Climate-Carbon Interactions in the Current Century

4C Carbon Outlook 2022

Launch: 16 February 2023

4C Carbon Outlook

4c-carbon.eu/resources/carbon-outlooks

- Recovery from the COVID-19 pandemic continues in 2022, leading to fossil CO_2 emissions reaching 37.5 billion tonnes of CO_2 ($GtCO_2$), showing a 0.9% increase over 2021 and further shrinking the remaining carbon budget to keep global warming below 1.5°C.
- In this year's 4C Carbon Outlook, we look at the changes in emissions by fossil-fuel category, major emitting countries, and focus particularly on changes in the last three years. We additionally consider what may happen with emissions during 2023.

1. INCREASE IN EMISSIONS CONTINUES IN 2022

Global fossil CO_2 emissions likely reached a record high in 2022, at 37.5 $GtCO_2$, which is estimated to be about 1% above the pre-COVID-19 levels in 2019, as the recovery from the pandemic continues amidst the backdrop of the war in Ukraine and high inflation (Fig. 1).

The significant drop in fossil CO_2 emissions during the pandemic was reversed on the back of relaxed constraints and government recovery packages, a pattern seen in many previous global crises (Fig. 2). The growth rate of fossil CO_2 emissions was 0.6% per year over 2012-2022 and remained largely unchanged in the five-year periods of 2012-2017 and 2017-2022, despite a shift from coal to gas, rapid growth in solar and wind power, and a major economic crisis.

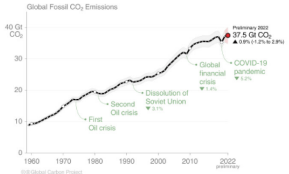

Figure 1. Fossil CO_2 emissions increased by 0.9% in 2022.

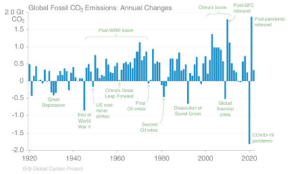

Figure 2. Annual changes in fossil CO_2 emissions, affected by global crises.

2. ATMOSPHERIC CO_2 GROWTH RATE

The total anthropogenic CO_2 emissions entering the atmosphere come from both fossil sources (37.5 $GtCO_2$) and from land-use change (LUC; 3.9 $GtCO_2$), reaching 41.3 $GtCO_2$ in 2022, or 40.6 $GtCO_2$ when CO_2 taken up by cement carbonation is removed.

While fossil CO_2 emissions have been trending upwards in the last decade, CO_2 emissions from LUC have likely been declining (although uncertainties are large), leading to a slight rise in total CO_2 emissions of around 0.3% per year in the last decade.

As a result of continued CO_2 emissions, atmospheric CO_2 is expected to have risen at near record-high levels in 2022, with the La Niña conditions in 2021 and 2022 keeping the growth rate lower than the record levels previously observed during El Niño years 1997, 2015, and 2016 (Fig. 3). The atmospheric CO_2 level reached 417.1 ppm in 2022, which is 51% above pre-industrial levels, according to the latest data.

3. TRENDS IN FOSSIL CO_2 EMISSIONS

Here, we discuss the trends in global fossil CO_2 emissions with three different foci: 1) fossil fuel categories since 1960; 2) top emitters since 1960; and 3) the COVID-19 pandemic (2020), recovery (2021 and 2022), and energy crisis (2022). Compared to the data released in the Global Carbon Budget in November 2022 (Friedlingstein et al., 2022; Global Carbon Project, 2022; Andrew, 2022), we have updated the CO_2 emission estimates for 2022 in the USA, EU, and India to include the latest sub-annual data.

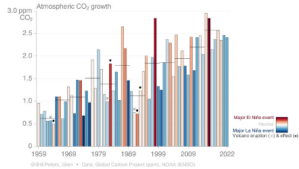

Figure 3. The atmospheric CO_2 growth (bars) with the bars coloured by the strength of the El Niño-Southern Oscillation (ENSO) index, based on NOAA Sea Surface Temperature data. The atmosphere CO_2 growth is larger in El Niño years (red) than in La Niña years (blue). Volcanic eruptions also affect the atmospheric CO_2 growth for up to 2 years after the event. Due to the ENSO variability and volcanic eruptions, it may take 5-10 years to detect a change in trend in CO_2 emissions (Peters et al., 2017).

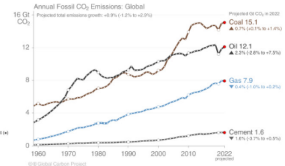

Figure 4. Contribution of different fossil fuel categories to annual CO_2 emissions. The smaller flaring and 'other' categories are not shown.

Trends by fossil fuel category since 1960

Fossil CO_2 emissions arise from the combustion of coal (40% of the total in 2022), oil (32%), and gas (21%), in addition to CO_2 emissions from chemical reactions in the production of cement (4%) (Fig. 4). A small amount of emissions arise from other processes (e.g. flaring) or chemical processes in industry.

Global emissions from coal use grew rapidly at 4.4% per year in the 2000s largely due to rapid growth in China, with CO_2 emissions from coal exceeding those of oil in the mid-2000s. The growth in CO_2 emissions from coal has slowed down to 0.6% per year (2010-2019) as growth slowed in China, and coal use declined in the EU and US. Emissions from coal appeared to have peaked in 2014.

Emissions from oil have grown at a steady 1.1% per year over recent decades, with economic crises generally being the only reason for a decline in oil use.

Emissions from natural gas have grown at a steady rate of 2.5% per year over several decades, and have been the main driver in the growth in global emissions in the last decade (Peters et al., 2020). However, the future trajectory of gas use is particularly uncertain due to the geopolitical response to the war in Ukraine.

Non-fuel emissions from cement production grew by 5.8% per year in the 2000s, but the growth decreased to 2.7% per year in the following decade due to slower growth in China, where about half of cement production occurs.

Top emitting countries since 1960

The top-4 emitters of total fossil CO_2 emissions in 2022 were China (30%), USA (14%), the EU27 (7%), and India (8%). Emissions from the rest of the world, including international bunker fuels, accounted for 41% of total emissions (Fig. 5).

Fossil CO_2 emissions in **China** grew rapidly at a rate of 9.0% per year in the 2000s, surpassing the US to become the world's biggest emitter in 2006. Emissions growth slowed rapidly in the 2010s, even declining in 2015 and 2016. Since 2016, emissions in China have risen steadily at 2.8% per year, even during much of the COVID-19 pandemic.

In the **United States**, fossil CO_2 emissions peaked in 2007 and have steadily declined at -1.1% per year since then, with a persistent shift from coal to natural gas and renewables.

In the **European Union** (EU27), fossil CO_2 emissions have been steadily declining since 1980, with a -0.2% per year decline in the 2000s and -1.3% in the 2010s.

Fossil CO_2 emissions **in India** have been growing strongly as India develops, with 5.2% per year growth in the 2000s and 5.1% in the 2010s.

International bunker fuels are used for international transport (aviation and shipping), and are not formally allocated in national emission inventories as the emissions occur outside of national territories. CO_2 emissions from bunkers fuels have grown at 3.7% per year in the 2000s, with their growth dropping to 2.0% per year in the 2010s, and were heavily affected by the COVID-19 pandemic.

In the rest of the world, fossil CO_2 emissions have grown strongly at around 2.2% per year in the 2000s, and this slowed down to 1.3% per year in the 2010s.

It should be noted that, while Fig. 5 shows the aggregated CO_2 emissions for the largest four emitters (and bunkers), these countries have very different populations. Taking this into account, fossil CO_2 emissions are estimated to be 14.9 tonnes of CO_2 (tCO_2)/person in the USA (2021), 8.0 tCO_2/person in China, 6.3 tCO_2/person in the EU27, and 1.9 tCO_2/person in India, with a global average of 4.7 tCO_2/person.

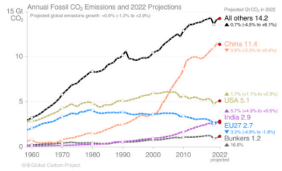

Figure 5. Annual fossil CO_2 emissions by country. Bunkers are international aviation and shipping.

COVID pandemic (2020), COVID recovery (2021 and 2022), and energy crisis (2022)

The last three years have seen very unusual dynamics in global fossil CO_2 emissions, driven by the pandemic in 2020, the recovery from the pandemic, and the war in Ukraine in 2022, and these dynamics have played out differently for different fuel categories (Fig. 6).

In 2020, emissions in most countries dropped across all fuels, with the exception of China, which successfully maintained a zero-COVID policy without curtailment of domestic activity.

The effects globally were most pronounced in emissions from oil because of the curtailment of movement across much of the world in efforts to restrict the spread of the virus. This led to drops in the use of liquid fuels for land transport as well as aviation, and international aviation saw the largest hit as international border crossings were closed. Emissions from coal also dropped significantly, a result of lower economic activity, and higher prices at the margin for power generation than natural gas in the USA and EU27.

With most of the world lifting many constraints on activity, emissions rebounded sharply in 2021. While emissions from coal increased more in 2021 than they had dropped in 2020, emissions from oil did not recover all of their lost ground as many constraints on movement remained in place across the world.

In 2022, emissions from oil continued to recover back to pre-pandemic levels, except in China, where long, repeated, and widespread lockdowns sharply curtailed activity. The increase in bunker emissions is largely due to recovery in international aviation, while international shipping had already recovered to pre-pandemic levels in 2021. Emissions from natural gas were up in the USA, a continuation of the long-term trend, while they were sharply reduced in the EU, showing a decline of over 10% as a result of the loss of supply from Russia. Europe's emissions from coal increased slightly to compensate, and India's emissions from coal also increased in line with the longer term trend.

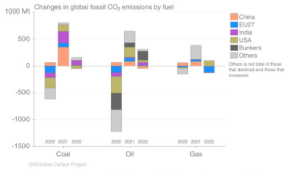

Figure 6. Country- and fuel-specific changes in CO_2 emissions in the last three years.

4. THE DRIVERS OF CHANGE

The Kaya decomposition is an effective way to describe the core factors behind the growth rate of fossil CO_2 emissions (Fig. 7). The fossil CO_2 emissions are divided into different components, and the growth rate is the addition of the growth rates in population, Gross Domestic Product (GDP) per population, primary energy per GDP, fossil CO_2 emissions per primary energy, plus a small interaction term since the decomposition is not exact due to the use of discrete data.

$$\Delta CO_2 = \Delta P + \Delta(GDP / P) + \Delta(Energy / GDP) + \Delta(CO_2 / Energy) + Interactions$$

Over recent decades, global population growth has been slowing, and is less important for the growth of CO_2 emissions. The most important factor pushing emissions up is the growth in GDP per person (economic activity). There are two main factors which counteract the growth in economic activity: structural change and efficiency improvements (Energy/GDP), and decarbonisation of energy use (CO_2/Energy), both of which put downward pressure on emissions.

In recent years, a shift from coal to gas, and from fossil fuels to solar and wind energy, has meant that decarbonisation has accelerated. This has helped slow the growth in fossil CO_2 emissions in the last decade. However, to reach aggressive climate targets (well below 2°C), Energy/GDP and CO_2/Energy need to decline considerably faster for a given level of economic activity (GDP).

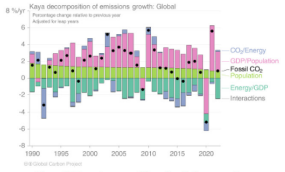

Figure 7. Kaya decomposition of emissions growth.

5. PROJECTION FOR FOSSIL CO_2 EMISSIONS GROWTH IN 2023

It is still very early in 2023, but there are some indications of how fossil CO_2 emissions may change in 2023. Here, we have used projections of coal, oil, and gas use developed by other organisations to obtain an initial and tentative estimate for the growth of fossil CO_2 emissions in 2023 of 0.5%. Our projection assumes that coal use remains stable in 2023 (IEA), oil use grows by 1.1% (EIA STEO), and gas use grows by 0.4% (IEA). It is also assumed that other components (mainly cement) grow at the same rate as in the last 10 years.

Independently, the International Monetary Fund has projected that GDP will grow by 2.9% in 2023 (IMF January Outlook update). If it is assumed that CO_2/GDP declines at the same rate as in the last 10 years (2.2%/yr), then this would imply that fossil CO_2 emissions would grow by 0.7% in 2023. This approach requires a different set of assumptions, but indicates some consistencies in the projections despite the large potential uncertainties in projecting 2023 emissions in January 2023.

Acknowledgements

The content of the 4C Carbon Outlook 2022 is based on the Global Carbon Budget 2022, conducted by the Global Carbon Project, which involves many 4C researchers and activities.

References

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- *Global Carbon Project. Global Carbon Budget 2022. https://www.globalcarbonproject.org/carbonbudget/*
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- *Peters, G.P., et al. (2017). Towards real-time verification of CO_2 emissions. Nature Clim Change 7, 848–850. https://doi.org/10.1038/s41558-017-0013-9*
- *Peters, G.P., et al. (2020). Carbon dioxide emissions continue to grow amidst slowly emerging climate policies. Nat. Clim. Chang. 10, 3–6. https://doi.org/10.1038/s41558-019-0659-6*

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GLOBAL CARBON PROJECT

WEBINAR: CARBON OUTLOOK

Thursday 16 February 2023 | 11:30-12:30 CET | Registration open

PROGRAMME

Welcome and Introduction
Ilaria Vigo, BSC | Moderator: Miriam Dahl, CICERO

Emissions in the last decade
Glen Peters, CICERO

World's top emitter: China
Jan Ivar Korsbakken, CICERO

Other top emitters: EU, US and India
Robbie Andrew, CICERO

How will emissions evolve in 2023?
Glen Peters, CICERO

The drivers of a recovery in 2023, the EU and China
Yan Qin, Refinitiv Carbon

Discussion & Questions

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SENIOR RESEARCHER
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RefinitivCarbon

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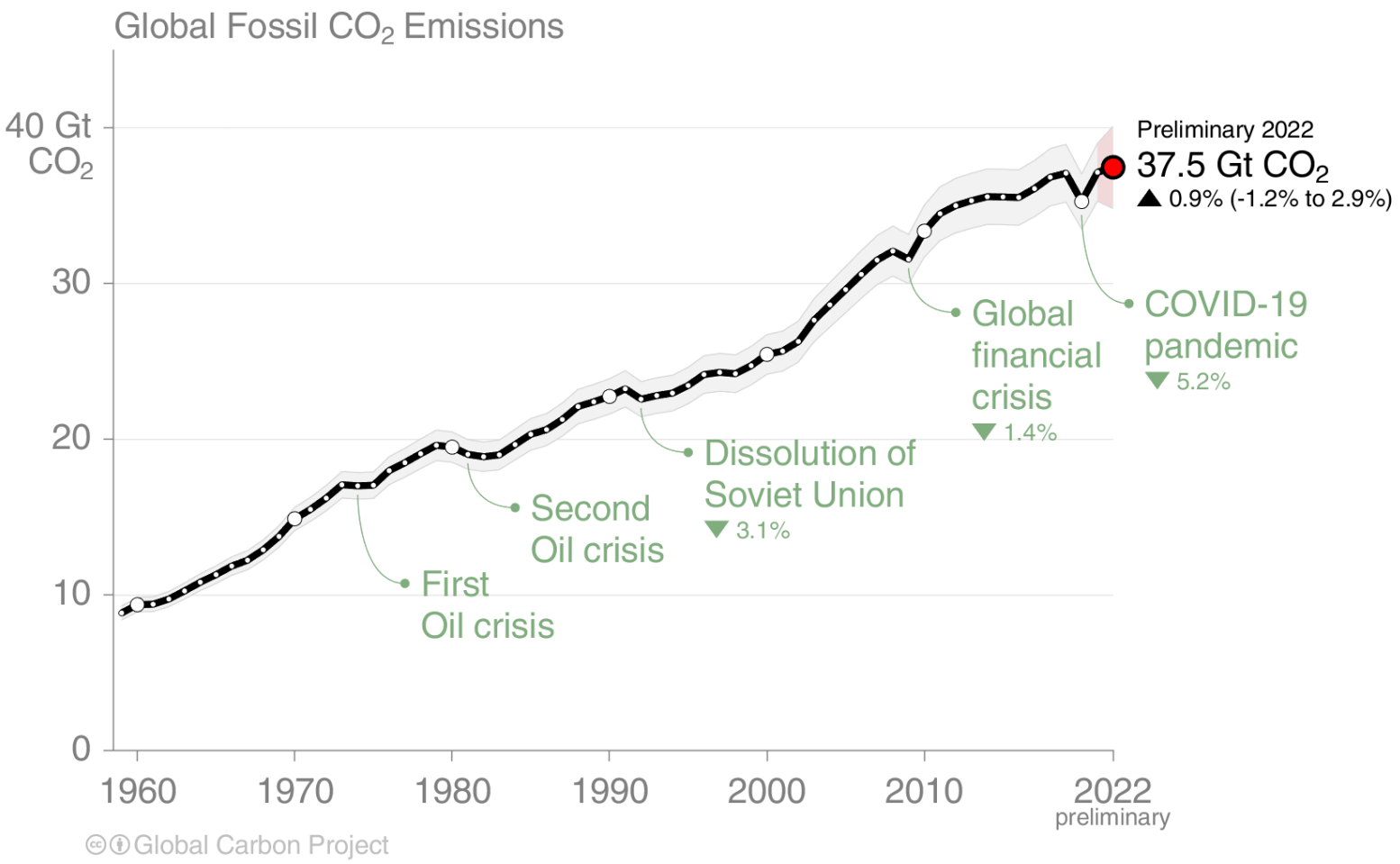
Trends in fossil CO_2 emissions

Glen Peters (CICERO)

Climate-Carbon Interactions in the Current Century

Increase in emissions continues

Global fossil CO_2 emissions likely reached a record high in 2022, at 37.5 $GtCO_2$, ~1% above the pre-COVID-19 levels
The recovery from the pandemic continues amidst the backdrop of the war in Ukraine and high inflation.

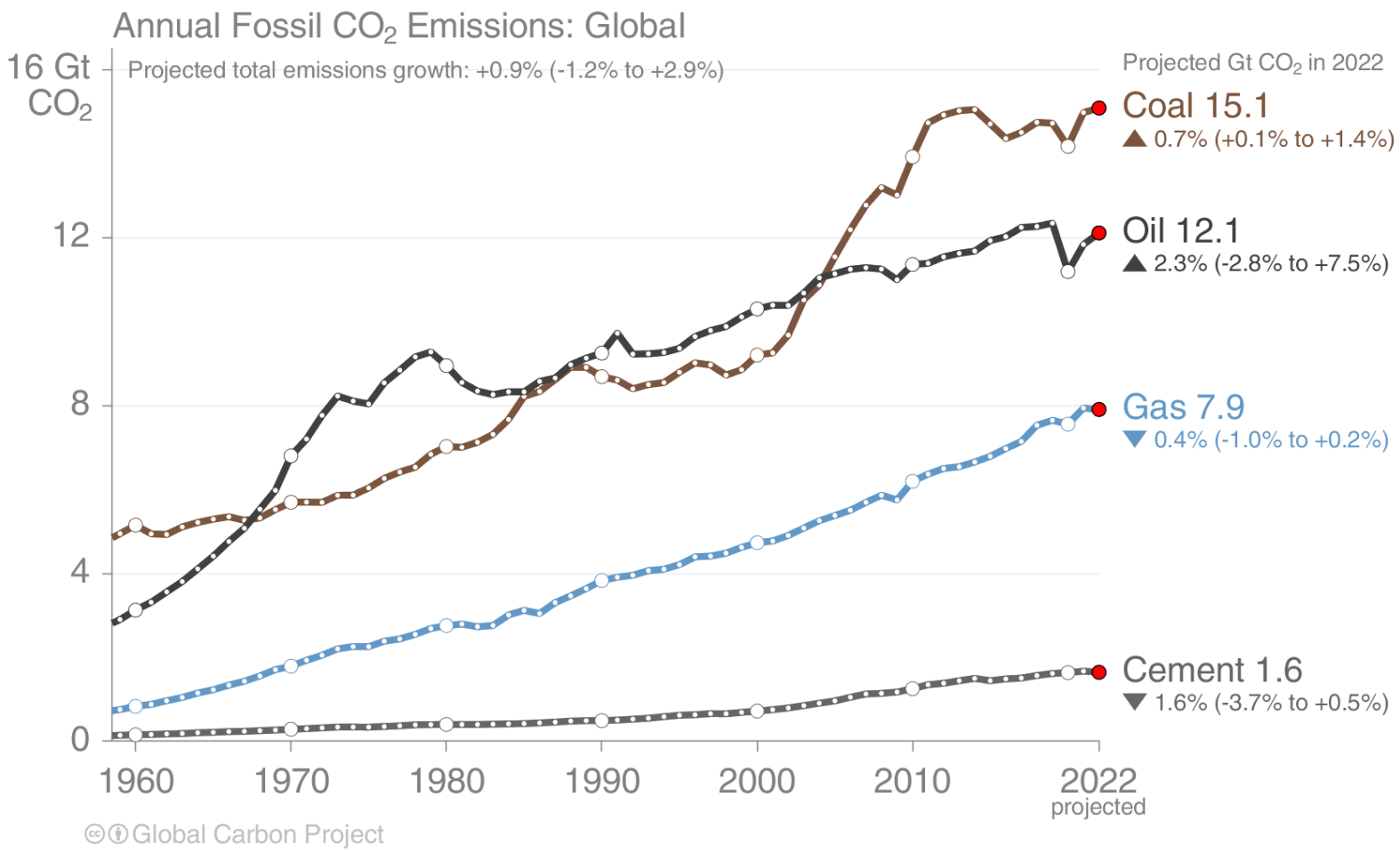


°CICERO

Source: Global Carbon Budget, 4C Carbon Outlook

Trends by fossil fuel category

Coal had explosive growth in the 2000s (China), but has been largely flat in the last decade
Oil & gas have had sustained growth, with gas driving much of the growth in emissions in the last decade

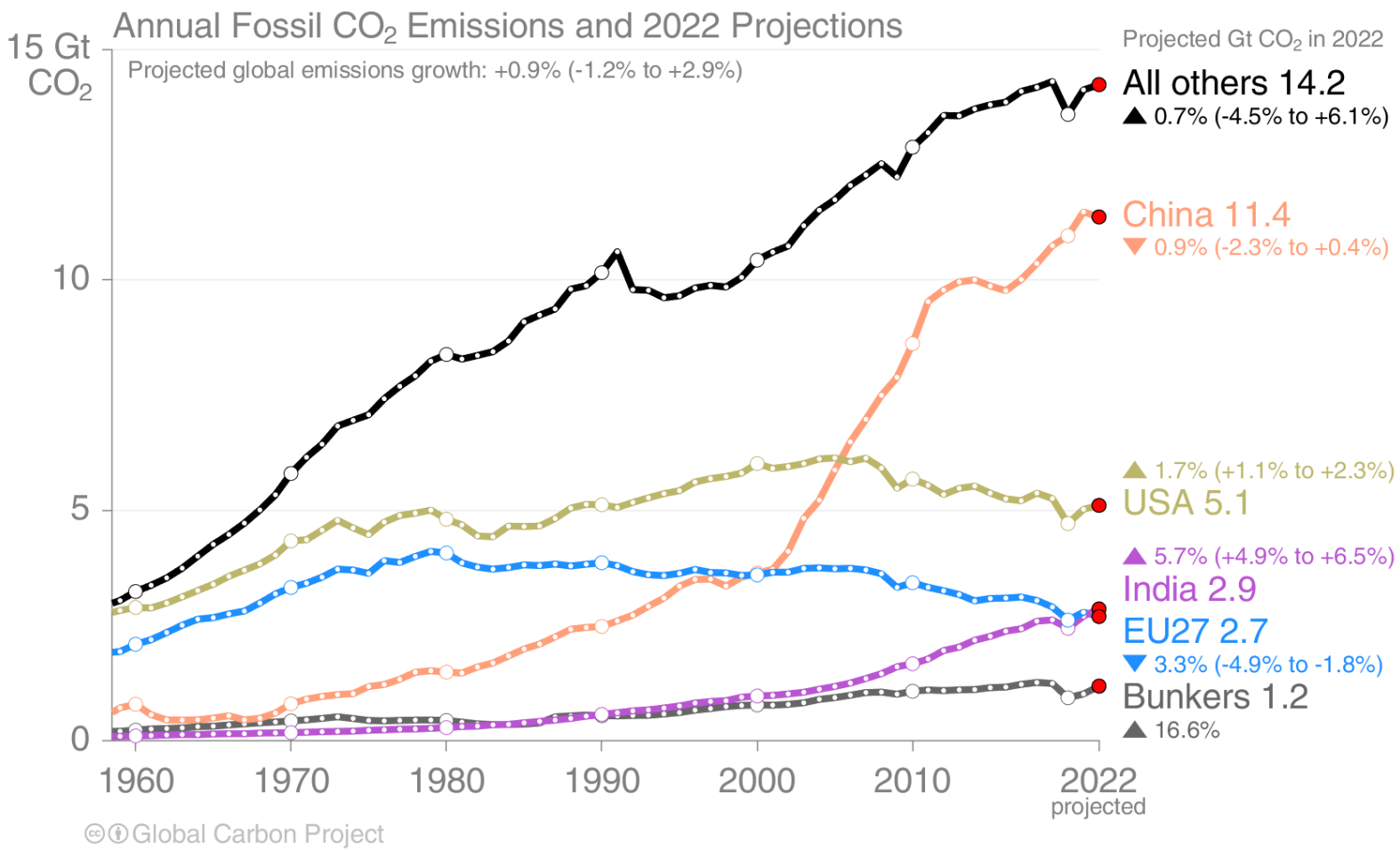


°CICERO

Source: Global Carbon Budget, 4C Carbon Outlook

Trends by top emitting countries

China surpassed the EU in 2000, the US in 2007, and growth continues despite slowdown in the 2010s
USA & EU with declining emissions (e.g., coal to gas & renewables), with India emerging rapidly



°CICERO

Source: Global Carbon Budget, 4C Carbon Outlook

China

Jan Ivar Korsbakken (CICERO)

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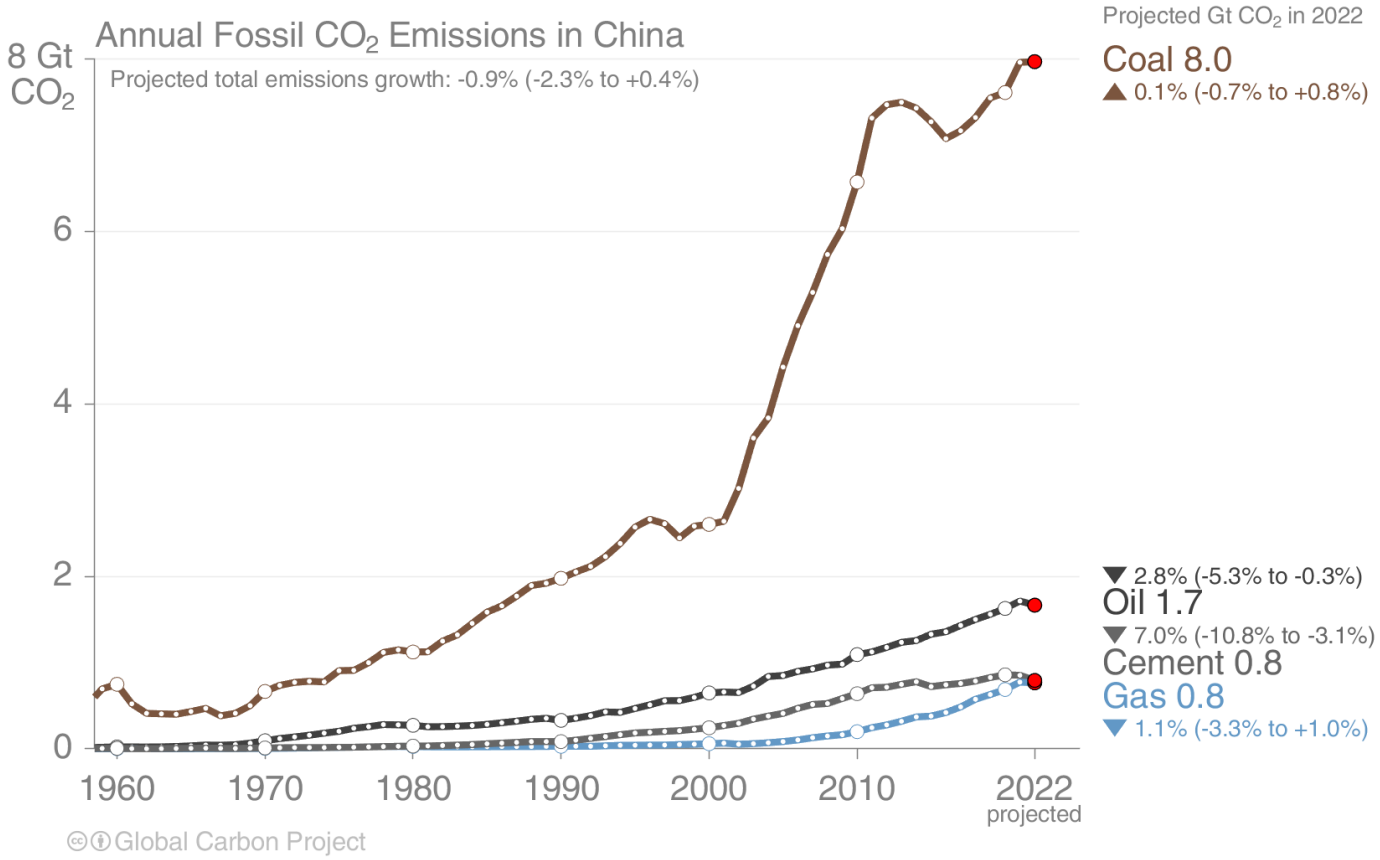
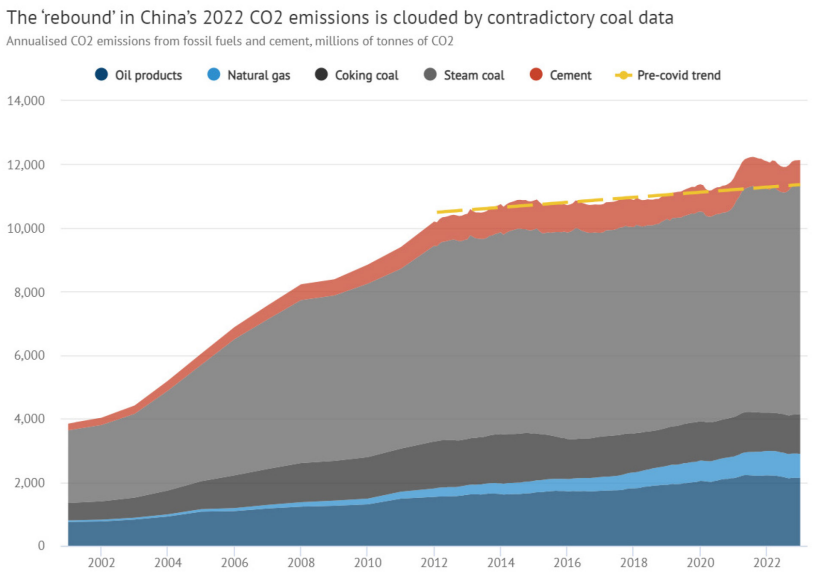
China: Challenging year, halted growth

- Energy-intensive economic growth
  - Industry-heavy exports (2000s)
  - Infrastructure construction (post-GFC)
  - Housing construction (late 2010s)
- Coal-heavy energy mix
- Emissions and coal consumption growth mirroring the economy
- Challenging economic conditions since 2021:
  - Real-estate debt crisis
  - COVID lockdowns
  - High oil/gas prices
- Unusual fall in oil and gas in 2022



But: Surprise on coal, 2022 emissions growth could be higher (?)

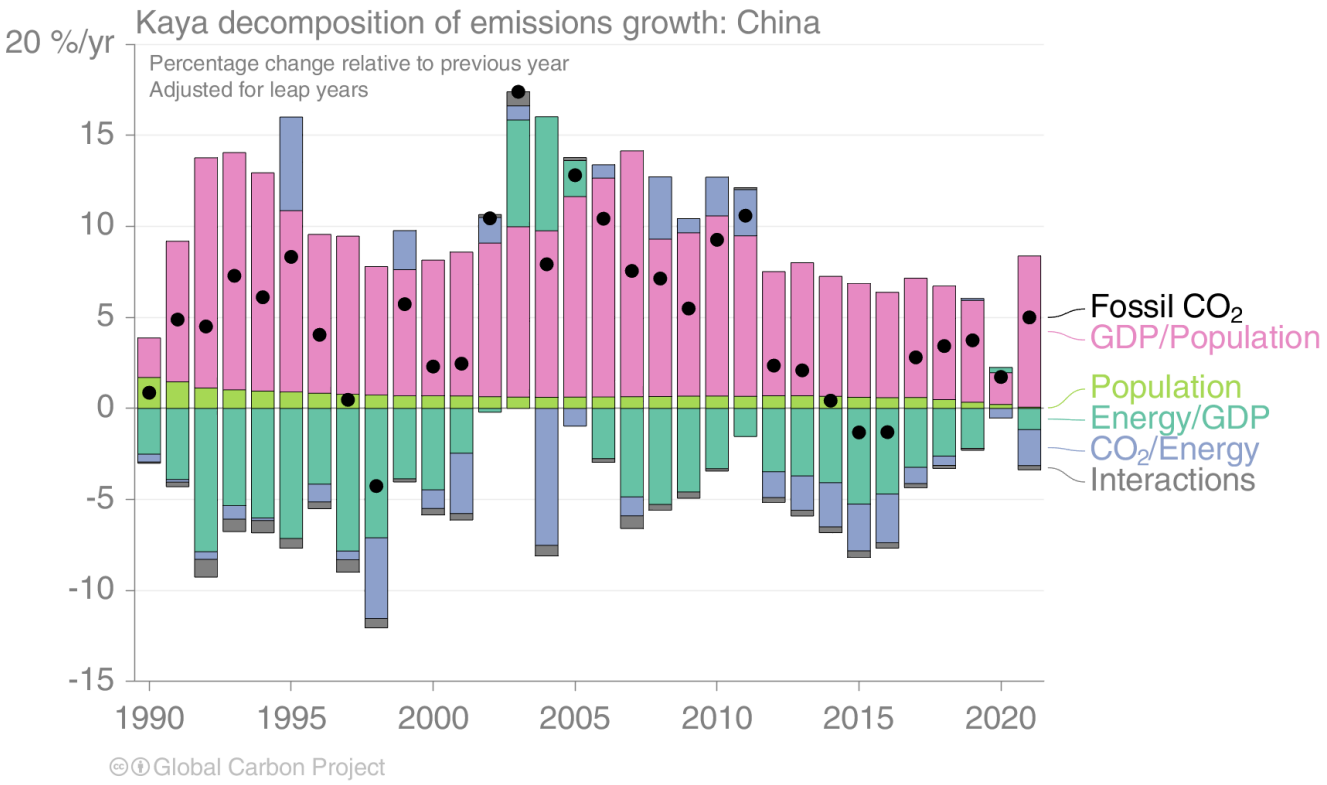
- Surprise preliminary estimate from NBS: Coal consumption up 3.3% in 2022 (?!): http://www.stats.gov.cn/tjsj/sjjd/202301/t20230118_1892180.html
  Good discussion article in Carbon Brief (Lauri Myllyvirta/CREA): https://www.carbonbrief.org/analysis-contradictory-coal-data-clouds-chinas-co2-emissions-rebound-in-2022/
- ...and Tweet by Yan Qin:



China: Economic growth keeps emissions growing

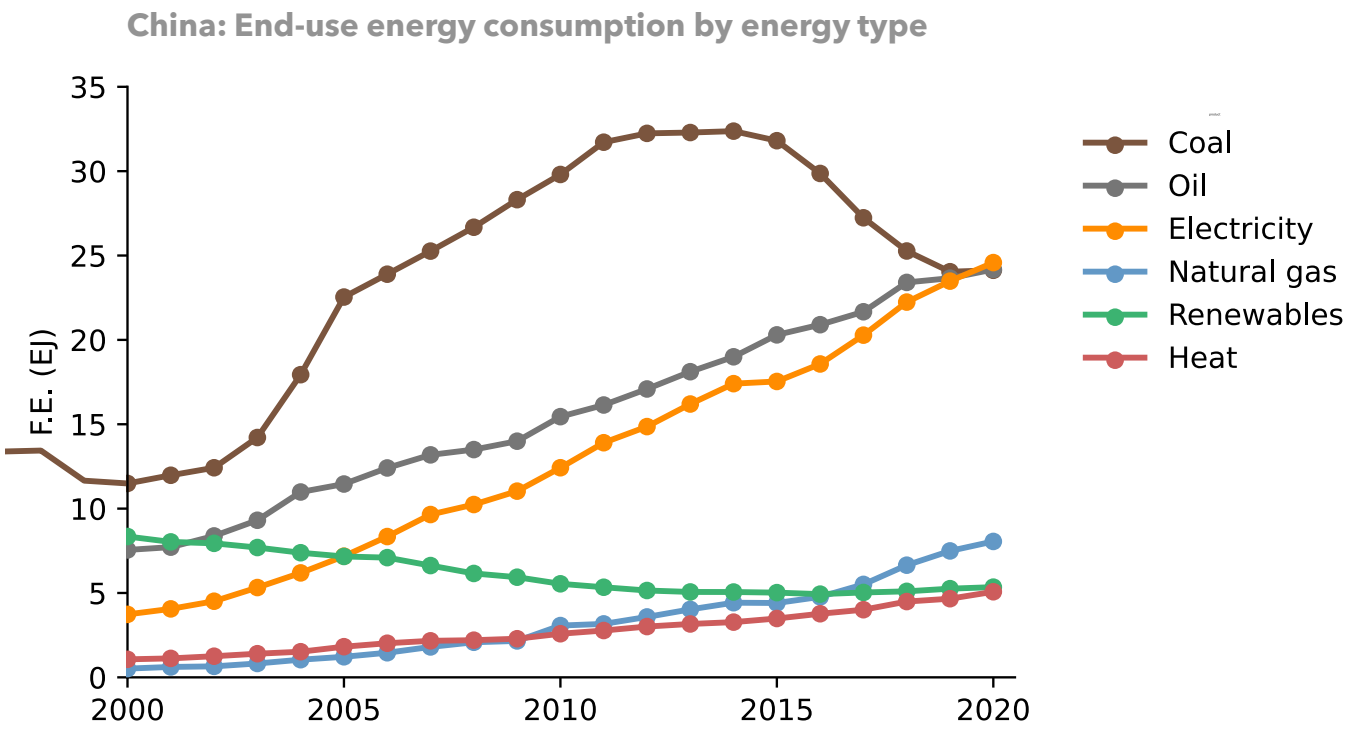
- Energy intensity of GDP and CO_2 intensity of the energy mix is improving in most years
- ...but not enough to keep up with high GDP growth
- Energy/GDP and CO_2/Energy improvements in line with advanced economies, but from a worse starting point
- Higher GDP growth means CO_2 emissions keep going up

Kaya decomposition



China: The way in which energy is consumed is changing

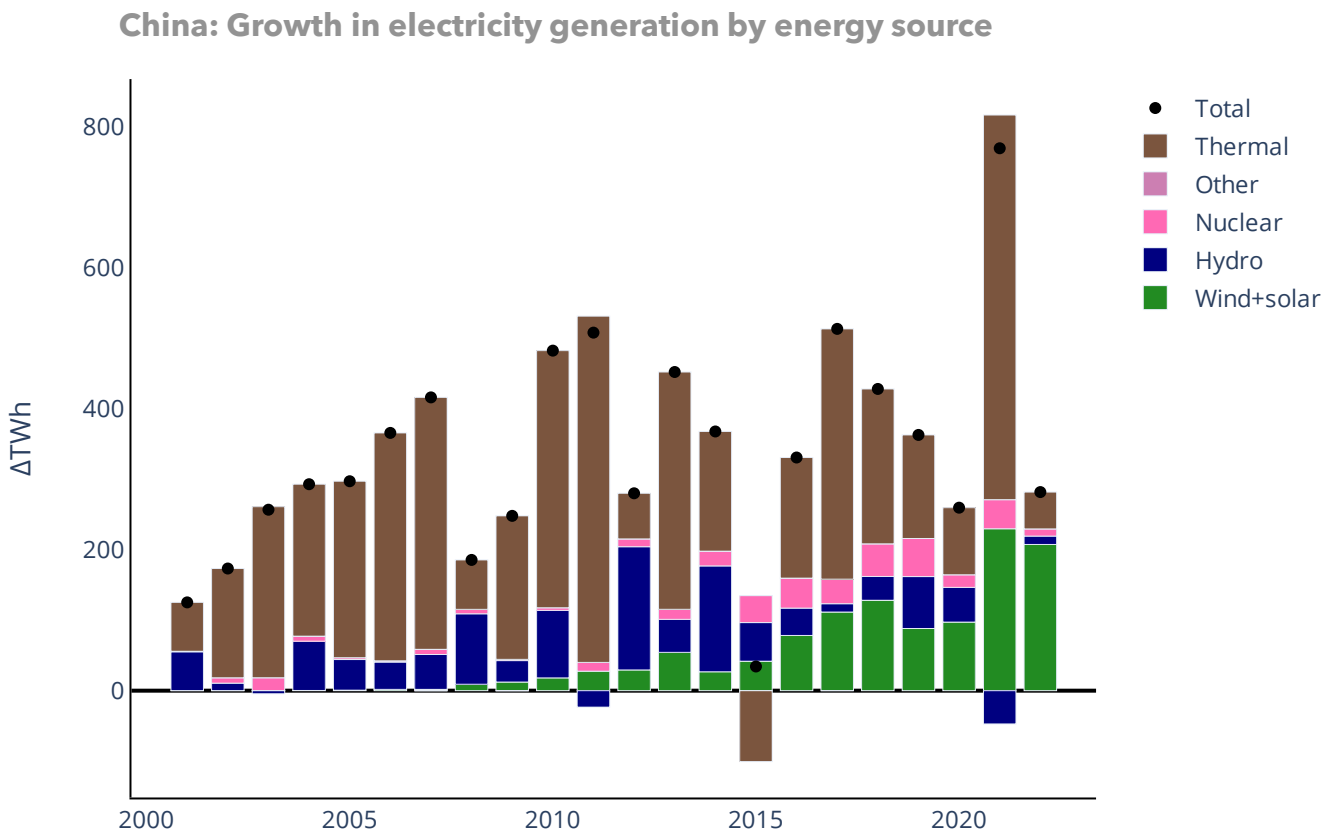
- Direct use of coal *falling* strongly, in industry and in building heat
- Strong growth in other energy types, especially electricity
- Main trend: Industry is *reducing* coal use, but *increasing* all other energy use, *especially electricity*
  - Coal use moving from industry to the power sector
  - High growth in electricity demand, renewables can't keep up



Data: IEA World Energy Balances 2022

China: Non-fossil electricity growing, but demand growing faster

- Renewable power generation (esp. wind/solar) growing strongly since mid-2010s
- Electricity demand growth very high most years
- Coal power keeps growing because of high demand growth, other sources can only keep up when demand growth is weak



Data: IEA Energy Balances (through 2021), China National Energy Agency press conference (solar/wind 2022), China National Bureau of Statistics monthly data (others 2022)

USA

Robbie Andrew (CICERO)

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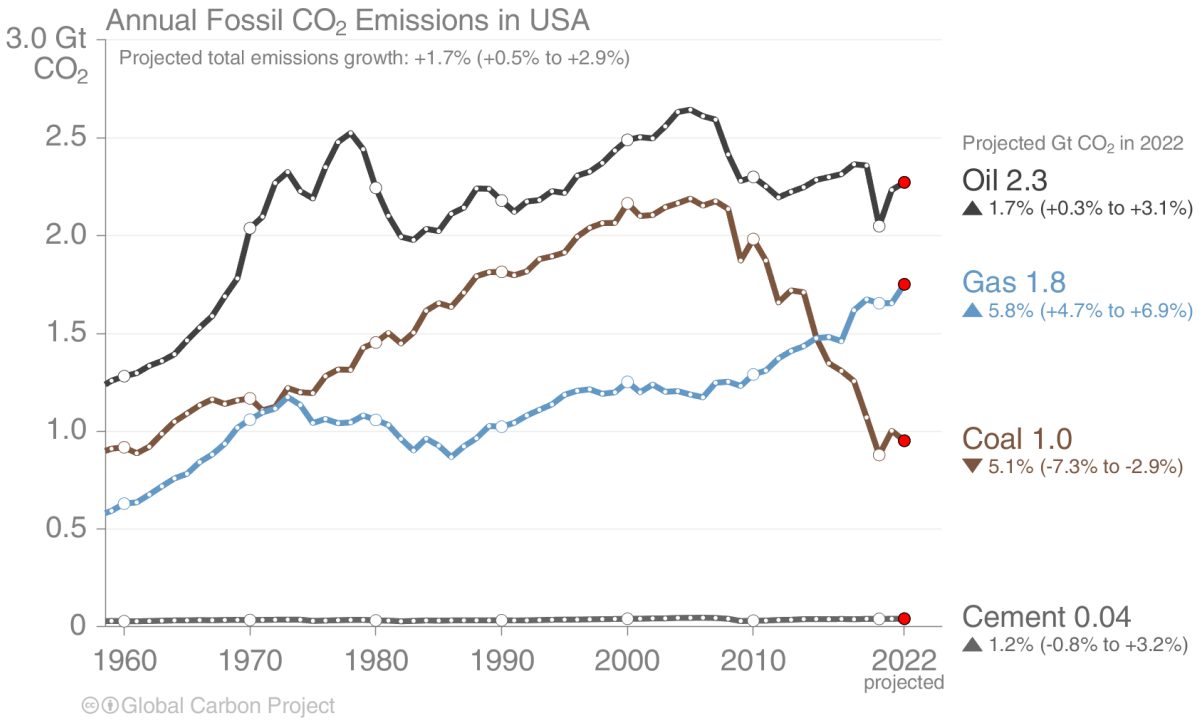
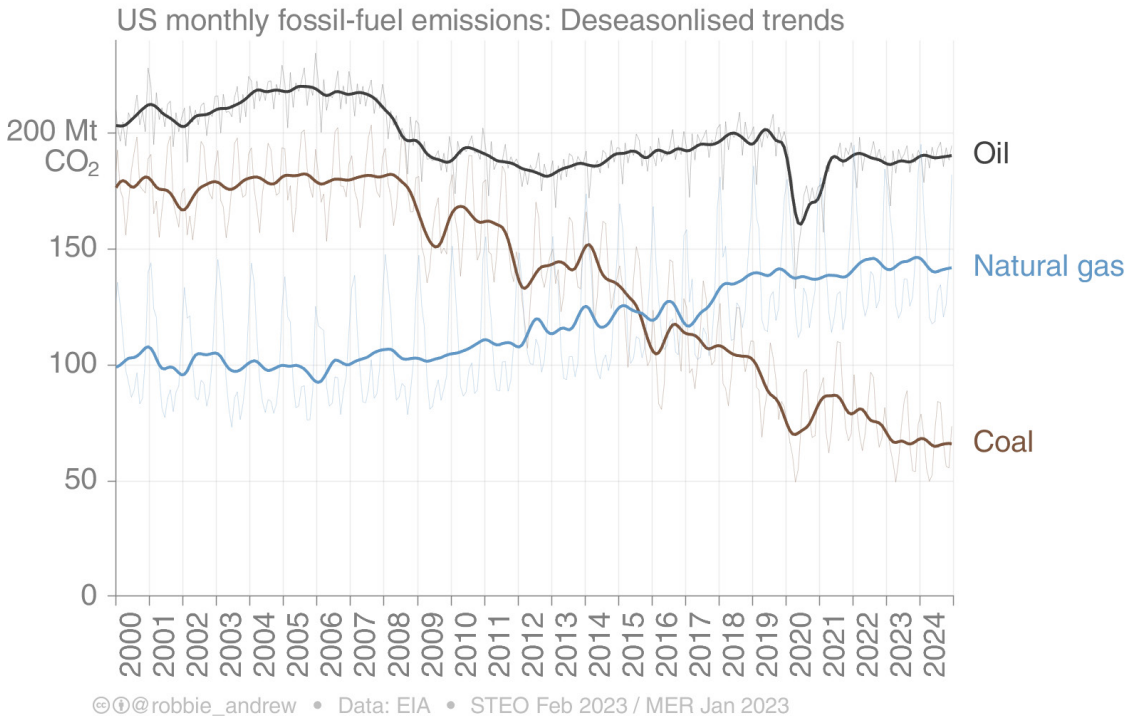
USA

- Long-term trends
- Growth of natural gas, decline of coal
- Oil hasn't recovered from the GFC



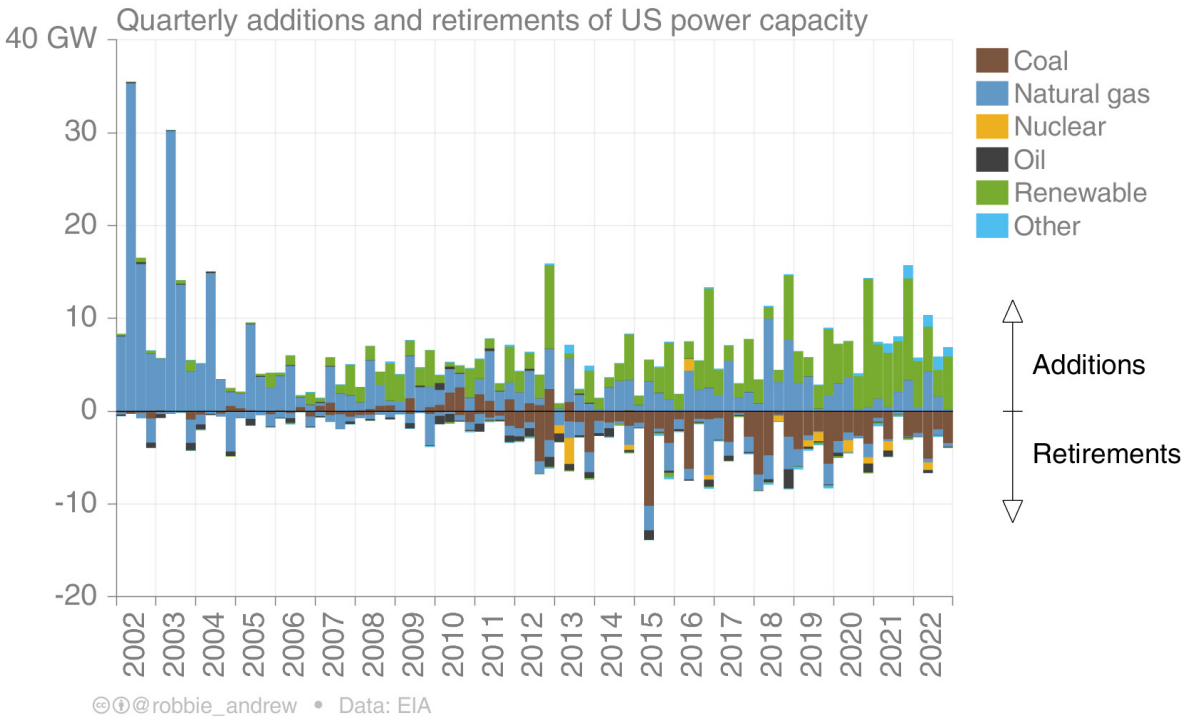
USA

- Effect on pandemic was largest on oil
  - Restrictions on movement: transport
- Natural gas very little effect
  - Rebound in 2022 is partially economic recovery, but also weather
  - Prices are higher, but not enough to change things much
- Coal already declined considerably through 2019
  - But 2021-2023 are continuation of the long-term trend



USA: Coal decline

- Boom of natural gas power plants 1999-2005
- Shale gas production started to ramp up in 2008
- Coal-fired power stations have been retiring
  - First the older, less efficient stations, but now also relatively young stations
  - Cannot compete with alternative generation sources
  - Regulations on ash tightening
  - Those still operating are operating at much lower utilisation rates



European Union

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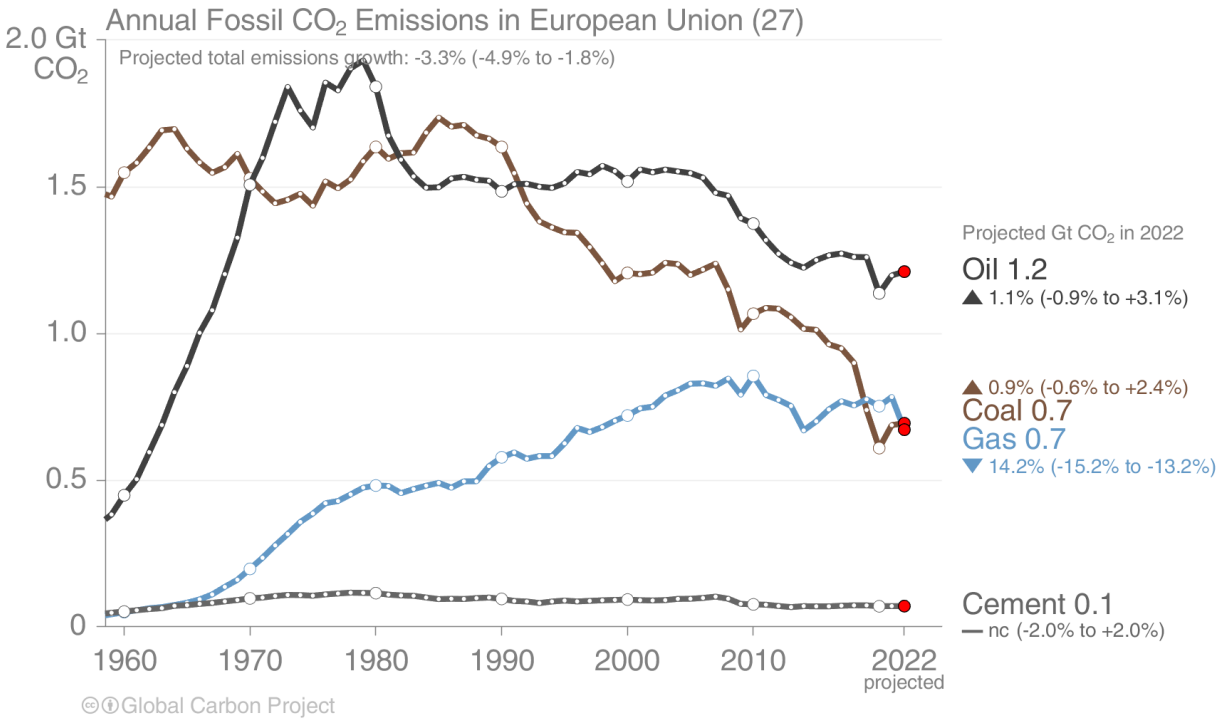
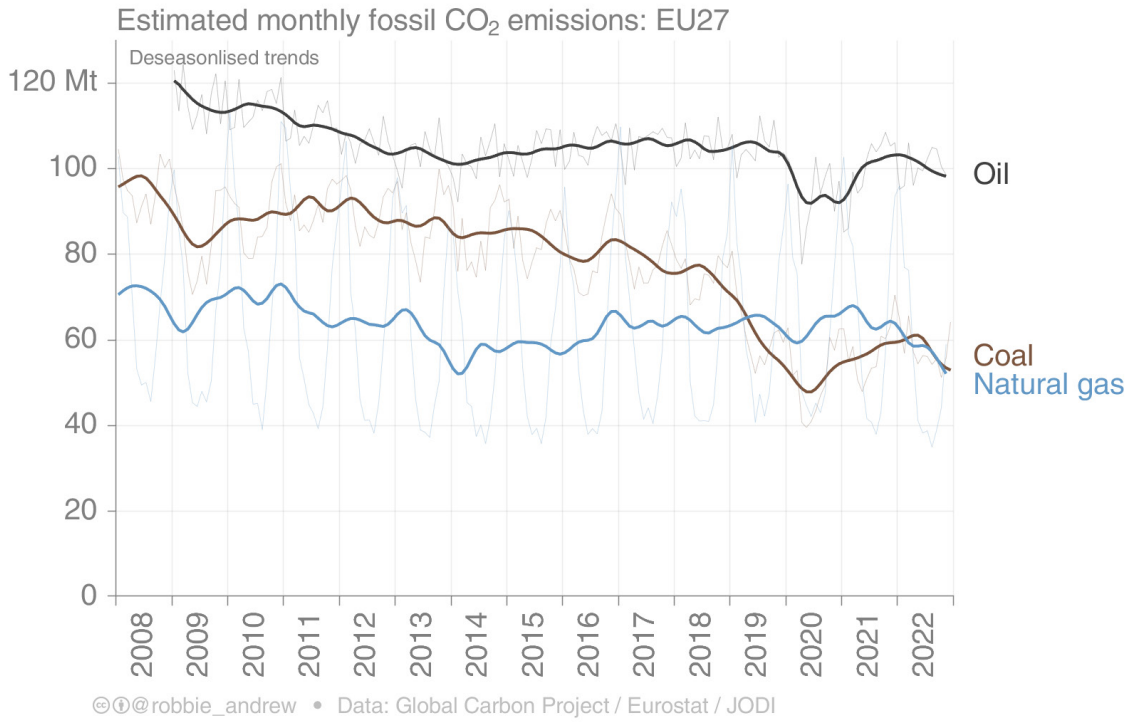
Europe

- Coal
  - Long-term decline
  - Tighter and tighter regulations on air pollution and waste handling
  - Partly also reduced manufacturing in the EU
- Gas
  - Steady growth for decades, but a shift with the GFC
- Oil
  - Long-term decline
  - Efficiency improvements effective



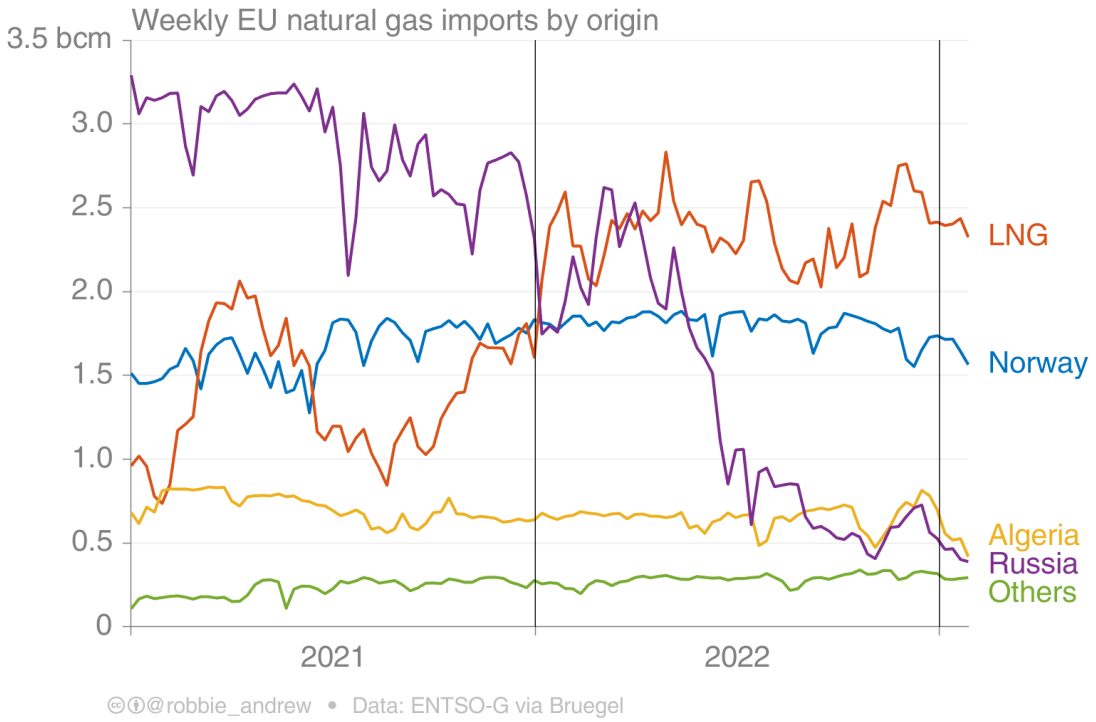
Europe

- Large dip in emissions from oil in 2020, extending into 2021
  - Hasn't completely recovered to pre-pandemic levels
  - 2022 weak demand
- Natural gas well down in 2022
- Coal rebounded in 2021
  - Appeared to continue growth in early 2022, but latter half of 2022 down again
- Expectations for very large drop in fossil share of power in 2023



Europe: Natural gas imports

- Russian supplies of natural gas started declining already in 2021
- Declines accelerated after Russia's invasion of Ukraine and have now reached very low levels
- Some of this was compensated for by a large growth in imports of LNG



India

Robbie Andrew (CICERO)

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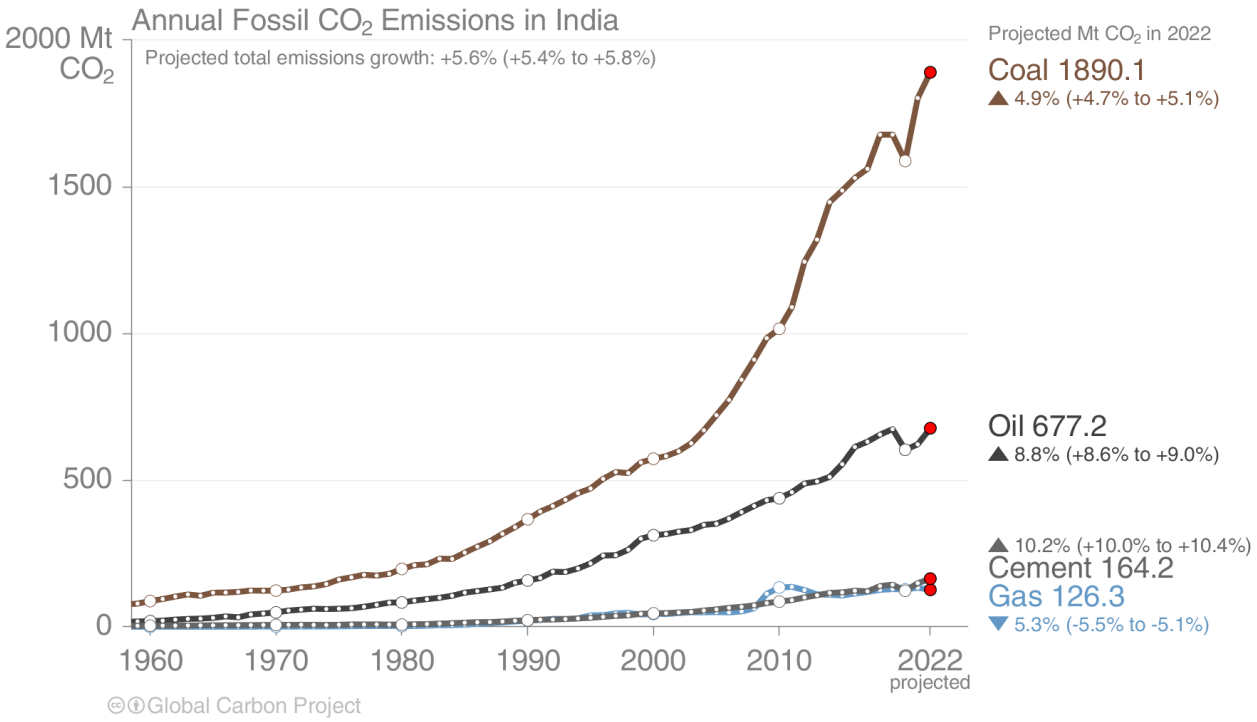
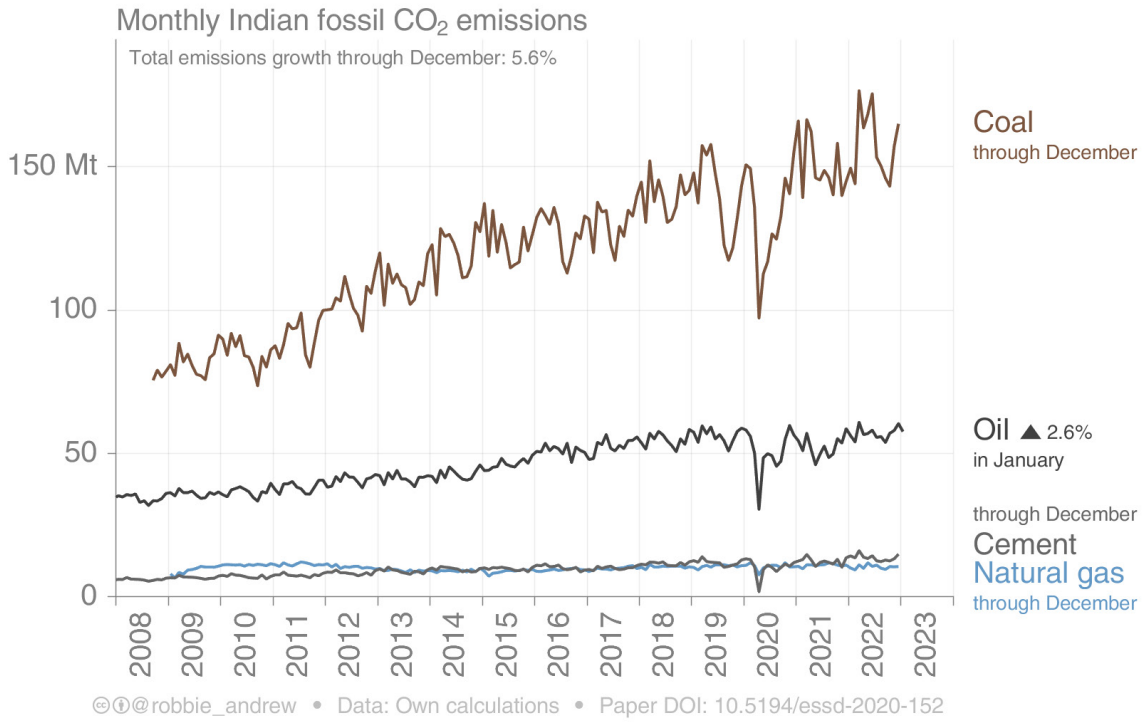
India

- India's emissions have been growing steadily, interrupted only by the pandemic
- India's economy has been growing strongly in recent years
- Particularly energy supply was very low per capita and energy access is an important part of development



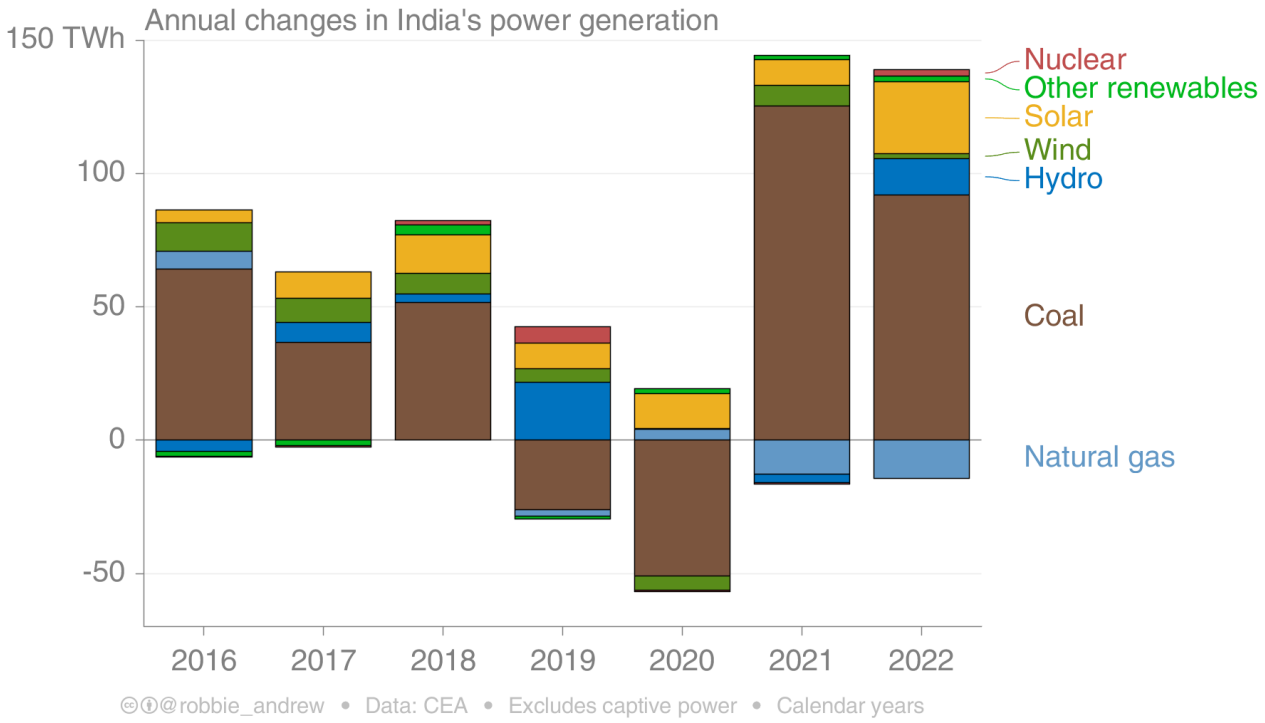
India

- Large dips across all four categories in 2020
  - Some of the strictest lockdowns in the world at the time (4 hours' notice)
- Natural gas is a small share of energy



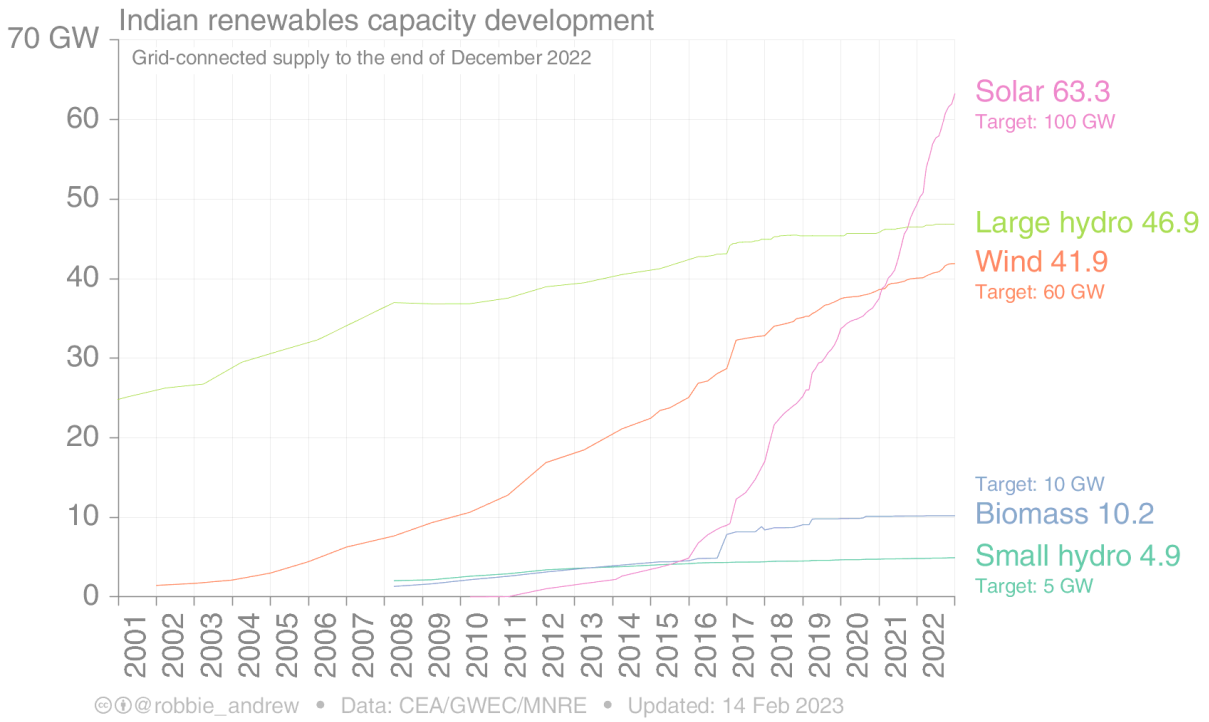
India: Power generation

- Power demand grew strongly in both 2021 and 2022
- The contribution of solar to the increase was a record 26.8 TWh
  - Capacity increased by 25% over the course of the year
  - Possibly reduced curtailment
- Hydro also grew, with a wetter-than-average monsoon
- But most of the growth was in coal
  - Up 92 TWh (8.6%) in 2022



India: Renewables capacity

- Total goal 175 GW; achieved 119 GW
- Solar capacity continued to grow strongly in 2022, gaining 14 GW (28%)
  - But fell well short of India's ambitious 100 GW target
- Wind has been growing more slowly
  - Added only 1.8 GW (4.5%)
  - And also fell short of India's 2022 target of 60 GW



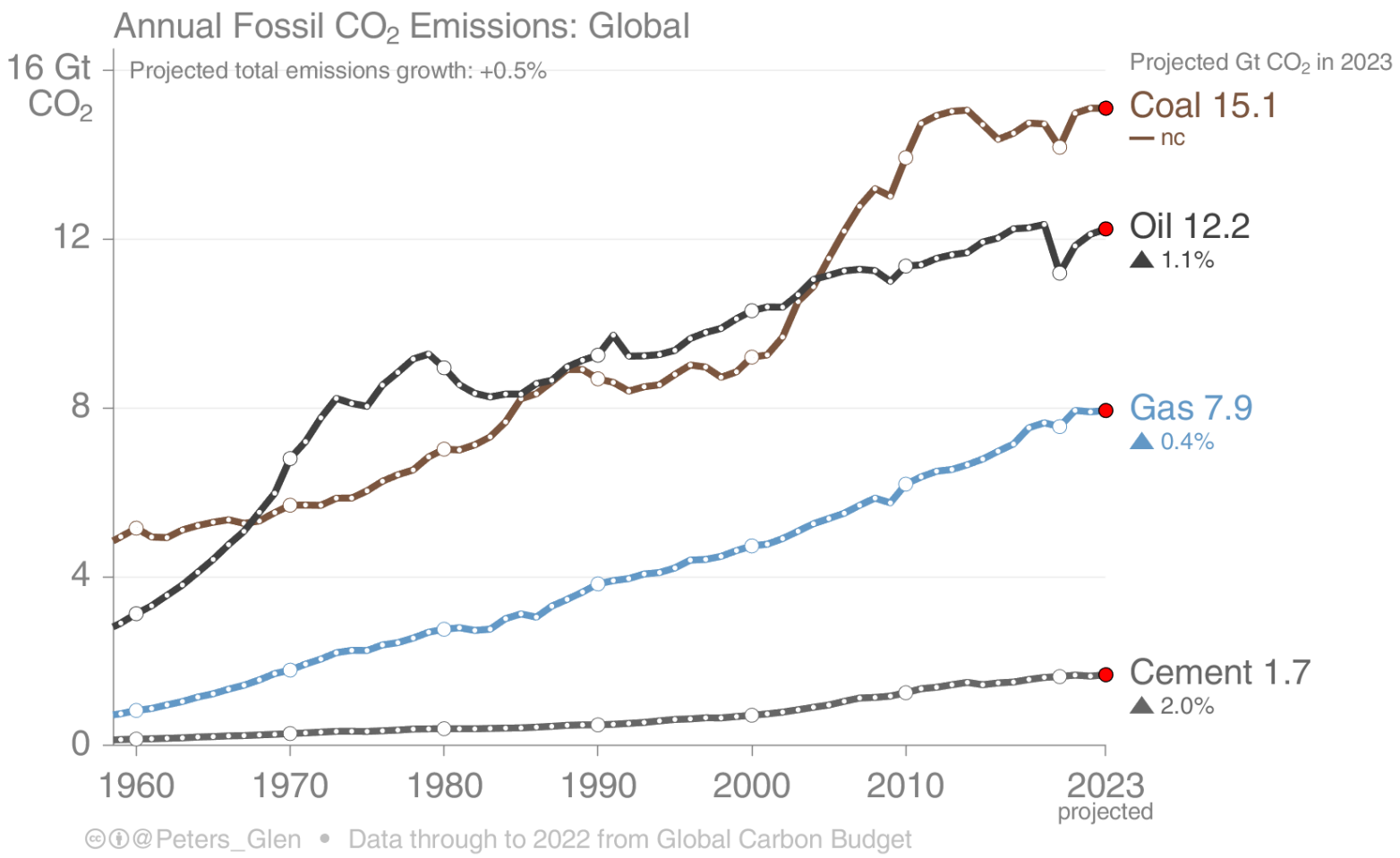
Projection for 2023

Glen Peters (CICERO)

Climate-Carbon Interactions in the Current Century

Fossil CO_2 emissions in 2023

Coal remains stable (IEA), oil grows 1.1% (EIA STEO), gas grows 0.4% (IEA), others on trend, gives growth of 0.5%
Using data on GDP growth 2.9% (IMF), CO_2/GDP trend (-2.2%), gives growth of 0.7%



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Source: Global Carbon Budget, 4C Carbon Outlook

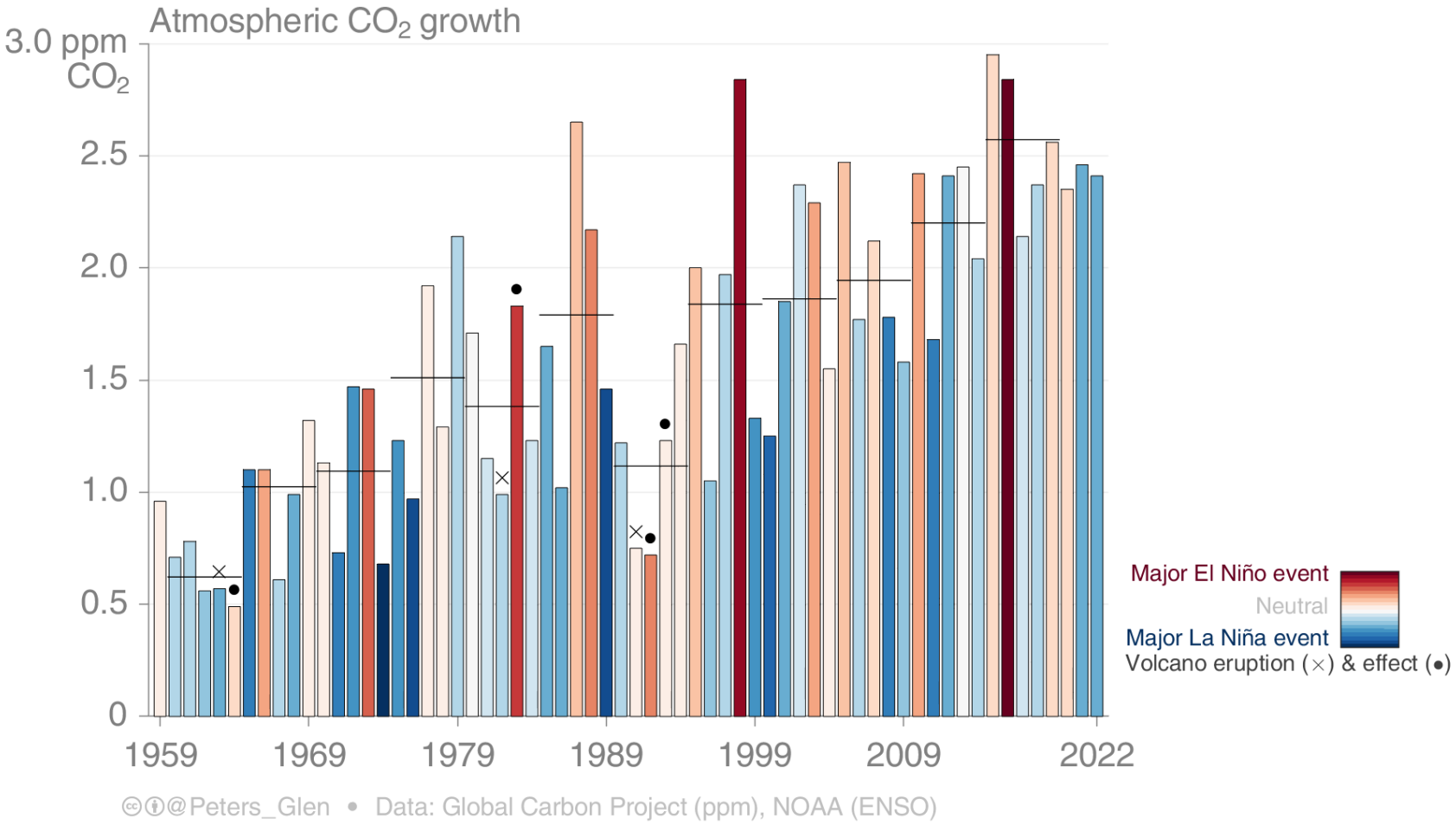
Atmospheric CO_2

Glen Peters (CICERO)

Climate-Carbon Interactions in the Current Century

Atmospheric CO_2 growth rate

Fossil CO_2 emissions trending upwards, CO_2 from land-use change declining, a slight rise in total CO_2 emissions
Atmospheric CO_2 is expected to rise at near record-high levels in 2022, despite La Niña conditions in 2021 and 2022



Major El Niño years 1997, 2015, and 2016
Source: Global Carbon Budget, 4C Carbon Outlook

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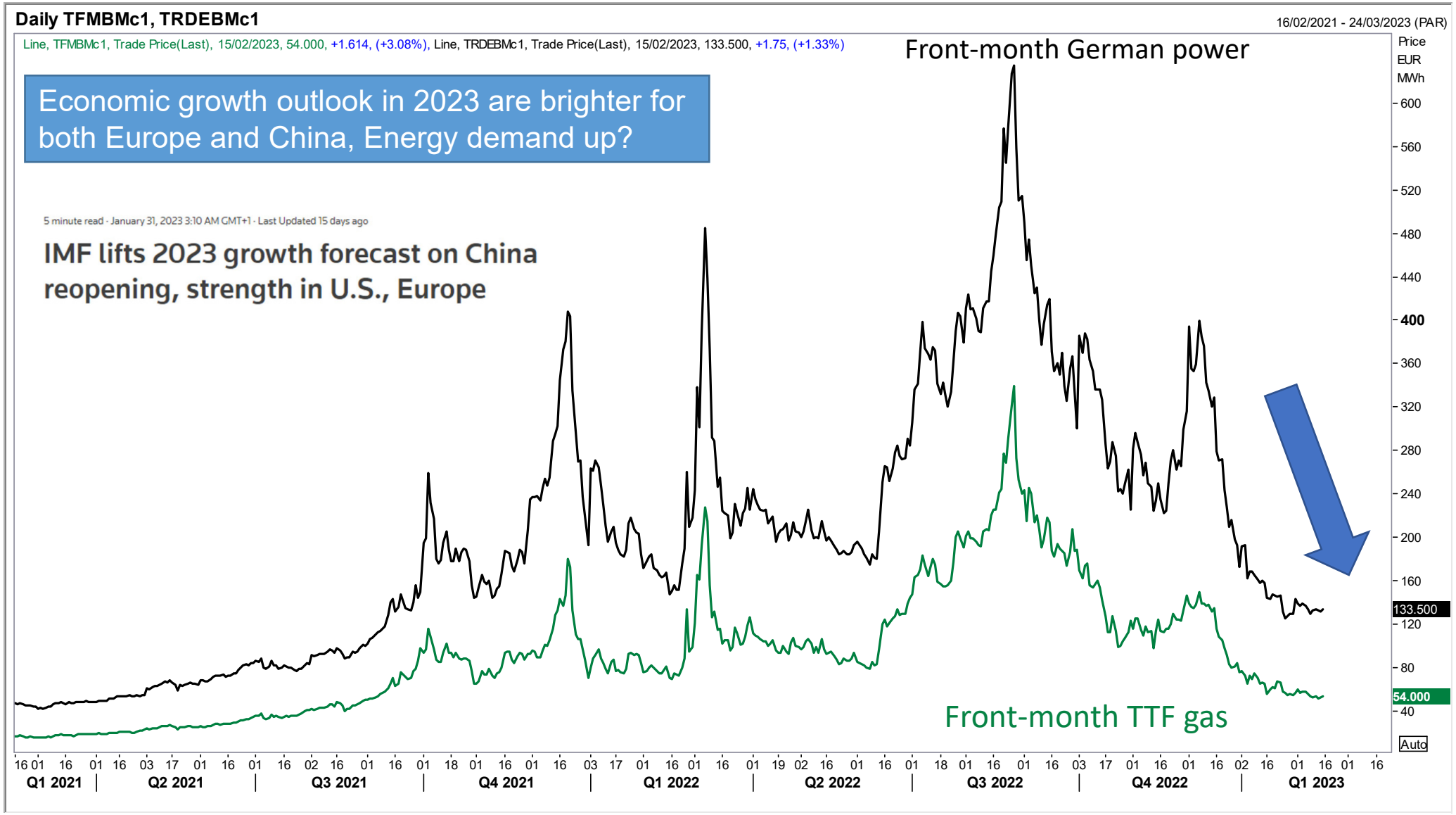
Market Perspective

Yan Qin (Refinitiv Carbon)

Climate-Carbon Interactions in the Current Century

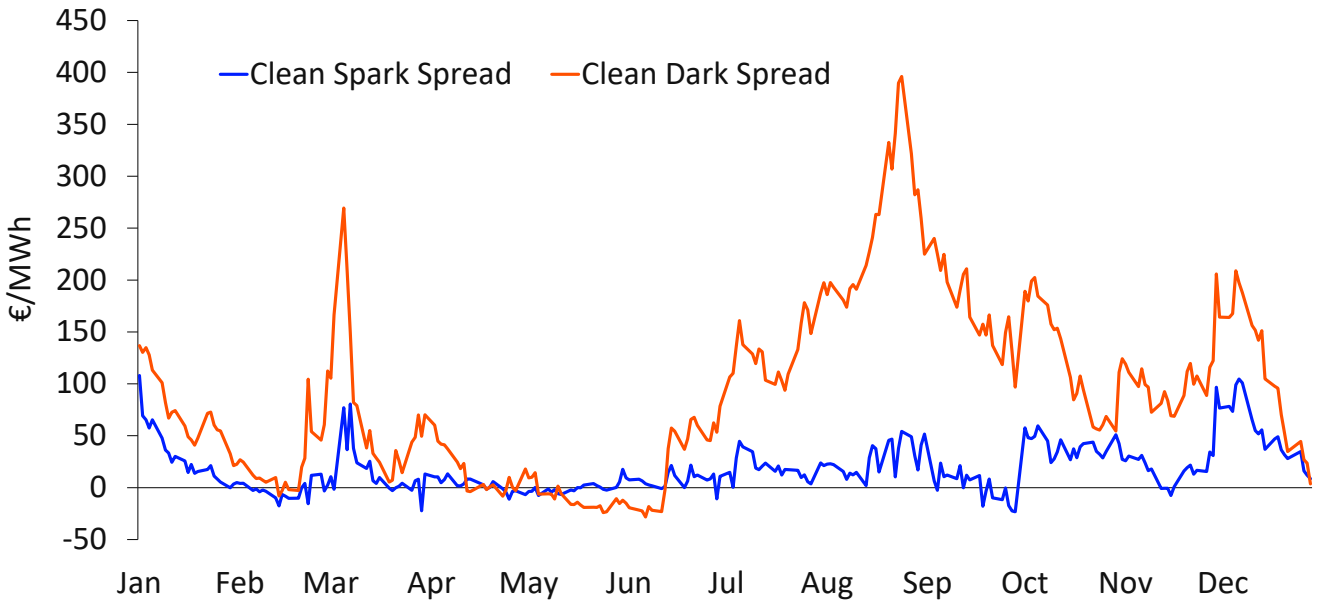
European wholesale gas and electricity prices are now back to autumn 2021 levels



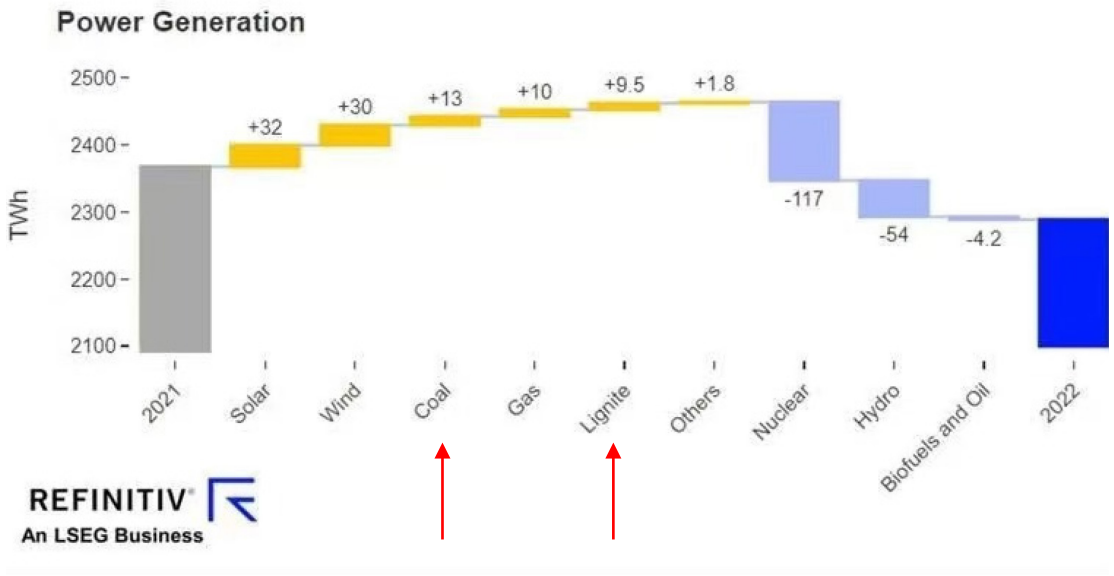
Source: Refinitiv Eikon

EU emissions in 2023: the Carbon price is (finally!) able to drive coal to gas switching

The skyrocketing gas prices in 2022 have made coal power plants consistently more competitive than gas plants in the merit order



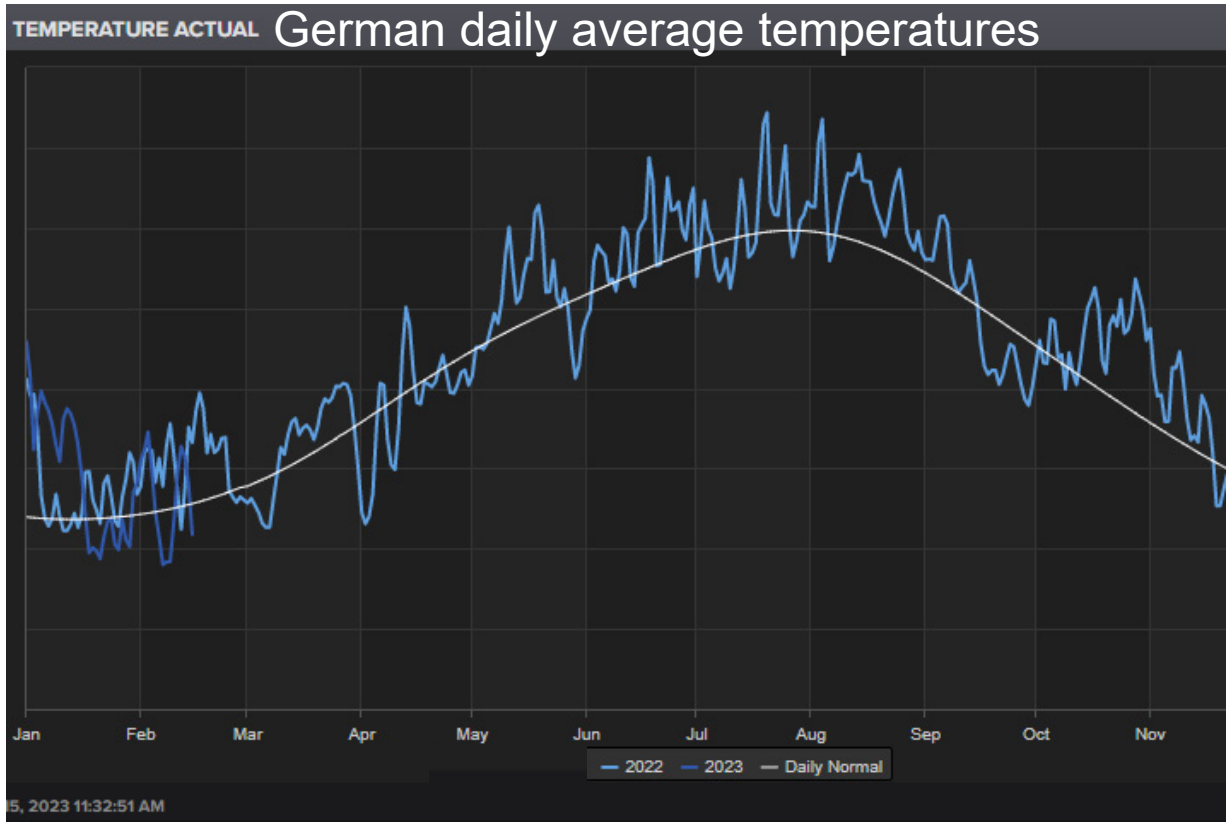
Both hard coal and lignite power generation have increased in 2022, but this temporary rebound is likely to halt in 2023

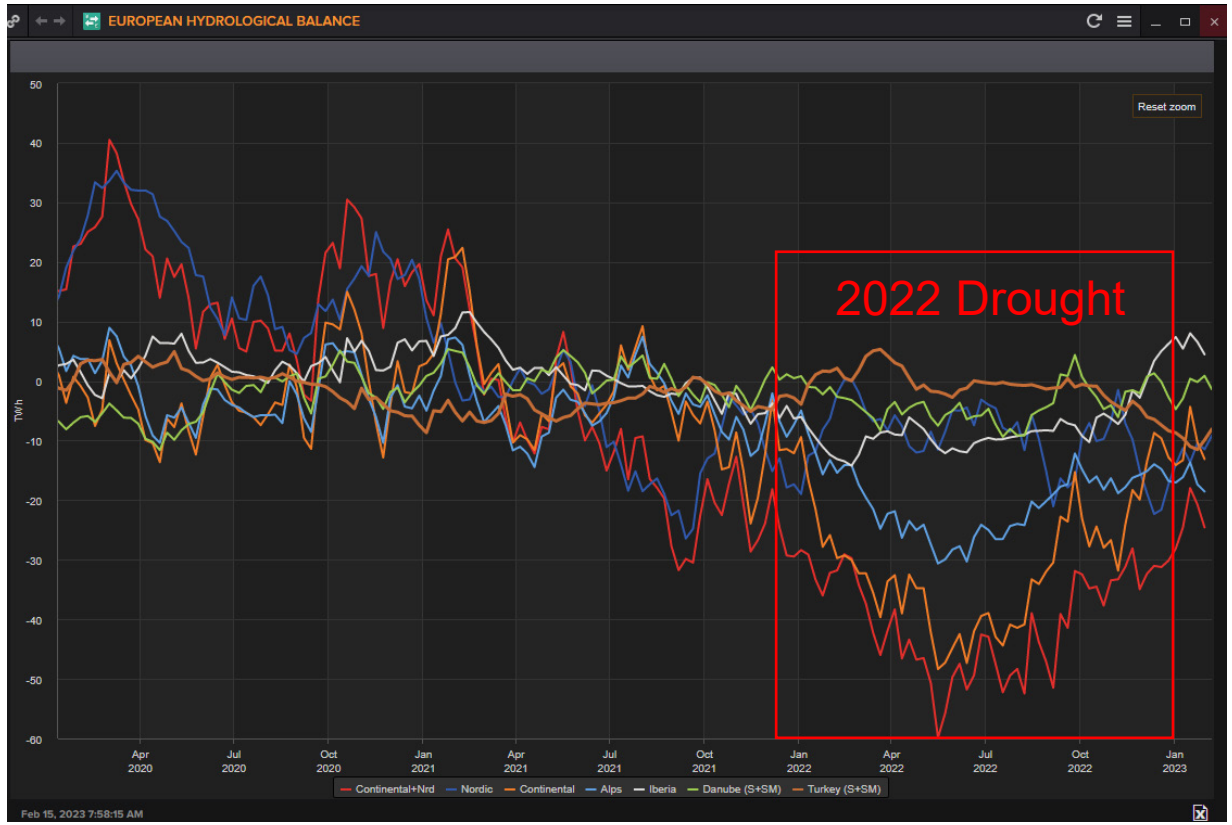


Front month spreads for 36% efficient coal and 50% efficient gas plants
Source: Refinitiv Eikon

EU power sector emissions in 2023: weather is an important factor

+ Mild winter so far, what if heatwaves in the summer?
- The recovery in hydro output will further limit fossil power generation



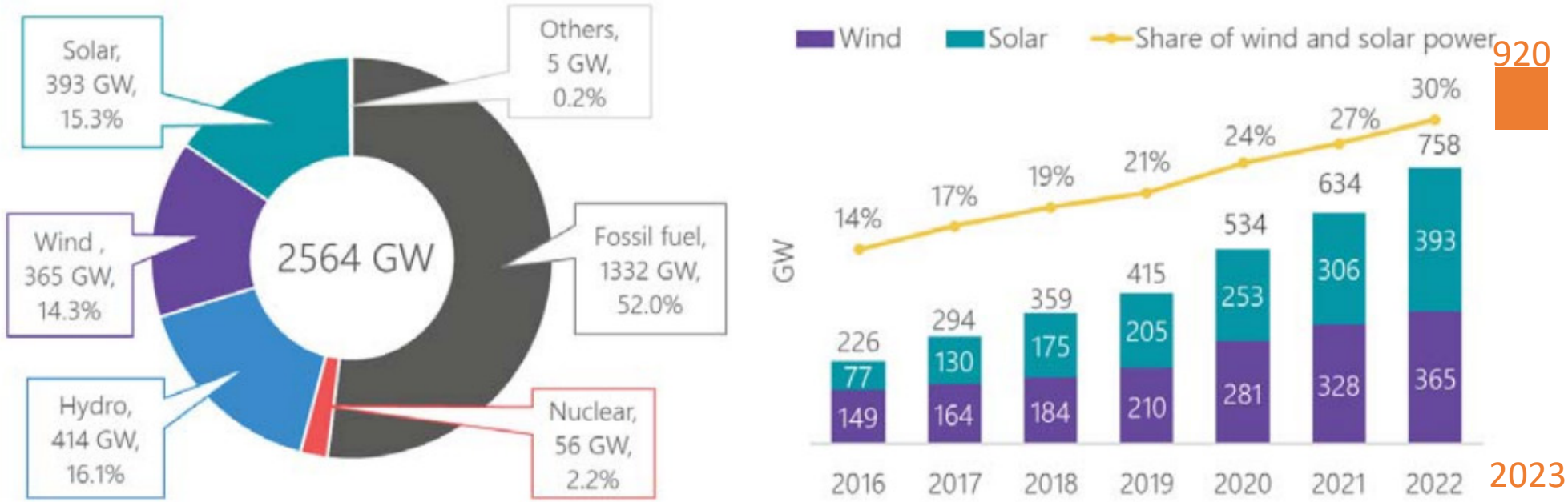


Source: Refinitiv Eikon

China: The reopening will boost energy demand, power consumption to **+5% to 6%** in 2023

Renewables buildout will continue to squeeze fossil power plants' running hours

2022 Total installed power generation capacity mix (left); 2016-2022 Total installed capacity and its proportion of wind and solar power (right)



+160 GW Wind and Solar in 2023

Improving hydro output is anther factor

Notes: Fossil fuel mainly includes coal, gas, and biomass. Source: China Electricity Council (CEC), National Energy Administration (NEA), accessed in February 2023

Source: China Energy Policy Newsletter February 2023, CET.energy

Uncertainties regarding the impacts of China's reopening

CHINA ECONOMY

China's economic recovery is off to a slow start

PUBLISHED TUE, FEB 14 2023•8:05 PM EST

Evelyn Cheng
@CHENGEVELYN

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KEY POINTS

- Preliminary economic data indicate overall growth isn't yet roaring back since mainland China ended its Covid controls in early December.
- "The mixed data send a clear message that markets should not be too bullish about growth this year," Nomura's chief China economist Ting Lu said in a report Monday.

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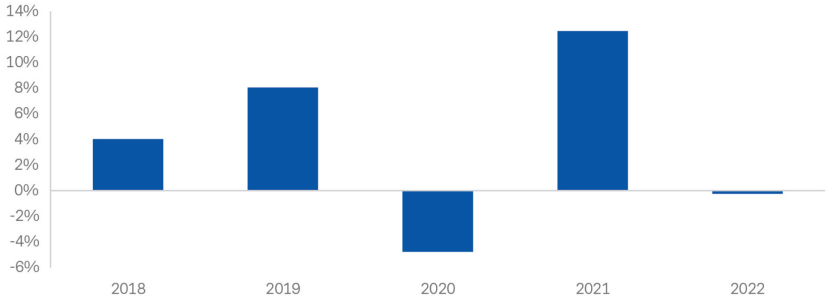
A few factors could alter the trajectory of China's recovery:

Consumer spending, Real estate

Construction site in Henan

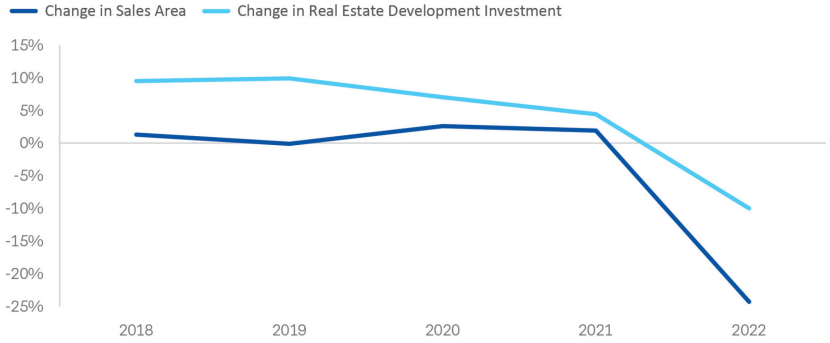
Change in Retail Sales of Consumer Goods



Source: "The total retail sales of social consumer goods," National Bureau of Statistics of China, accessed February 6, 2023, http://www.gov.cn/shuju/hgjjyxqk/xiangqing/tcg.html.

CSIS

China National Real Estate Development and Sales



Source: "National Bureau of Statistics of China Homepage," National Bureau of Statistics of China, accessed February 6, 2023, http://www.stats.gov.cn/tjsj/zxfb/202301/t20230117_1892085.html.

CSIS

https://www.csis.org/analysis/china-holds-key-global-energy-demand

WEBINAR: CARBON OUTLOOK

Thursday 16 February 2023 | 11:30-12:30 CET | Registration open

PROGRAMME

Welcome and Introduction
Ilaria Vigo, BSC | Moderator: Miriam Dahl, CICERO

Emissions in the last decade
Glen Peters, CICERO

World's top emitter: China
Jan Ivar Korsbakken, CICERO

Other top emitters: EU, US and India
Robbie Andrew, CICERO

How will emissions evolve in 2023?
Glen Peters, CICERO

The drivers of a recovery in 2023, the EU and China
Yan Qin, Refinitiv Carbon

Discussion & Questions

GLEN PETERS
SENIOR RESEARCHER
CICERO

ROBBIE ANDREW
SENIOR RESEARCHER
CICERO

JAN IVAR KORSBAKKEN
SENIOR RESEARCHER
CICERO

YAN QIN
CARBON ANALYST
RefinitivCarbon

Climate-Carbon Interactions in the Current Century

Climate-Carbon Interactions in the Current Century

Thank you!

Get in touch for more information

Public reports of the project will be available for download on the 4C website: https://4c-carbon.eu/
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Follow us on Social Media: @4C_H2020

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