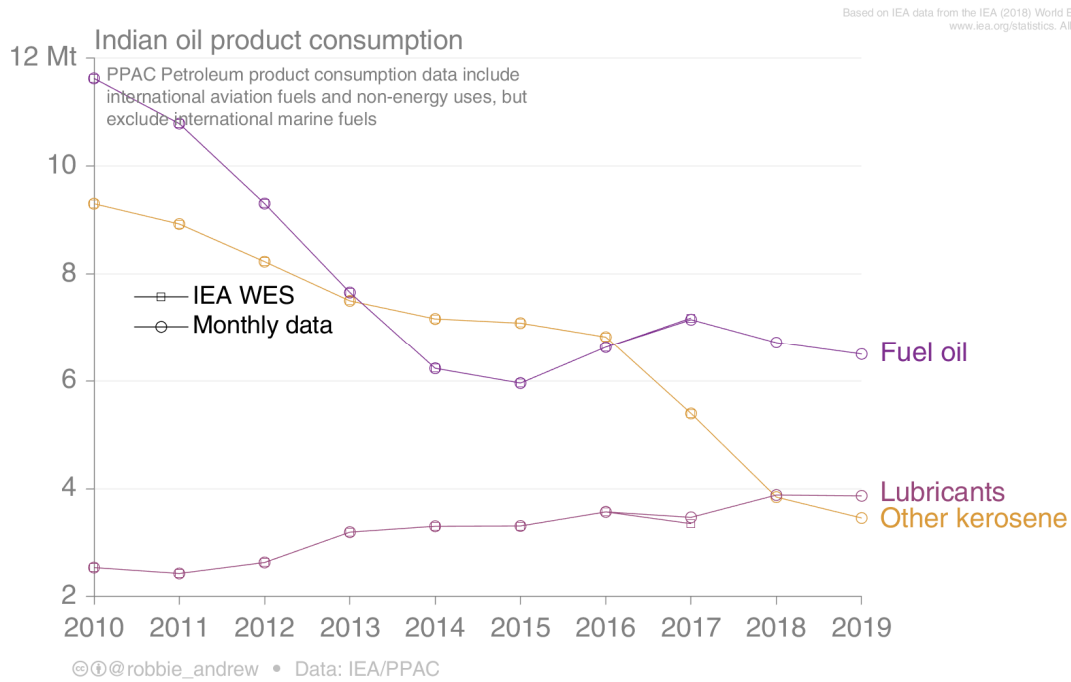


Figure S28: Comparison of consumption of fuel oil, lubricants, and other kerosene in physical units between aggregated monthly data from PPAC and annual data from IEA.

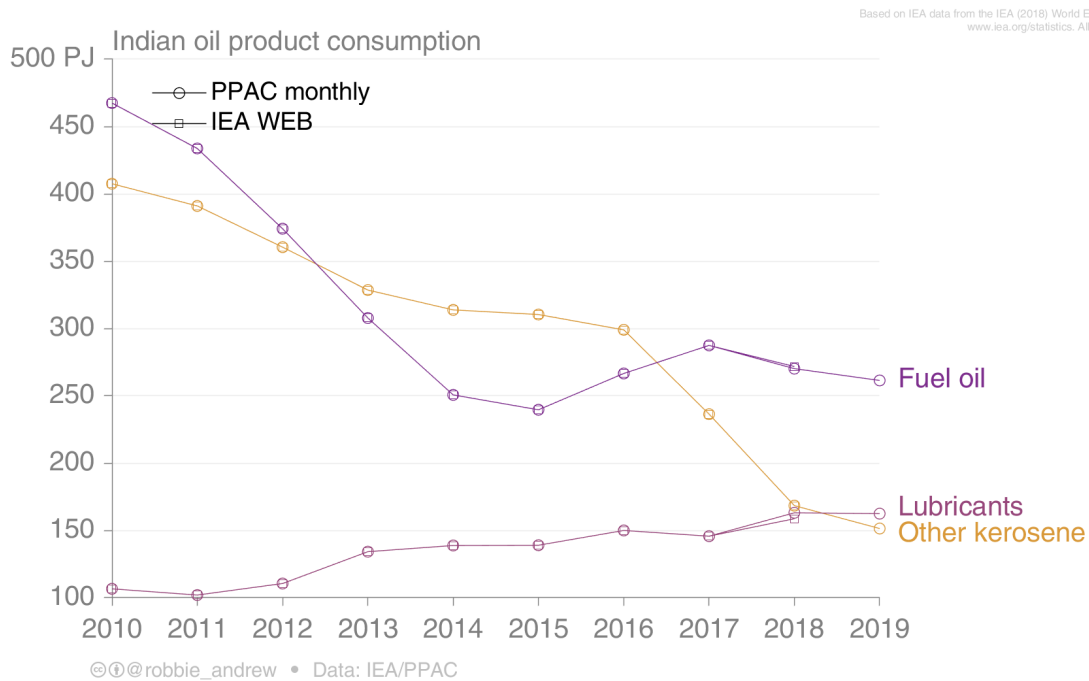


Figure S29: Comparison of consumption of fuel oil, lubricants, and other kerosene in energy units between aggregated monthly data from PPAC and annual data from IEA.

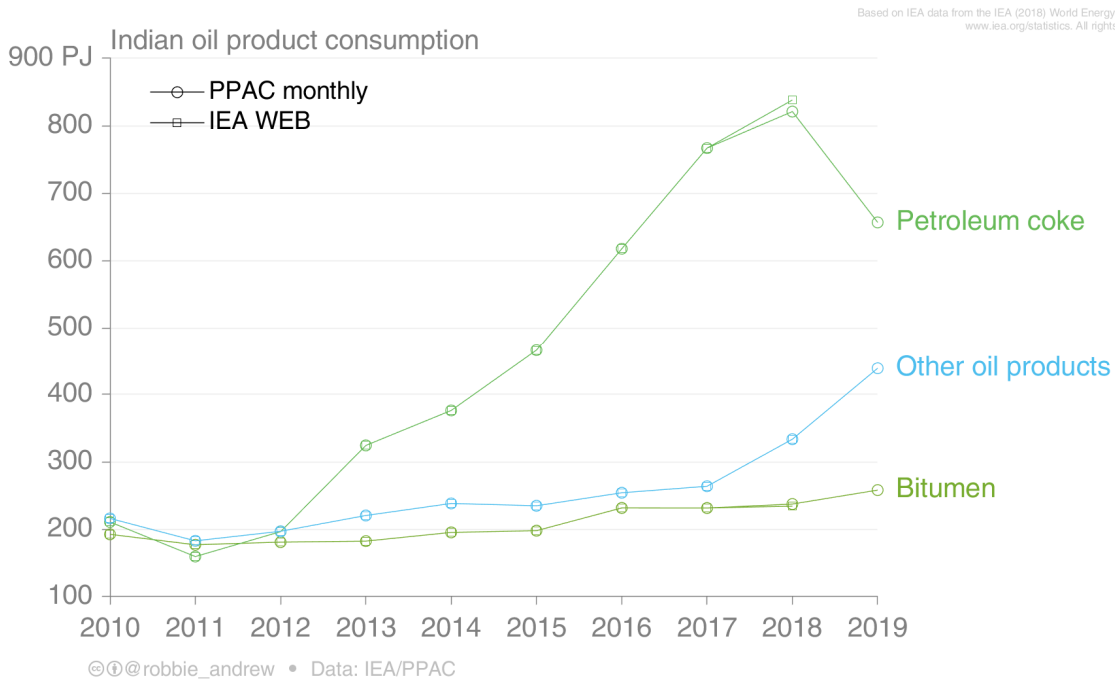


Figure S30: Comparison of consumption of petroleum coke, bitumen, and other oil products in physical units between aggregated monthly data from PPAC and annual data from IEA.

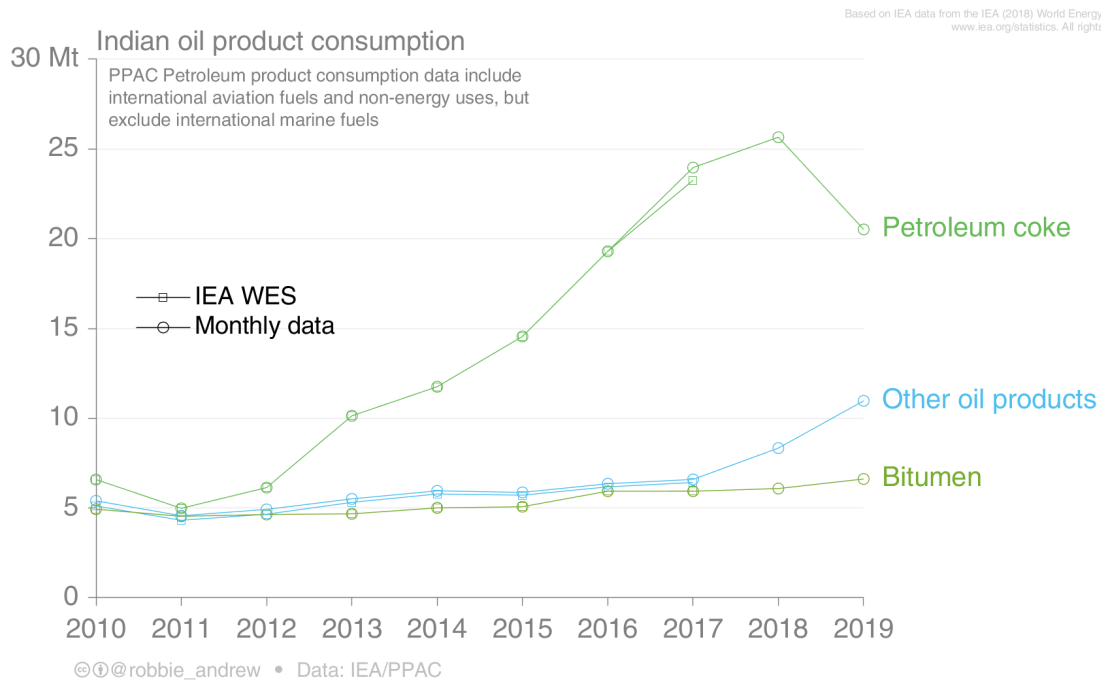


Figure S31: Comparison of consumption of petroleum coke, bitumen, and other oil products in energy units between aggregated monthly data from PPAC and annual data from IEA.

S9. 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 S1 shows the format and lag between the end of the month for which data are available and the publication of the report.

Table S1: 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 S2 shows which reports include each term, and what they are called. India does not export natural gas.

Table S2: 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 S32, For the purposes of a continuous series, the two-month data gap in domestic production in early 2010 is filled with simple linear interpolation.

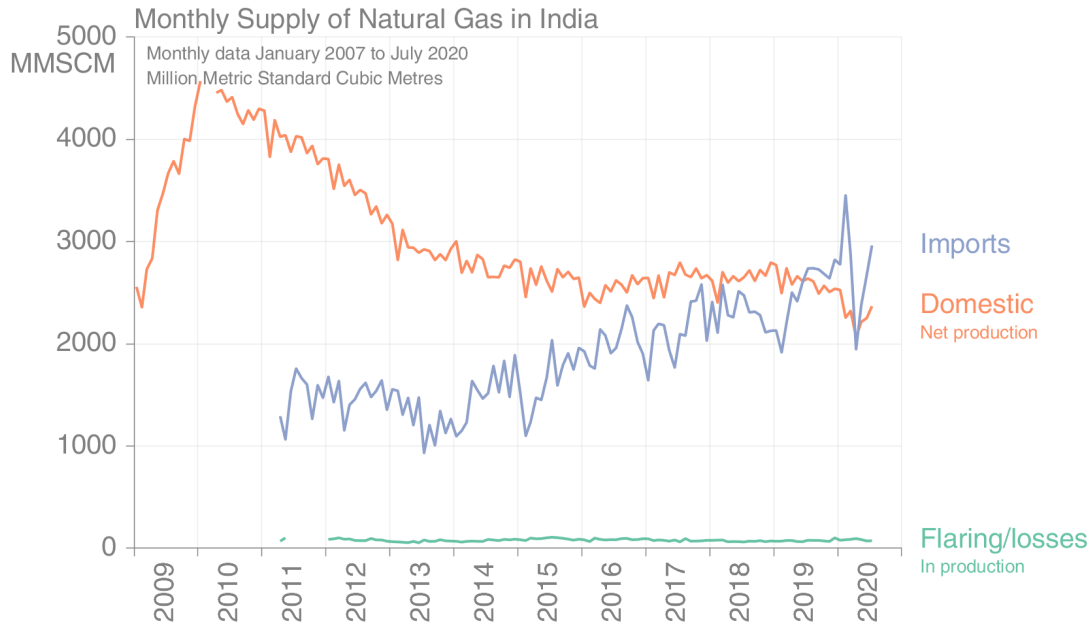


Figure S32: Monthly supply of natural gas in India. Source: PPAC, UN Statistics.

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 S33. 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.

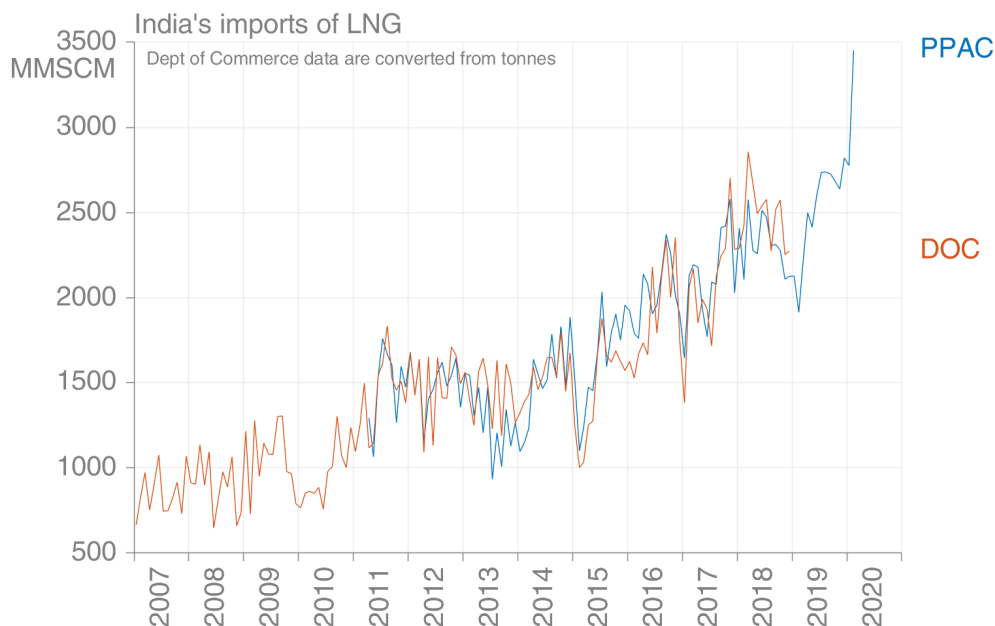


Figure S33: Comparison of LNG import statistics: Source: Petroleum Planning & Analysis Cell (PPAC) of the Ministry of Petroleum and Natural Gas and the Department of Commerce (DOC).

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 CO₂ 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 're injection' 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 S34). 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.

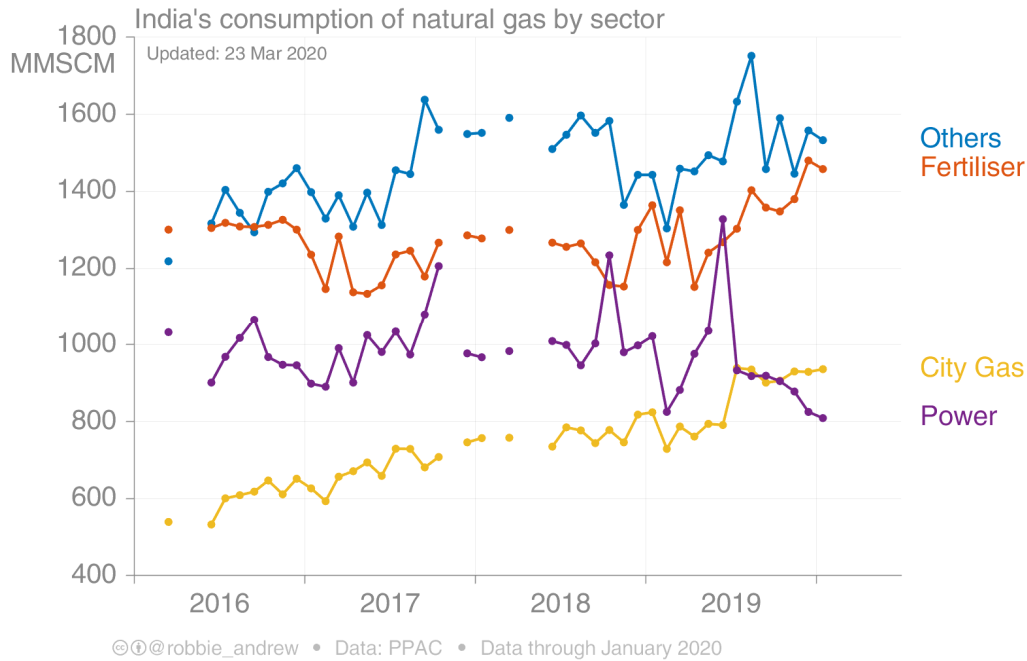


Figure S34: Consumption of natural gas by sector. Reports for missing months were probably produced but have not been located for this analysis. Source: PPAC.

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). CO₂ emissions factors are taken from the IPCC guidelines (Gómez et al., 2006), resulting in the monthly emissions shown in Figure S35.

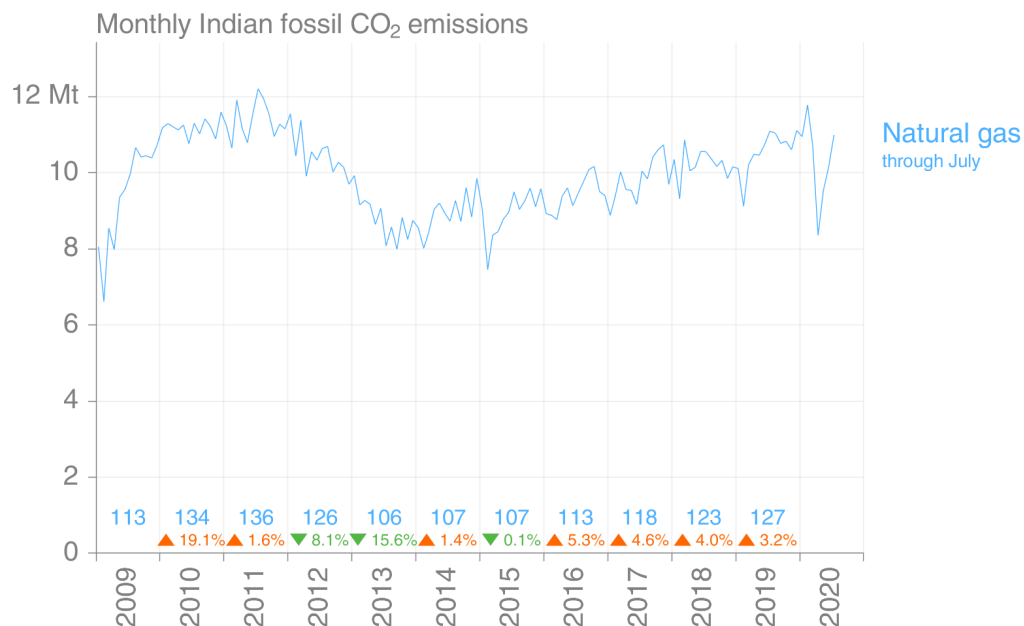


Figure S35: Final monthly estimates of CO₂ emissions from oxidation of natural gas in India.

S10. Cement production

Cement production has two major sources of emissions. The first is the use of fossil energy for heating, 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 CO₂ (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 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 S36). 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 S37).

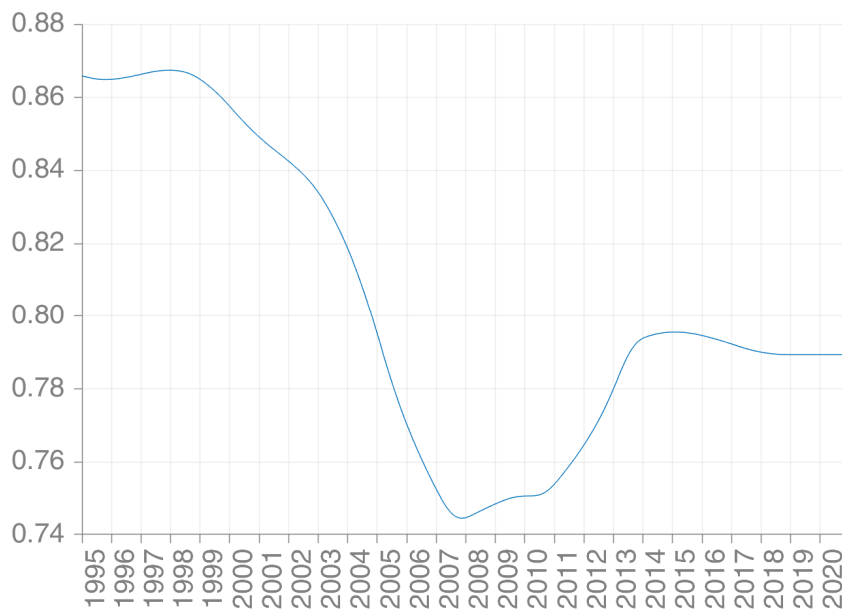


Figure S36: Interpolated/extrapolated monthly Indian clinker-cement ratio.

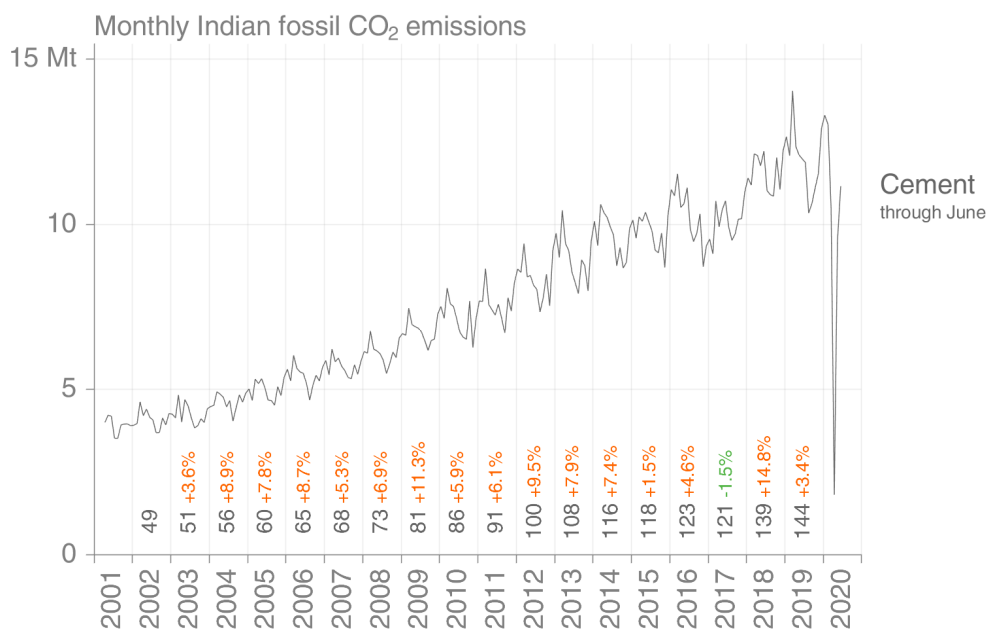


Figure S37: Final monthly estimates of CO₂ process emissions from cement production in India.

S11. Financial-year CO₂ emissions

Table S3: Financial-year CO₂ emissions in India by category, million tonnes.

Year	Coal	Oil	Natural gas	Cement	Total
2010	1003	427	123	83	1636
2011	1013	440	134	87	1675
2012	1120	462	136	94	1811
2013	1261	491	121	103	1975
2014	1336	493	102	109	2040
2015	1480	515	107	116	2217
2016	1487	572	109	121	2290
2017	1530	604	115	119	2369
2018	1621	639	120	126	2507
2019	1685	659	122	143	2609
2020	1661	662	131	142	2596
CAGR 2016-20*	2.9%	5.0%	3.9%	4.5%	3.5%

* Continuous compounding and adjusted for leap years.

S12. Electricity generation capacity

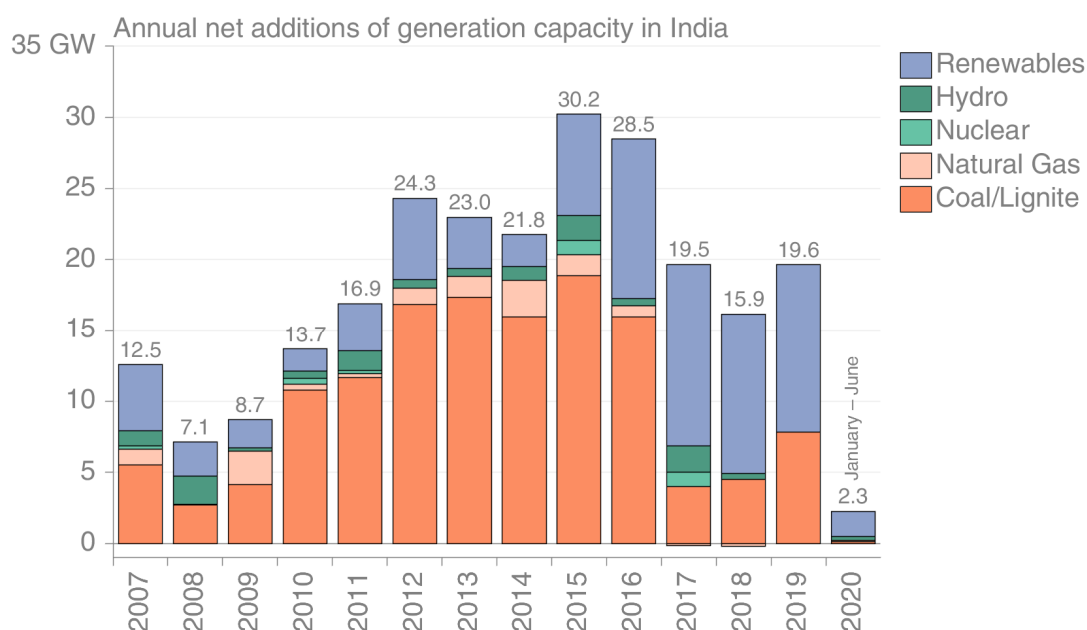


Figure S38: Annual net additions of electricity generation capacity in India. Source: CEA.

S13. Quarterly GDP growth

Figure S39 shows official estimates of India's quarterly growth in gross domestic product from 2012, the values published in March 2020 shown in red. This release reveals substantial revisions compared

to the previous release from December 2019, resulting from changed estimates of the “informal” sector, largely operating with cash and therefore less visible to data collection efforts.

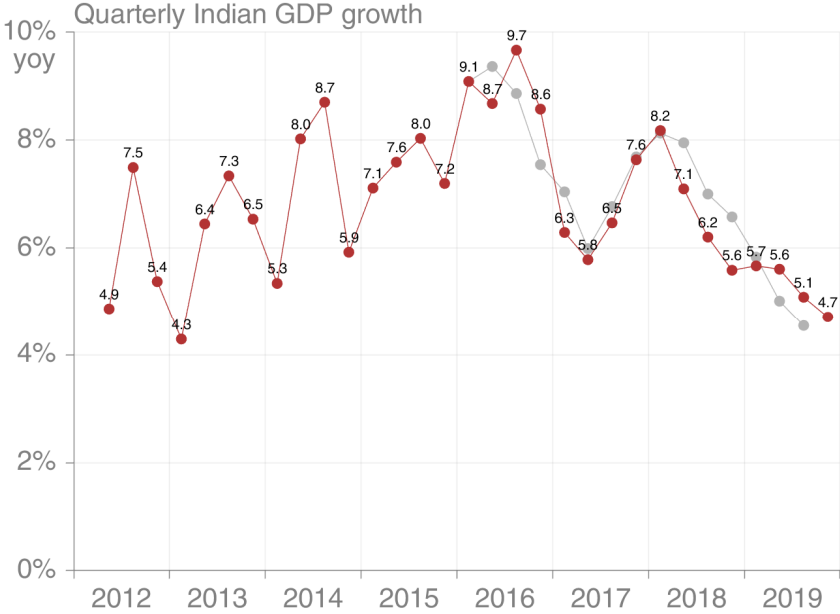


Figure S39: India’s Quarterly GDP growth. Latest revision in red, estimates from December 2019 in grey. Source: MOSPI.

S14. Emissions intensity of economic production

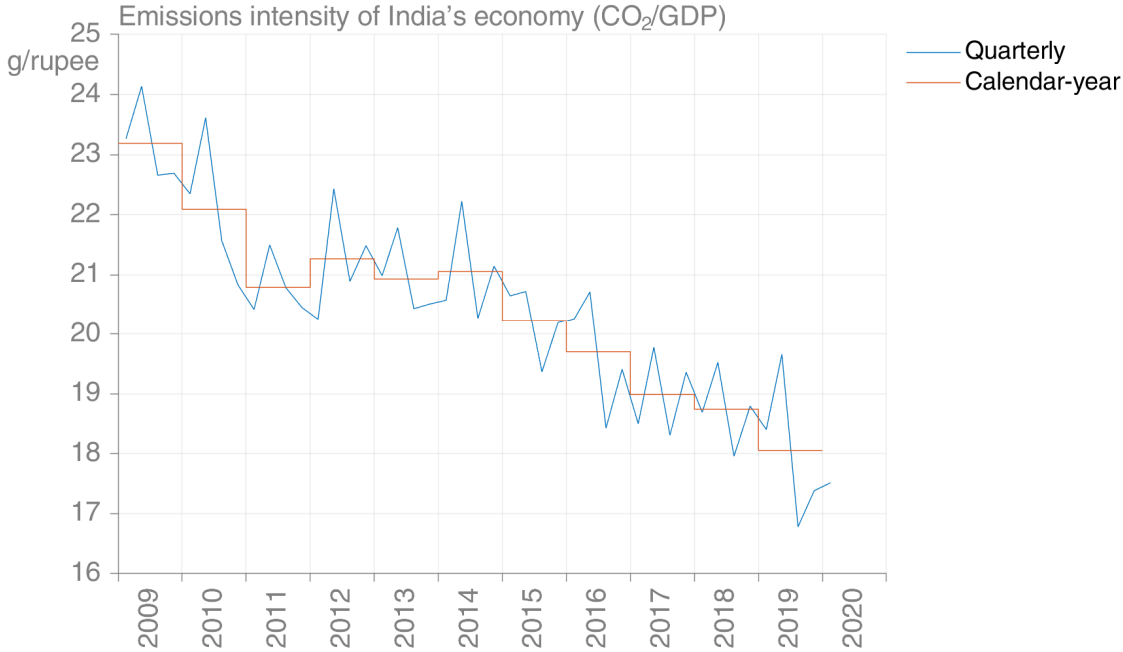


Figure S40: CO2-emissions intensity of India’s GDP, measured in constant 2011-12 prices.

S15. Total monthly electricity demand

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

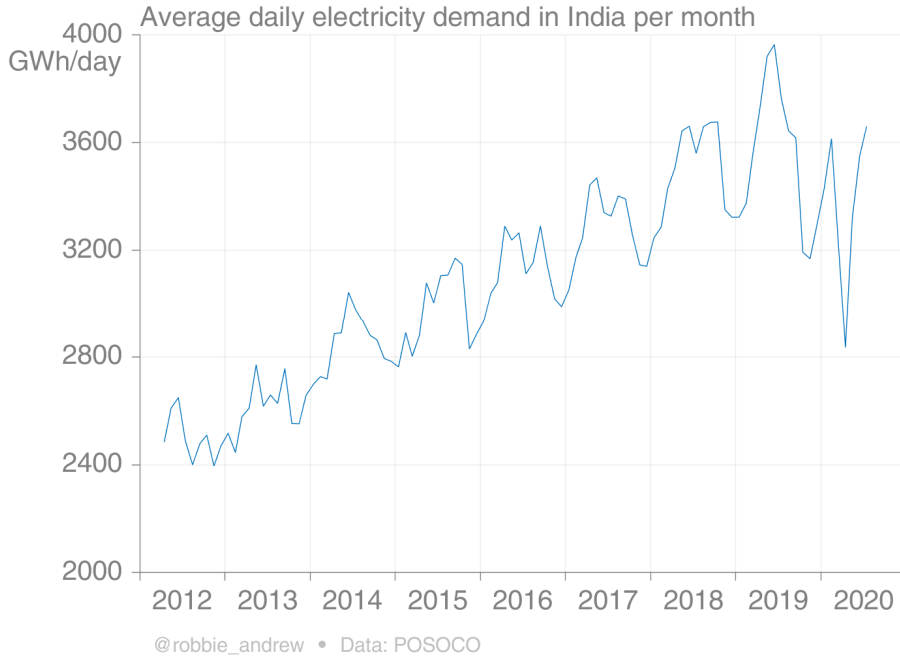


Figure S41: Monthly total electricity demand in India, adjusted for the number of days in the month. Source: POSOCO (2020).

S16. Share of fossil fuels in India's energy supply

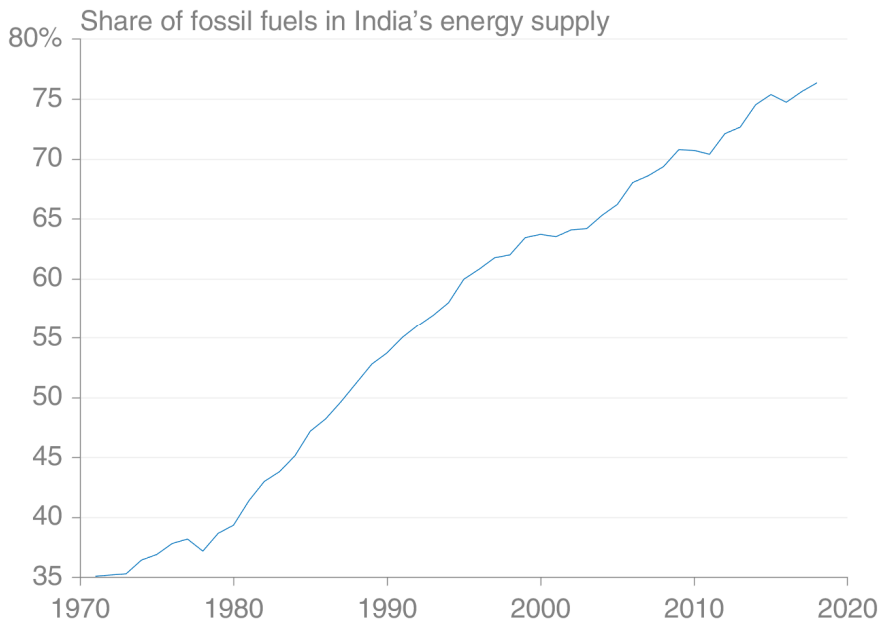


Figure S42: Share of India's energy supplied from fossil fuels, source: (IEA, 2020).

S17. COVID-19

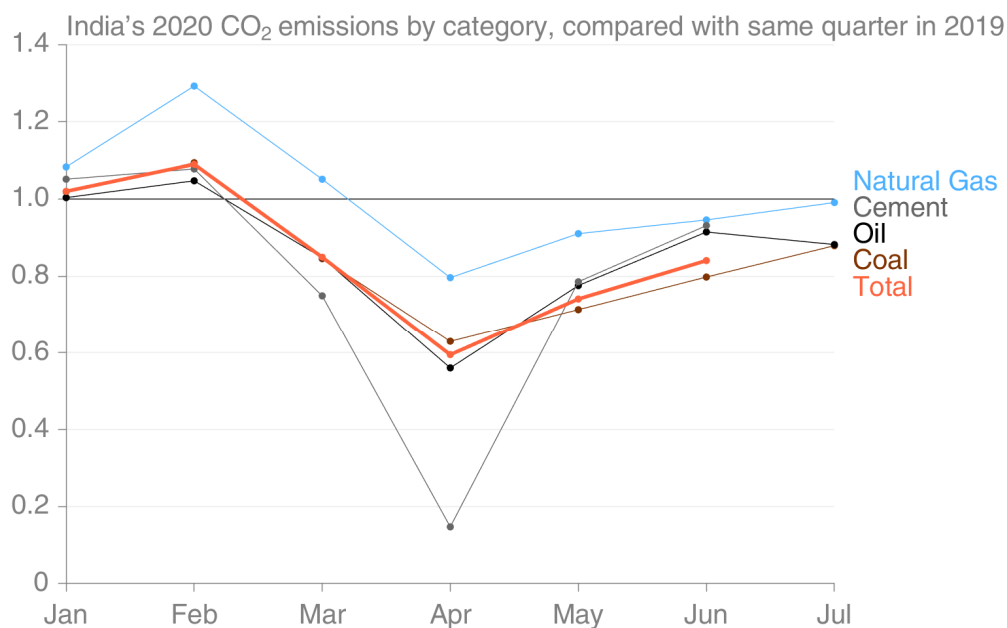


Figure S43: Quarter-on-quarter changes of CO₂ emissions by category during the first months of 2020.

S18. 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

S19. 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 tCO₂ per tonne. These imports would then lead to emissions of 1.76 Mt CO₂ when used in Indian agriculture.

S20. India activity data sources

Category	Organisation	Report	URL
Coal	Ministry of Coal	Monthly Summary to Cabinet	https://coal.nic.in/content/monthly-summary-cabinet
Coal	Coal Controller	Provisional Coal Statistics	http://www.coalcontroller.gov.in/pages/display/20-provisional-coal-statistics
Coal	Coal Controller	Coal Directory	http://www.coalcontroller.gov.in/pages/display/16-coal-directory
Coal	National Power Portal	Daily Coal Reports	https://npp.gov.in/dailyCoalReports
Coal	Central Electricity Authority	Coal Statement	http://cea.nic.in/monthlycoal.html
Coal	Directorate General of Commercial Intelligence and Statistics	Foreign Trade Data	http://14.98.253.4/
Coal	Department of Commerce	System on India's Monthly Trade	https://commerce-app.gov.in/meidb/Default.asp
Coal	Ministry of Coal	Production and Supplies	https://coal.nic.in/content/production-and-supplies
Coal	Coal India	UTTAM	http://uttam.coalindia.in/
Coal	Indian Bureau of Mines	Monthly Statistics of Mineral Production	https://ibm.gov.in/index.php?c=pages&m=index&id=497
Coal	United Nations	Monthly Bulletin of Statistics Online	https://unstats.un.org/unsd/mbs/app/DataSearchTable.aspx
Coal	Coal India	Physical Performance	https://www.coalindia.in/en-us/performance/physical.aspx
Coal	Singareni Collieries Company Ltd	Production	https://scclmines.com/scclnew/performance_production.asp
Oil	Petroleum Planning & Analysis Cell	Consumption of Petroleum Products	https://www.ppac.gov.in/content/147_1_ConsumptionPetroleum.aspx
Oil	Petroleum Planning & Analysis Cell	Production of Petroleum Products	https://www.ppac.gov.in/content/146_1_ProductionPetroleum.aspx
Natural Gas	Petroleum Planning & Analysis Cell	Consumption of Natural Gas	https://www.ppac.gov.in/content/147_1_ConsumptionPetroleum.aspx
Natural Gas	Petroleum Planning & Analysis Cell	Production of Natural Gas	https://www.ppac.gov.in/content/151_1_ProductionNaturalGas.aspx
Natural Gas	Petroleum Planning & Analysis Cell	Snapshot of India's Oil & Gas Data	https://www.ppac.gov.in/View_All_Reports.aspx
Natural Gas	Petroleum Planning & Analysis Cell	Monthly Report on Natural Gas	https://www.ppac.gov.in/View_All_Reports.aspx
Cement	Office of the Economic Adviser	Eight Core Industries	https://eaindustry.nic.in/
Electricity	Power System Operation Corporation Ltd	Daily Reports	https://posoco.in/reports/daily-reports/
Energy	Ministry of Statistics and Programme Implementation	Energy Statistics	http://www.mospi.gov.in/recent-reports

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