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DEPARTMENT OF MATHEMATICS

UNEARTHING THE ENVIRONMENTAL IMPACT OF HUMAN ACTIVITY : A GLOBAL C02 EMISSION ANALYSIS

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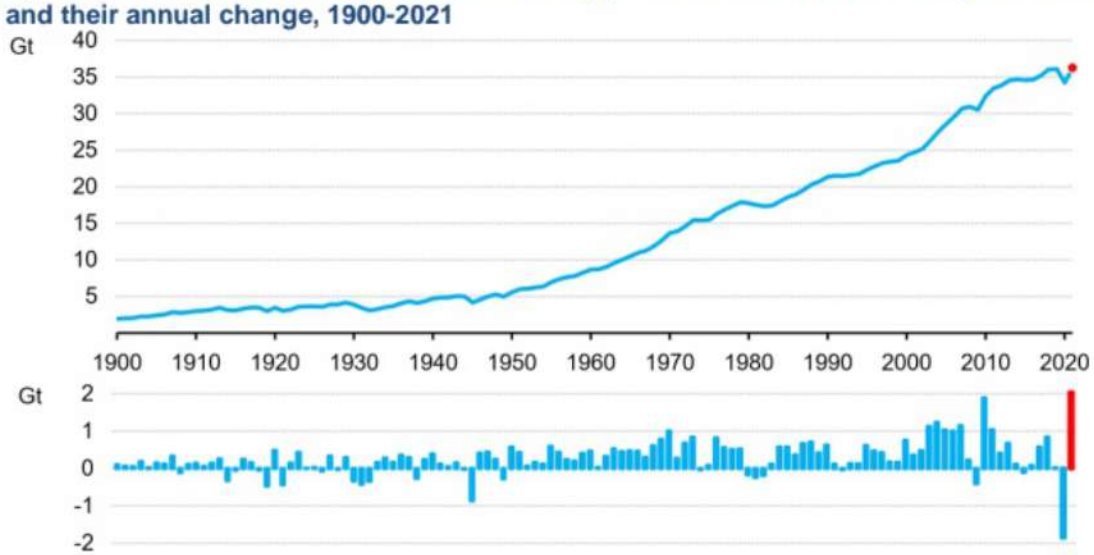
Introduction

Global CO_2 emissions from energy combustion and industrial processes [1] rebounded in 2021 to reach their highest ever annual level. A 6% increase from 2020 pushed emissions to 36.3 gigatonnes (Gt), an estimate based on the IEA's detailed region-by-region and fuel-by-fuel analysis, drawing on the latest official national data and publicly available energy, economic and weather data.

The Covid-19 pandemic had far-reaching impacts on energy demand in 2020, reducing global CO_2 emissions by 5.1%. However, the world has experienced an extremely rapid economic recovery since then, driven by unprecedented fiscal and monetary stimulus and a fast – although uneven – roll-out of vaccines. The recovery of energy demand in 2021 was compounded by adverse weather and energy market conditions, which led to more coal being burnt despite renewable power generation registering its largest ever annual growth.

Emissions increased by over 2.0 Gt from 2020 levels. This puts 2021 above 2010 as the largest ever year-on-year increase in energy-related CO_2 emissions in absolute terms. The rebound in 2021 more than reversed the pandemic-induced decline in emissions of close to 1.9 Gt experienced in 2020. CO_2 emissions in 2021 rose to around 180 megatonnes (Mt) above the pre-pandemic level of 2019.

Figure 1 Total CO2 emissions from energy combustion and industrial processes and their annual change, 1900-2021



[1]

The 6% increase in CO_2 emissions in 2021 was in line with the jump in global economic output of 5.9%. This marks the strongest coupling of CO_2 emissions with Gross domestic product (GDP) growth since 2010, when global emissions rebounded by 6.2% while economic output grew by 5.1% as the world emerged from the Global Financial Crisis.

The world has not heeded the call for a sustainable recovery from the Covid-19 crisis

With carbon-intensive growth reminiscent of 2010, the global economic recovery from the Covid-19 crisis has not been the sustainable recovery that IEA Executive Director Fatih Birol called for at the onset of the pandemic in 2020. Nonetheless, certain advanced economies have emphasised decarbonisation measures in their economic recovery. The IEA's Sustainable Recovery Tracker has shown that as of October 2021, USD 470 bilion had been earmarked for sustainable measures within recovery packages through 2030. Looking at the crucial 2021-2023 period, measures to date could mobilise around USD 400 billion a year in clean energy and sustainable recovery investment. However, this would still only represent 40% of the investment needed in the IEA's Sustainable Recovery Plan, which is aligned with a pathway towards reaching net zero emissions by 2050 globally.

Clean energy provisions in the recovery packages of several major economies have contributed somewhat to mitigating the near-term rebound in emissions, largely where low-carbon programmes were already in place and could channel the additional support quickly. However, many recovery plans have added new programmes, which are set to have greater mitigation impacts in the coming years.

The world must now ensure that the global rebound in emissions in 2021 was a one-off – and that sustainable investments combined with the accelerated deployment of clean energy technologies will reduce CO_2 emissions in 2022, keeping alive the possibility of reducing global CO_2 emissions to net zero by 2050.

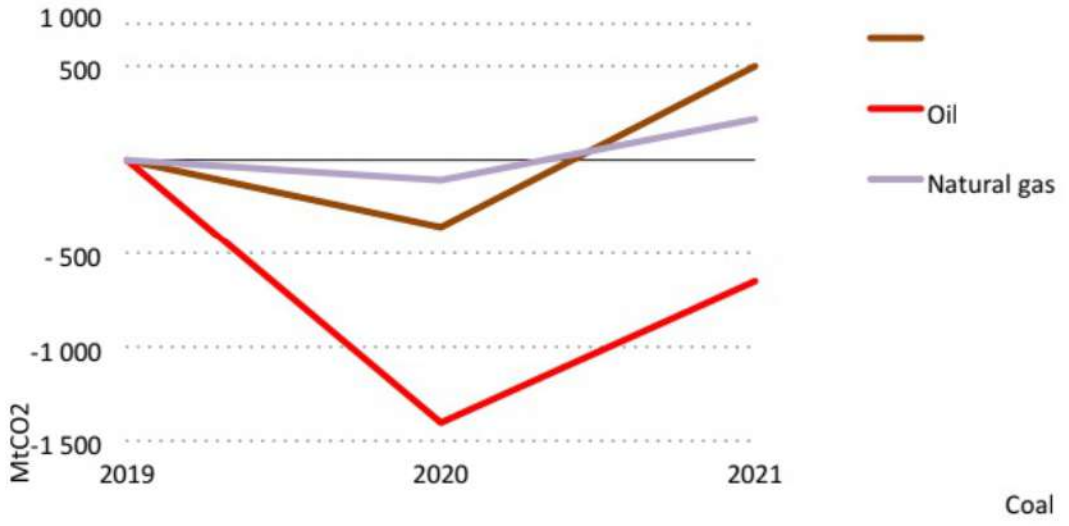
CO2 emissions from coal rise to all-time high

Coal accounted for over 40% of the overall growth in global CO_2 emissions in 2021. Coal emissions now stand at an all-time high of 15.3 Gt, surpassing their previous peak (seen in 2014) by almost 200 Mt. CO_2 emissions from natural gas also rebounded well above 2019 levels to 7.5 Gt, as demand increased in all sectors. At 10.7 Gt, emissions from oil remained significantly below pre-pandemic levels because of the limited recovery in global transport activity in 2021.

Oil demand for transport remained 8% below prepandemic levels

The pandemic continued to impact oil use for transport in 2021, with demand more than 6 million barrels per day below 2019 levels, and emissions 600 Mt lower. CO_2 emissions related to international aviation in 2021 stood at only 60% (370 Mt) of their pre-pandemic levels. Continued lockdowns and other Covid-19 transmission reduction measures in many major economies through the course of the year also stymied the recovery of road transport activity. A return to pre-pandemic levels of transport activity would have added another 600 Mt to global CO_2 emissions in 2021. That would have brought emissions from oil in line with 2019 levels. The resultant 7.8% increase in total CO_2 emissions would have been the fastest rate of growth since the 1950s.

Figure 2 Change in CO2 emissions by fossil fuel, relative to 2019 levels, 2019-2021

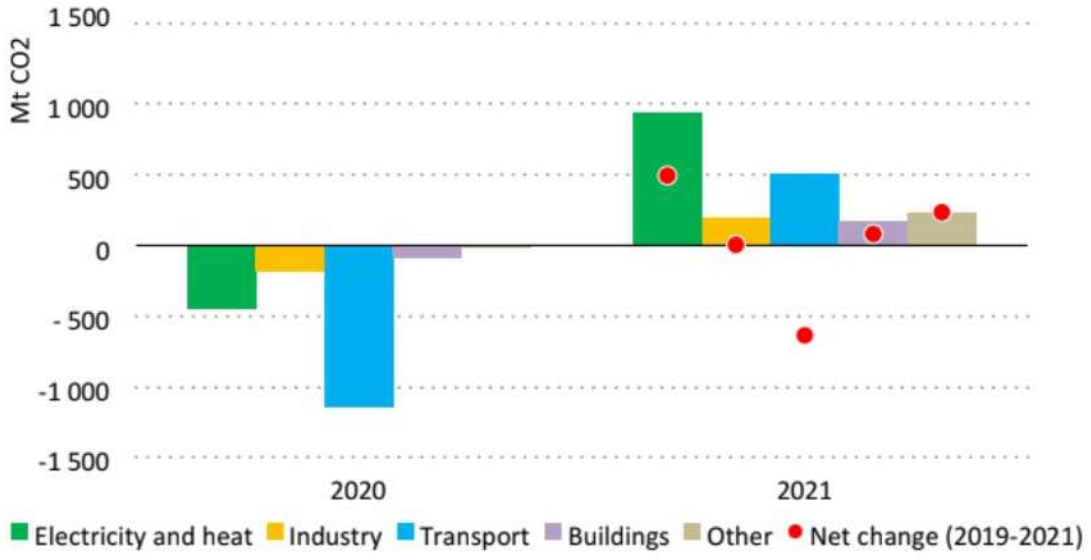


Emissions from the world's power plants reached their highest ever level

The biggest increase in CO_2 emissions by sector in 2021 took place in electricity and heat production, where they jumped by more than 900 Mt. This accounted for 46% of the global increase in emissions, since the use of all fossil fuels increased to help meet electricity demand growth. CO_2 emissions from the sector neared 14.6 Gt, their highest ever level and around 500 Mt higher than in 2019. The People's Republic of China (hereafter "China") accounted for almost all of the global increase in electricity and heat sector emissions between 2019 and 2021. A small decline from the rest of the world was insufficient to offset the increase in China.

Global CO_2 emissions from the buildings and industry sectors rebounded back to their 2019 levels, driven by increases in both advanced economies and emerging market and developing economies. China was the notable exception, with lower coal use in industry pushing CO_2 emissions from the industry sector below their 2019 level for the second year in a row. Transport was the only sector in which global CO_2 emissions remained well below 2019 levels. The emissions reduction impact of record electric car sales in 2021 was cancelled out by the parallel increase in sales of SUVs.

Figure 3 Annual change in CO2 emissions by sector, 2020-2021



The 6.9% increase in CO2 emissions from the electricity and heat sectors in 2021 was driven by the biggest ever year-on-year increase in global electricity demand. Rising by close to 1 400 terawatt-hours (TWh), or 5.9%, the growth in electricity demand in 2021 was more than 15 times the size of the drop in demand in 2020.

Coal-fired power plants were called upon to meet half of the increase in global electricity demand in 2021, with coal's share of total generation rebounding above 36%. CO_2 emissions from coal power plants rose to a record 10.5 Gt, which is 800 Mt above their 2020 level and more than 200 Mt above their previous peak in 2018. Without supply constraints and high prices that affected China and India during certain periods of the year, global coal use for electricity generation in 2021 would have been even higher.

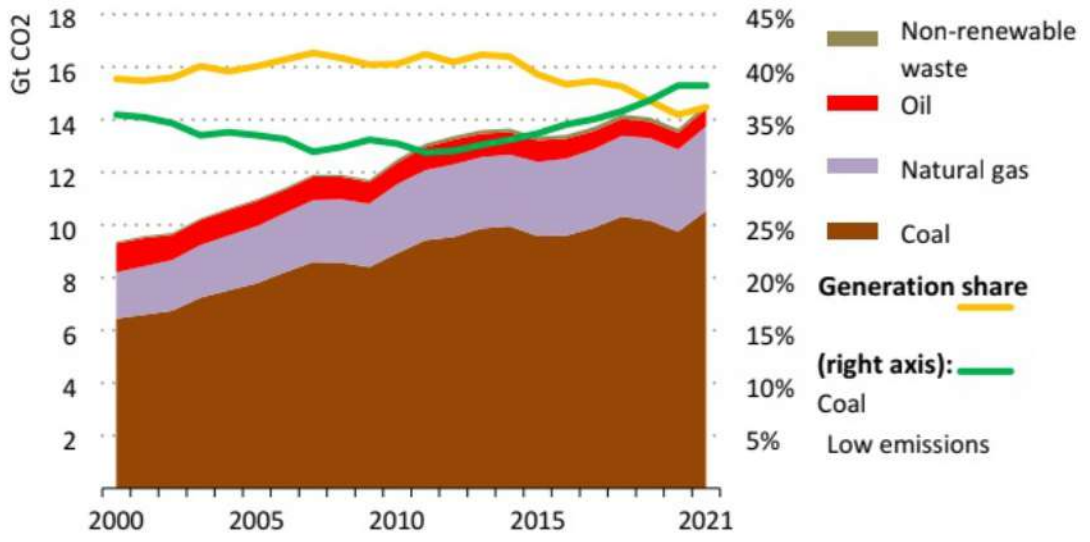
Spiking natural gas prices resulted in gas-to-coal switching, increasing emissions by over 100 Mt

The recourse to coal-fired electricity generation in 2021 was compounded by record high natural gas prices. The costs of operating existing coal plants across the United States and many European power systems were considerably cheaper than the operating costs for gas-fired power plants for the majority of 2021. Gasto-coal switching pushed up global CO_2 emissions from electricity generation by well over 100 Mt, notably in the United States and Europe where competition between gas- and coal-fired power plants is tightest. In the United States, emissions from coal-fired plants jumped by 17% in 2021 but nonetheless remained lower than in 2019. The increase was 16% in the European Union, but this was still significantly smaller than the 21% decline in 2020.

Renewable power posted its biggest ever increase in 2021

Despite the rebound in coal use, renewable energy sources and nuclear power provided a higher share of global electricity generation than coal in 2021. Renewables-based generation reached an all-time high, exceeding 8 000 TWh in 2021, a record 500 TWh above the level in 2020. Output from wind and solar PV increased by 270 TWh and 170 TWh, respectively, while hydro generation declined by 15 TWh due to the impacts of drought, notably in the United States and Brazil. Nuclear power output expanded by 100 TWh. Without increasing output from renewables and nuclear power, the rise in global CO_2 emissions in 2021 would have been 220 Mt higher.

Figure 4 **CO2 emissions from electricity and heat production by fuel, and share by fuel, 2000-2021**



The rebound of global CO2 emissions above prepandemic levels has largely been driven by China

Almost all regions posted an increase in CO_2 emissions in 2021, with the annual change ranging from growth of more than 10% in Brazil and India, to less than 1% in Japan. Emissions in China rose by 5%, while the United States and European Union both registered increases of around 7%.

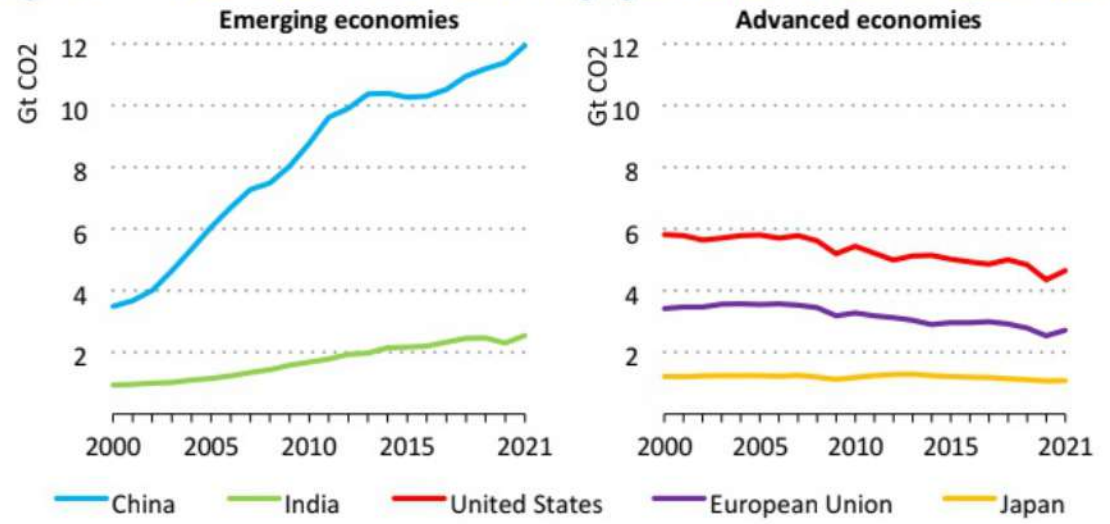
China's CO_2 emissions increased by 750 Mt over the two-year period between 2019 and 2021. China was the only major economy to experience economic growth in both 2020 and 2021. The emissions increase in China more than offset the aggregate decline in the rest of the world of 570 Mt between 2019 and 2021.

Electricity demand in China jumped by 10% in 2021, adding the equivalent of the total demand of all of Africa

The economic recovery in China appears to be particularly energy intensive. The primary energy demand intensity of China's GDP between 2019 and 2021 improved by an average of only 1% annually, compared with 1.2% between 2008 and 2010 when China enacted huge economic stimulus, and an average improvement rate of 3.7% from 2010 to 2019. China's energy intensity in 2021 was impacted primarily by evolutions in the electricity sector. With rapid GDP growth and additional electrification of energy services, electricity demand in China grew by 10% in 2021, faster than economic growth at 8.4%. The increase in demand of almost 700 TWh was the largest ever experienced in China. With demand growth outstripping the increase of low emissions supply, coal was called on to fill 56% of the rise in electricity demand. This was despite the country also seeing its largest ever increase in renewable power output in 2021. Electricity generation from renewables in China neared 2 500 TWh in 2021, accounting for 28% of total generation in the country.

CO_2 emissions in India rebounded strongly in 2021 to rise 80 Mt above 2019 levels, led by growth in coal use for electricity generation. Coal-fired generation reached an all-time high in India, jumping 13% above the level in 2020 when coal generation had declined by 3.7%. This was in part because the growth of renewables slowed to one-third of its average rate of the previous five years.

Figure 5 **CO2 emissions in selected emerging and advanced economies, 2000-2021**



Global economic output in advanced economies recovered to pre-pandemic levels in 2021, but CO_2 emissions rebounded less sharply, signalling a more permanent trajectory of structural decline. CO_2 emissions in the United States in 2021 were 4% below their 2019 level. In the European Union, they were 2.4% lower. In Japan, emissions dropped by 3.7% in 2020 and rebounded by less than 1% in 2021. Across advanced economies overall, structural changes such as increased uptake of renewables, electrification and energy efficiency improvements avoided an additional 100 Mt of CO_2 emissions in 2021 compared with 2020.

Per capita CO2 emissions in China now exceed the average in advanced economies

On a per capita basis, CO_2 emissions in advanced economies have fallen to 8.2 tonnes on average and are now below the average of 8.4 tonnes in China. However, the overall average for advanced economies masks significant differences: per capita emissions average 14 tonnes in the United States, 6 tonnes in the European Union, and 3.2 tonnes in Mexico.

Figure 6 **CO2 emissions per capita by region, 2000-2021**

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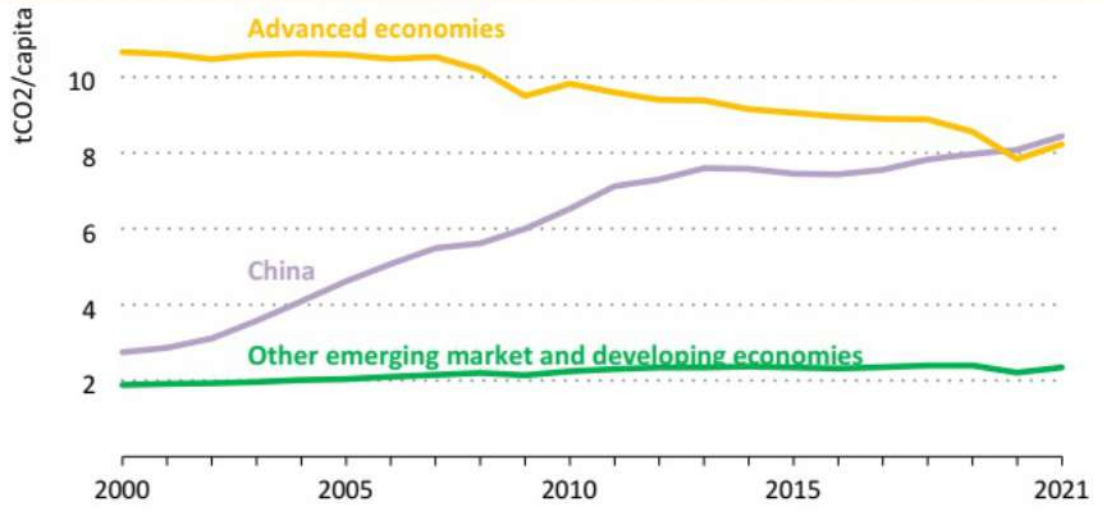
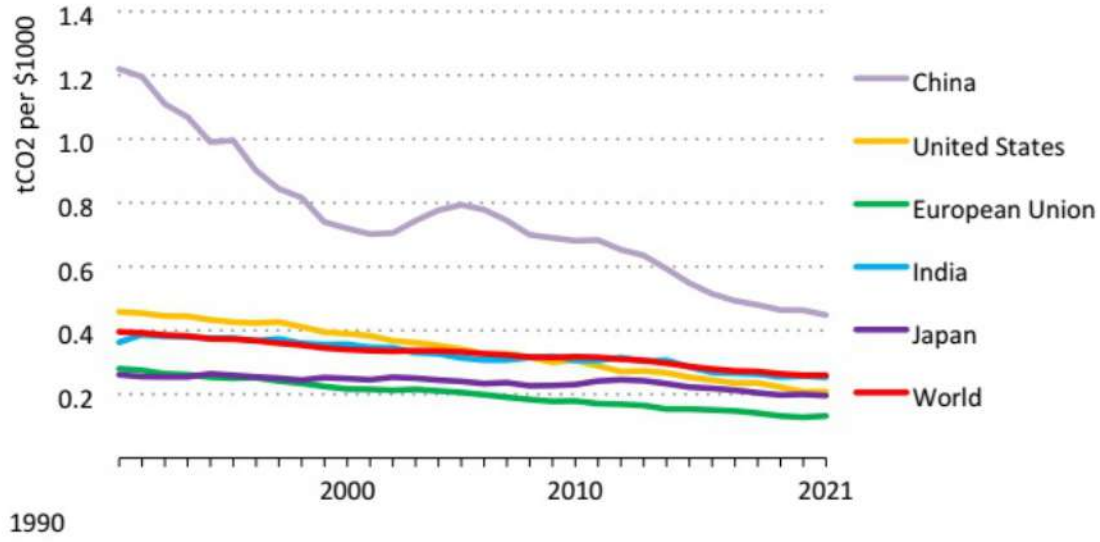


With both global CO_2 emissions and GDP rising by around 6% in 2021, the average emissions intensity of global economic output stayed constant at 0.26 tonnes of CO_2 per USD 1 000. The emissions intensity of GDP declined in China, falling by more than 3% to 0.45 tonnes of CO_2 per USD 1 000 of GDP. China nonetheless has the highest emissions intensity of GDP among major economies. This is a result of the dominant role of coal in China's energy mix (60% compared with the global average of 27%) and the high share of industry in China's GDP (39% compared with the global average of 30%). The emissions intensity of China's GDP has nonetheless declined by 40% since the year 2000.

In advanced economies, the emissions intensity of GDP ticked up slightly in 2021 but nonetheless remained on a declining trend. The United States and the European Union have averaged an annual improvement rate of around 3% since 2010.

Figure 7 CO2 emissions intensity of GDP, 1990-2021

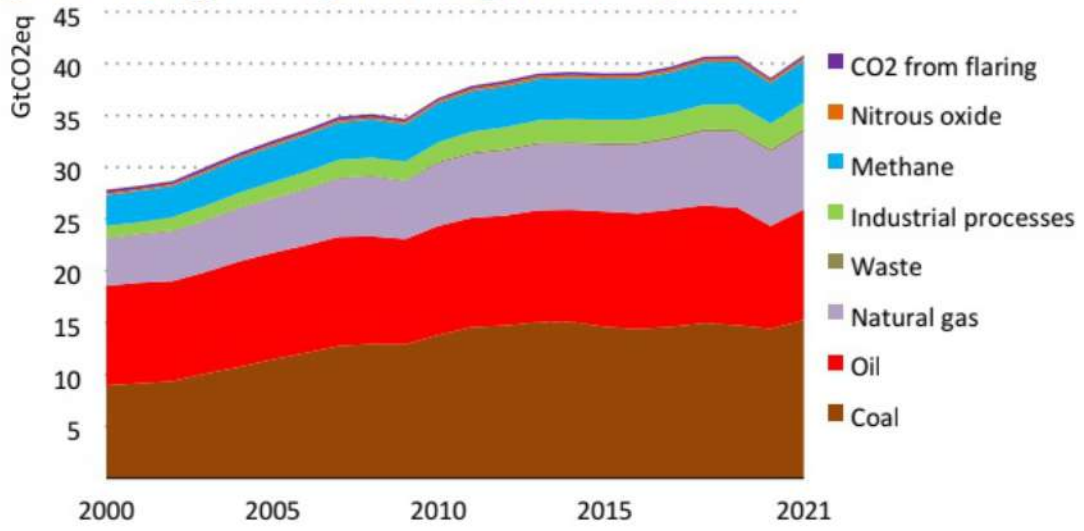


The jump in fossil fuel use pushes greenhouse gas emissions to a new peak

The rise in energy-related CO_2 emissions pushed overall greenhouse gas emissions from energy to their highest ever level in 2021. Total greenhouse gas emissions reached 40.8 Gt of CO_2 equivalent (CO_2eq) in 2021 when using a 100year global warming potential time horizon (see "Data sources and method" for GWP values), surpassing the previous all-time high in 2019. CO_2 emissions from energy combustion and industrial process accounted for close to 89% of energy sector greenhouse gas emissions in 2021. CO_2 emissions from gas flaring accounted for another 0.7%. Beyond CO_2, fugitive and combustion-related methane emissions represented almost 10% of the total, and combustion-related emissions of nitrous oxide 0.7%.

Methane emissions from the energy sector rose by just under 5% in 2021 but remain below their 2019 level.

Figure 8 Energy-related greenhouse gas emissions, 2000-2021



Data sources and method

The IEA draws upon a wide range of respected statistical sources to construct estimates of energy demand, CO_2 emissions and other energy-related greenhouse gas emissions for the year 2021. Sources include the latest monthly data submissions to the IEA Energy Data Centre (including November and December 2021, when available), real-time data from power system operators across the world, other statistical releases from national administrations, and recent market data from the IEA Market Report series that covers coal, oil, natural gas, renewables, electricity and energy efficiency. Where data are not available on an annual or monthly basis, estimates may be used.

CO_2 emissions include emissions from all uses of fossil fuels for energy purposes, including emissions from the combustion of non-renewable waste. The scope of emissions covered in this year's *Global Energy Review* has been expanded to also include CO_2 emissions from industrial processes such as cement, iron and steel, and chemicals production. Estimates of industrial process emissions draw upon the latest statistical data on clinker production for cement and steel production, and relevant chemicals data. CO_2 emissions from the combustion of flared gases are also included for the first time.

Non-CO_2 greenhouse gas emissions included within the scope of the *Global Energy Review* for the first time this year include fugitive methane emissions from oil, gas and coal supply. Methane and nitrous oxide emissions related to energy combustion are also evaluated, based on typical emissions factors for given

Enduces and regions. When converting non – Co_2 green house gas emission to Co_2

CONCLUSION:

It is clear from the material presented in this report that the modern rise in the air's CO_2 content is providing a tremendous economic benefit to global crop production. As Sylvan Wittwer, the father of agricultural research on this topic, so eloquently put it nearly two decades ago:

"The rising level of atmospheric CO_2 could be the one global natural resource that is progressively increasing food production and total biological output, in a world of otherwise diminishing natural resources of land, water, energy, minerals, and fertilizer. It is a means of inadvertently increasing the productivity of farming systems and other photosynthetically active ecosystems. The effects know no boundaries and both developing and developed countries are, and will be, sharing equally," for "the rising level of atmospheric CO_2 is a universally free premium, gaining in magnitude with time, on which we all can reckon for the foreseeable future" .

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