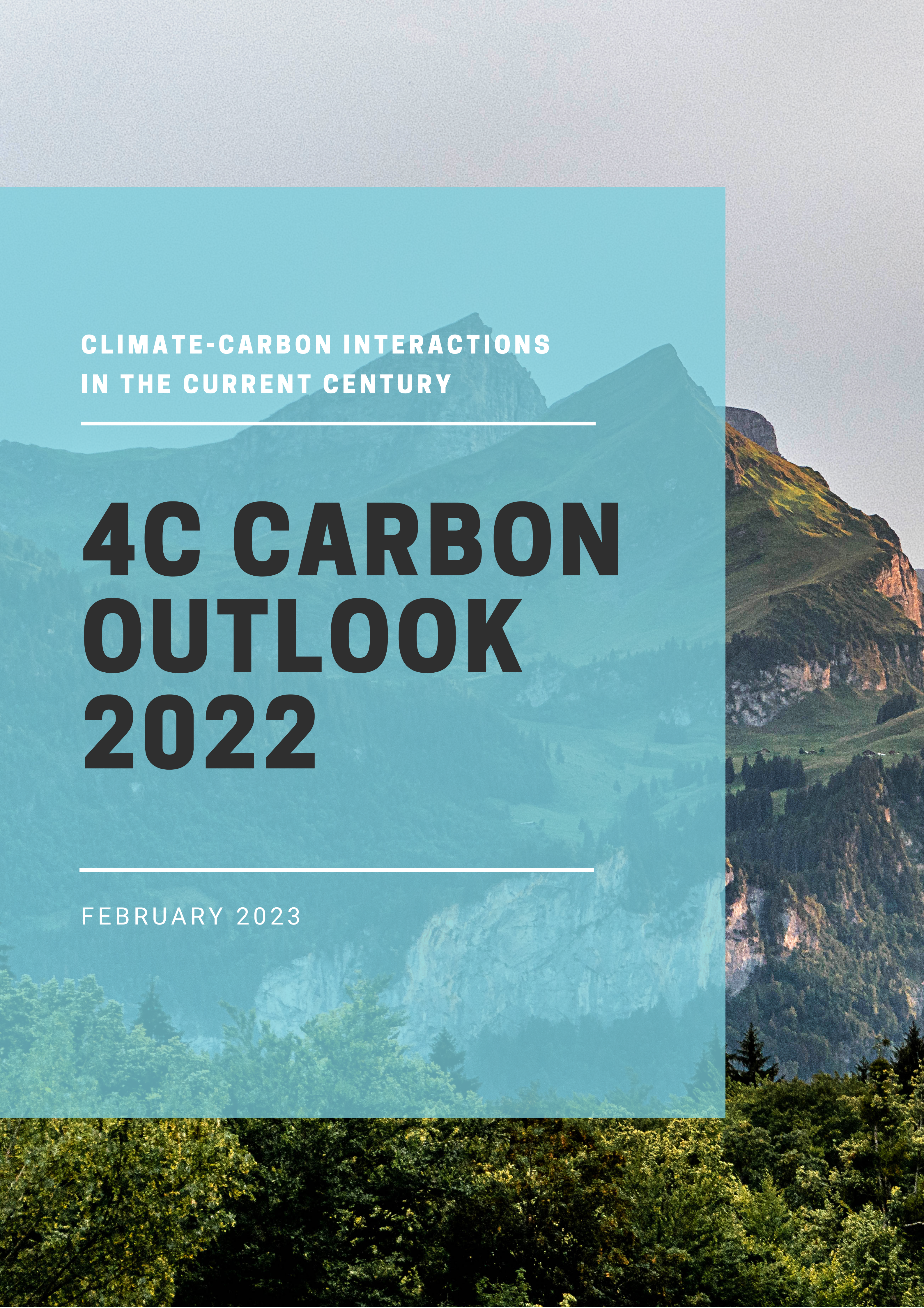

CLIMATE-CARBON INTERACTIONS
IN THE CURRENT CENTURY

4C CARBON OUTLOOK 2022

FEBRUARY 2023

- 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.

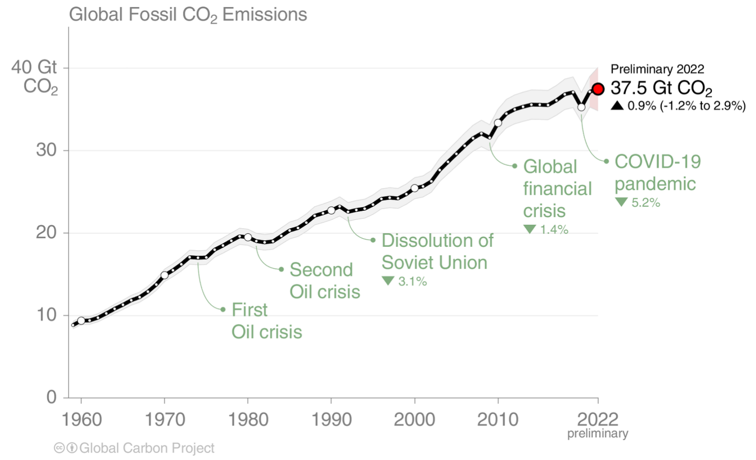

Figure 1. Fossil CO_2 emissions increased by 0.9% in 2022.

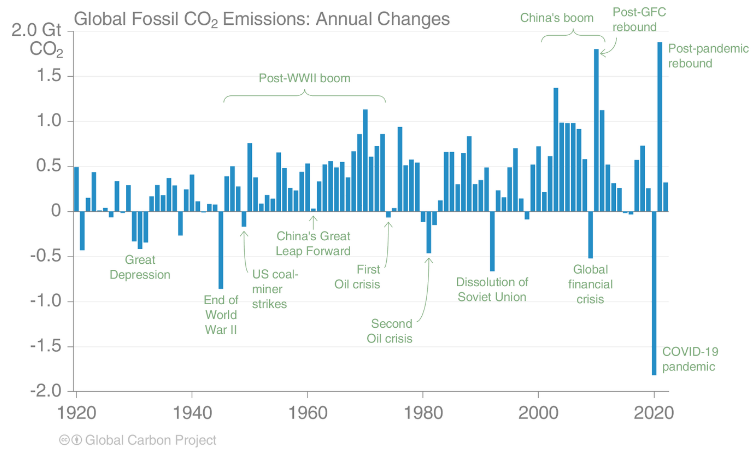

Figure 2. Annual changes in fossil CO_2 emissions, affected by global crises.

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.

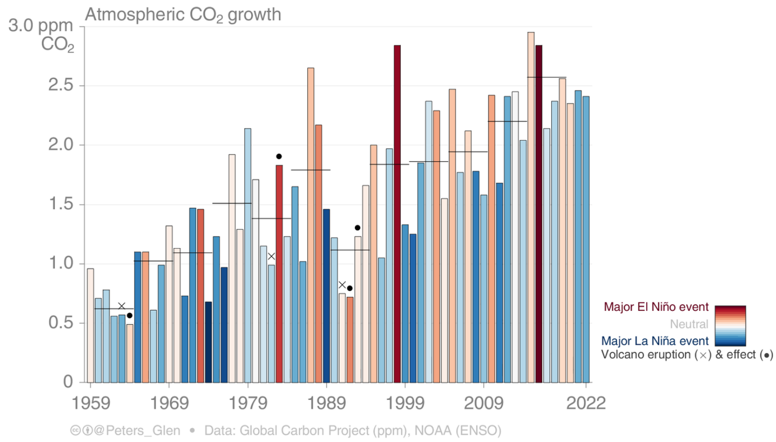

Figure 3. The atmospheric CO_2 growth (bars) with the bars coloured by the strength of the El Niño–Southern Oscillation (ENSO) index, based on NOAA Sea Surface Temperature data. The atmosphere CO_2 growth is larger in El Niño years (red) than in La Niña years (blue). Volcanic eruptions also affect the 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).

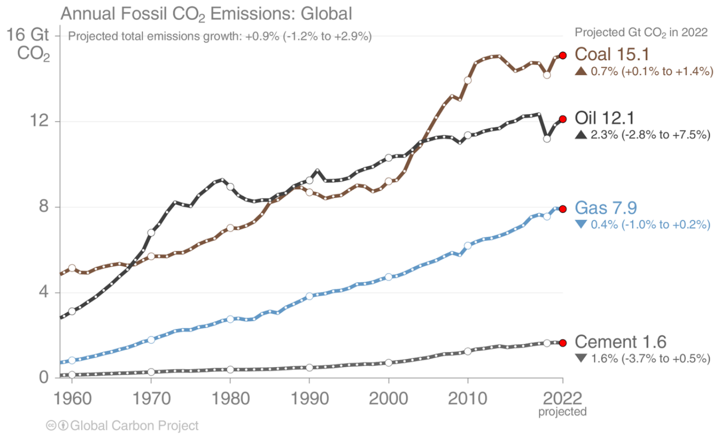

Figure 4. Contribution of different fossil fuel categories to annual CO_2 emissions. The smaller flaring and 'other' categories are not shown.

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.

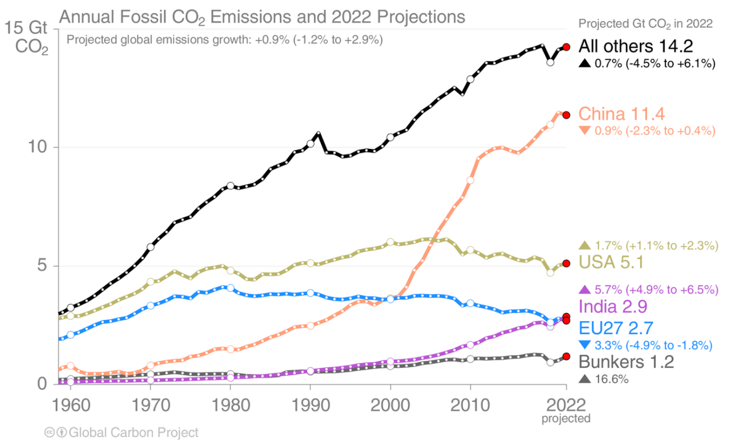

Figure 5. Annual fossil CO_2 emissions by country. Bunkers are international aviation and shipping.

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.

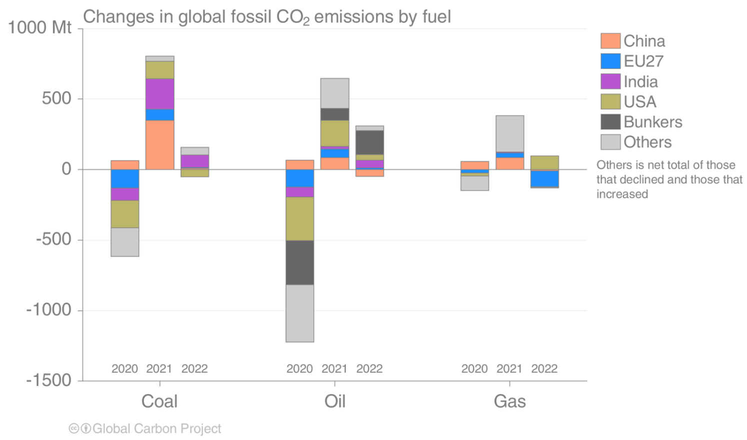

Figure 6. Country- and fuel-specific changes in CO_2 emissions in the last three years.

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).

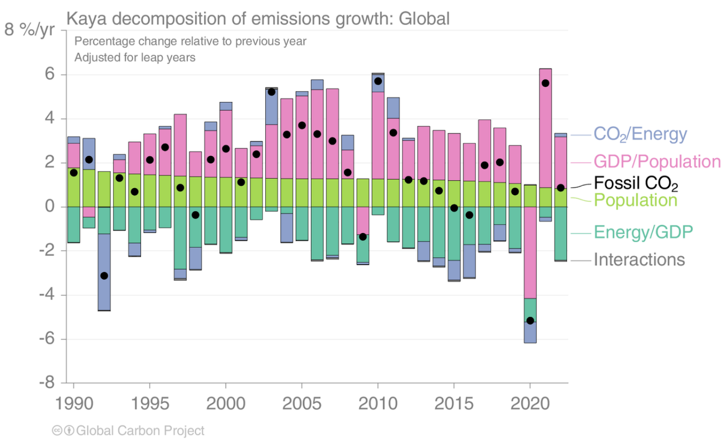

Figure 7. Kaya decomposition of emissions growth.

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

- *Friedlingstein P., et al. (2022). Global Carbon Budget 2022. Earth Syst. Sci. Data 14: 4811–4900. https://doi.org/10.5194/essd-14-4811-2022*
- *Global Carbon Project. Global Carbon Budget 2022. https://www.globalcarbonproject.org/carbonbudget/*
- *Andrew R. (2022). Figures from the Global Carbon Budget 2022. https://robbieandrew.github.io/GCB2022/*
- *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*

This project has received funding from the Horizon 2020 programme under Grant Agreement no. 821003. The content of this document reflects only the authors' view. The European Commission is not responsible for any use that may be made of the information it contains.

www.4c-carbon.eu
twitter.com/4C_H2020
4C@exeter.ac.uk