The Reality of Climate Change

Linden Energy

A Linden Company – November 2021

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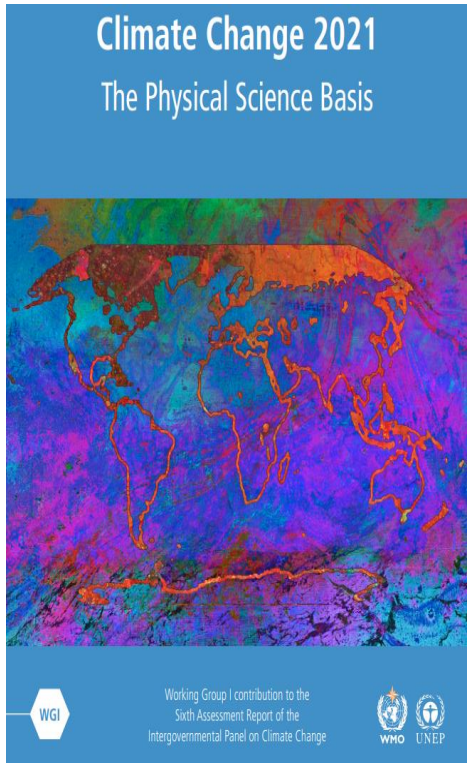
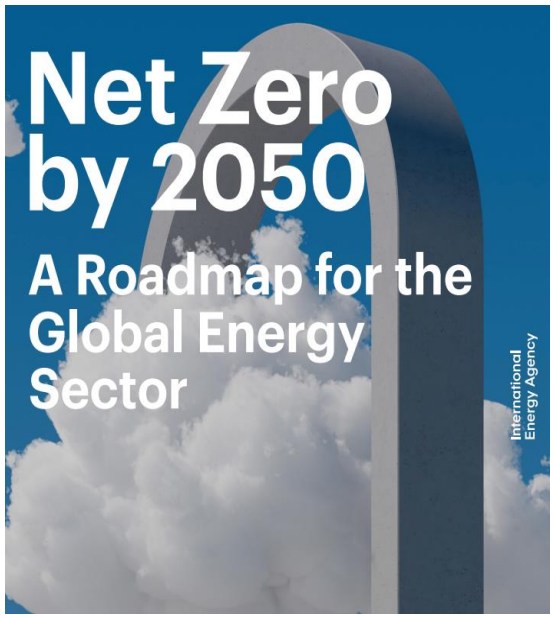
The 2021 publication of the IPCC report and the IEA report on road to “net zero” place the world and the energy industry at a crossroads



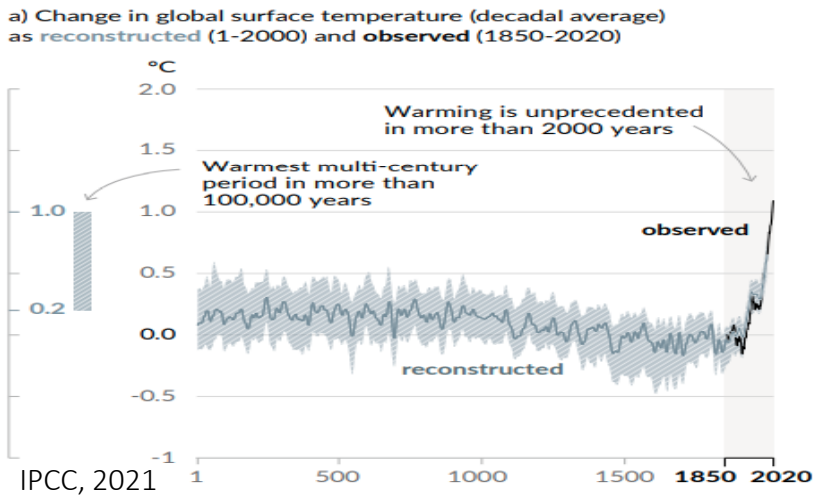
- The 2021 IPCC report delivered a clear message; the world will reach 1.5 deg C temperature within 10 years and likely 2 degree C increase by 2050. **However, what we do in the coming decades will have a major impact on what happens after that point.**
- The International Energy Agency (IEA) issued a report on how the world could reach “net zero” CO2 emissions by 2050. The steps needed are extremely unlikely to be taken in the coming decade.
- Concurrently, the IEA issued a report on the shortage of critical minerals. The required increase in mineral production for renewables in transportation and power will not be able to take place under existing technology.
- With the assistance of massive economic stimulus, the world has recovered from the Covid-related 2020 downturn. However, underinvestment in fossil fuels has caused an energy shortage and renewables are unable to full the gap resulting in price rise.

The Role of Critical Minerals in Clean Energy Transitions

INTERNATIONAL ENERGY AGENCY

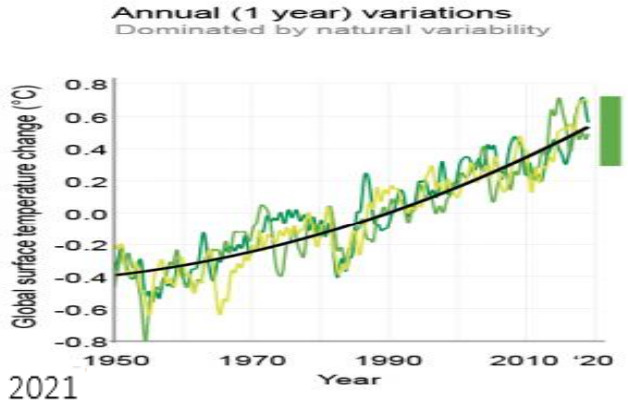


Many factors have contributed to temperature change



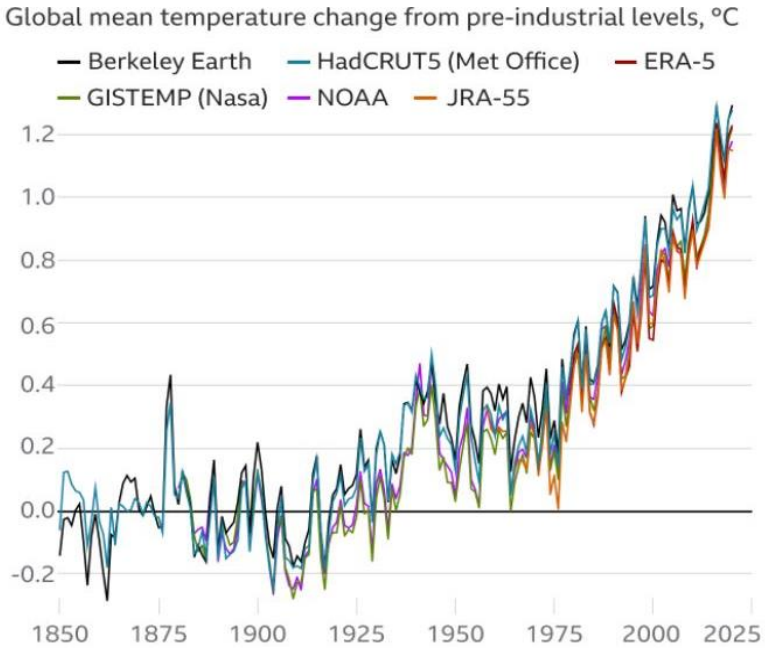
IPCC, 2021

What has happened since 1980 is not within the bounds of natural variability in recorded history



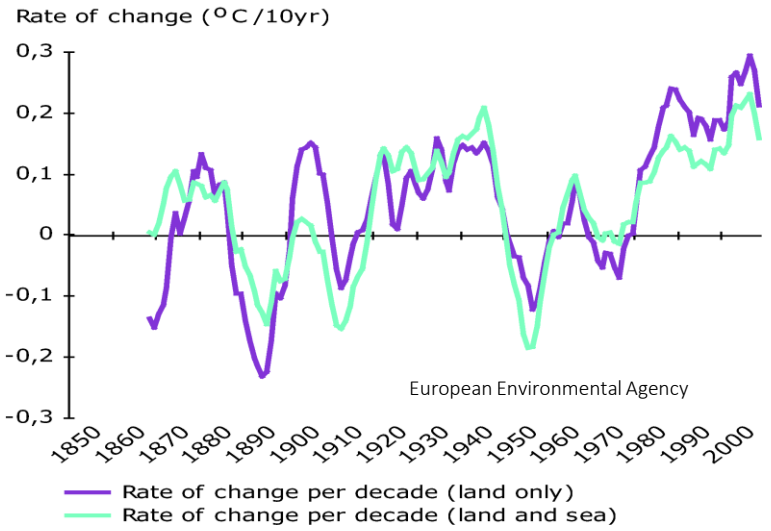
IPCC, 2021

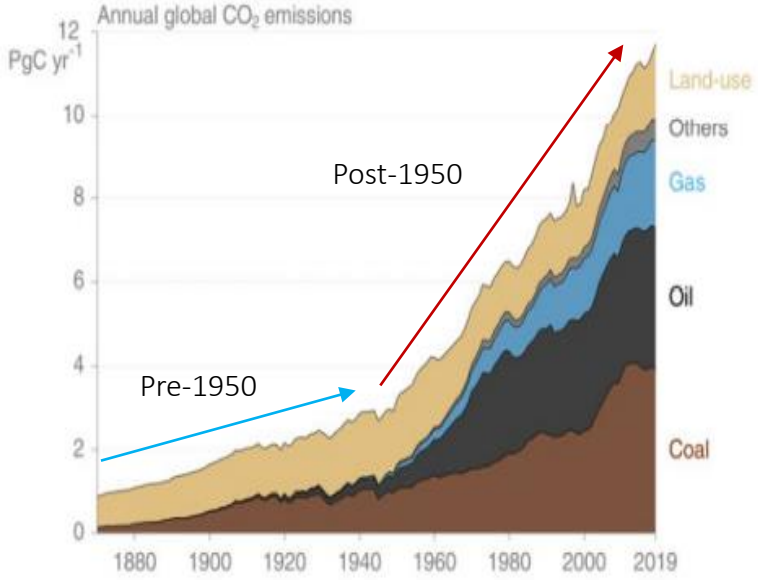
Year to year variability can be +/- 0.3 deg. C based on solar radiation, ocean currents, volcanic eruptions



- Temperature rise of about 0.4 deg C from 1910-1950, flat to 1980 and 0.8 deg increase since 1980
- Rate of change avg 0.2 deg C since 1980
- CO2 emissions gradual increase until about 1950, then accelerating increase to present

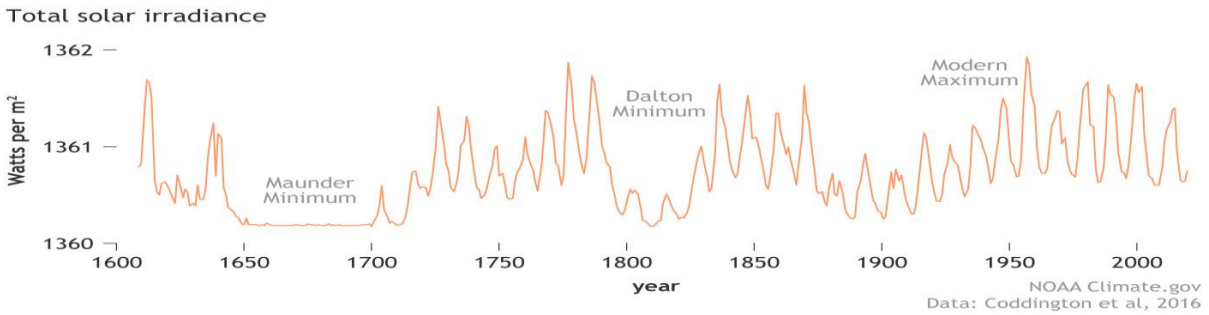
Clearly, CO2 emissions are not only factor in temperature rise



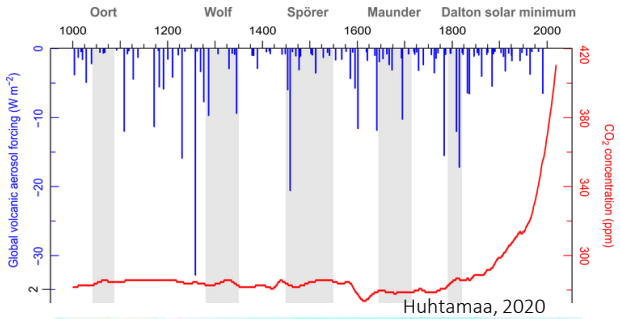


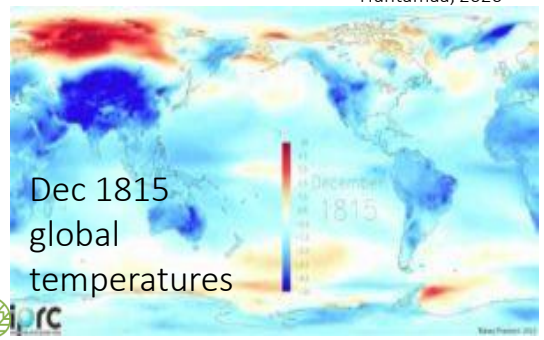
IPCC, 2021

How significant are natural causes in temperature variation?

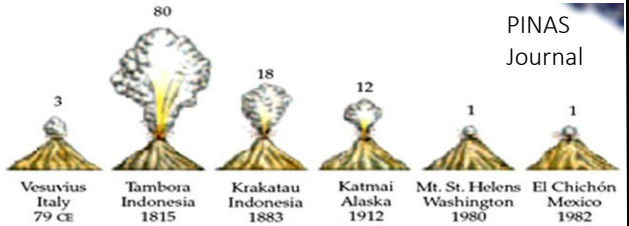


Solar radiation varies by about 0.13%, enough to make a significant difference. The Maunder Minimum or Little Ice Age dropped temperatures by about 0.5 deg over a 70-year period, and the Dalton Minimum reduced by 0.4 deg over a 20-year period. The strengthening cycles from 1900-1960 caused a 0.4 deg. increase. The 0.8 deg increase since 1980 is not connected with solar activity.

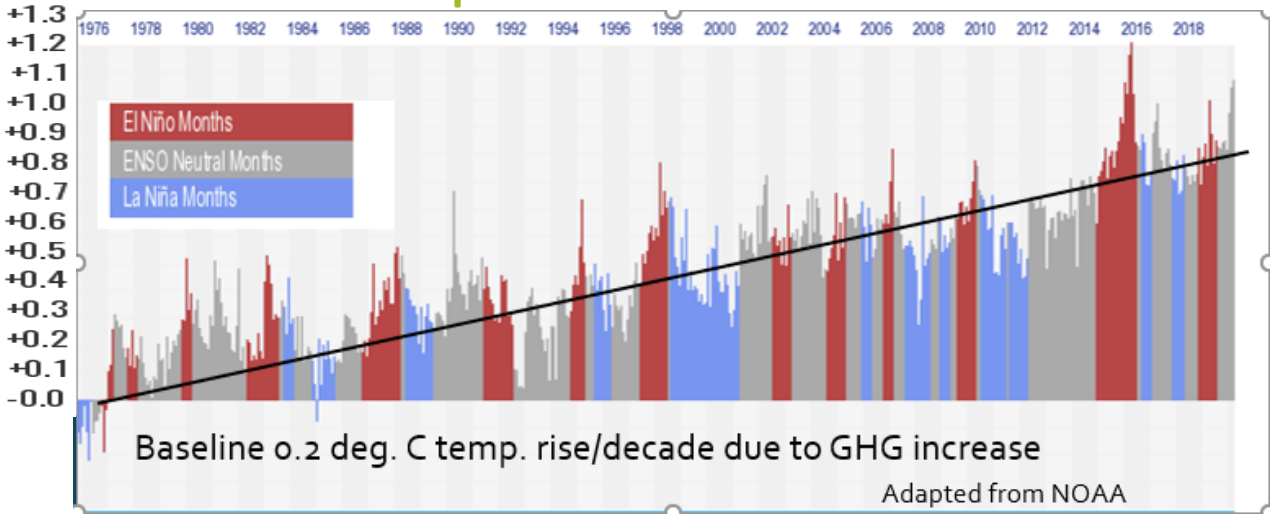




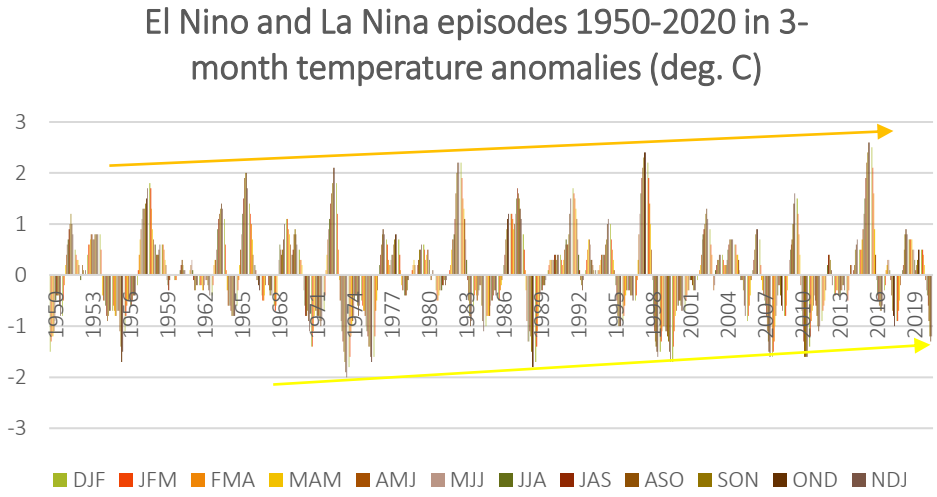
Severe volcanic events can have significant short lived (<1-3 years) reduction of temperatures



On April 5th, 1815, the world experienced the largest eruption in 600 years. It reduced global temperatures by between 0.4–0.7 °C. (0.7–1.3 °F) 1816 was known as "The Year Without a Summer".

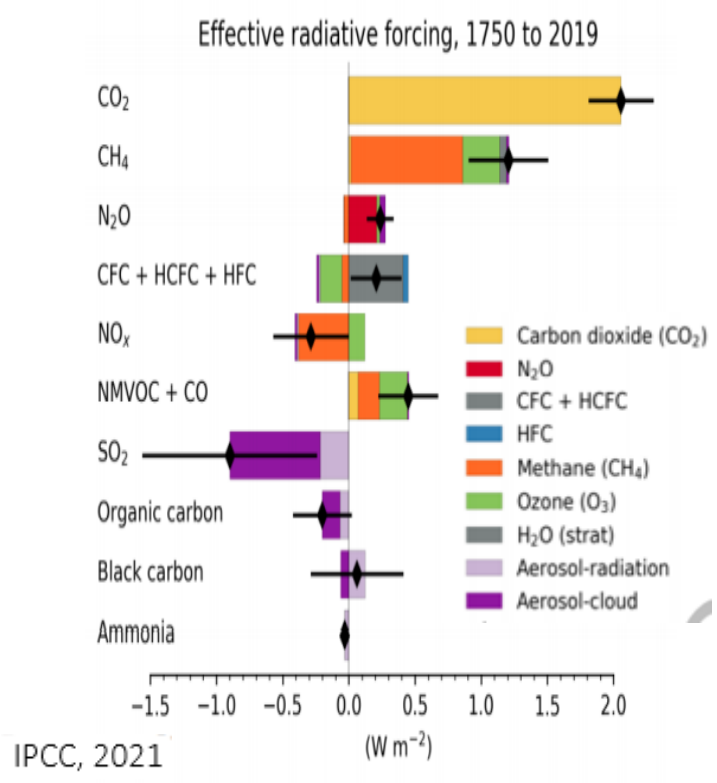


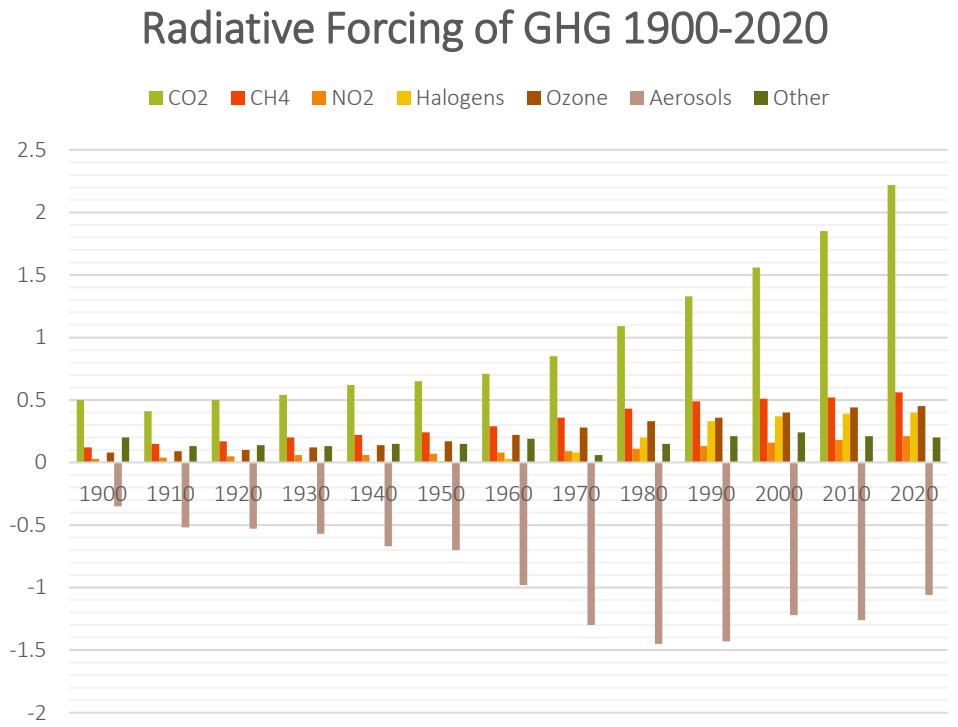
El Nino and La Nina occur at irregular periods and varying strengths. El Nino ads approximately +.15 deg C global temperature per 1 deg. C strength while La Nina subtracts the same amount.

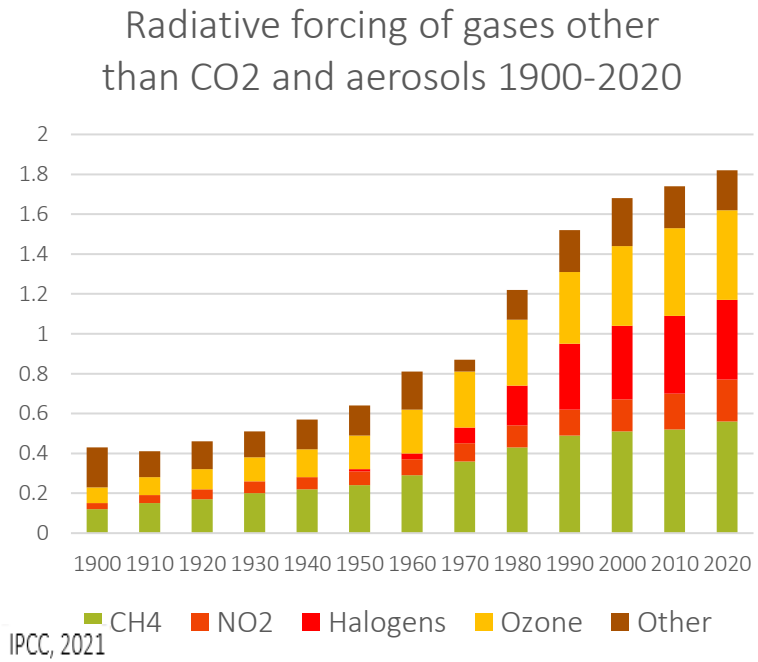


With the warming oceans, the El Nino's are getting stronger. The 3 strongest ever recorded were in 1981/2, 1998/9 and 2015/6

Greenhouse gases and the Atmosphere: It's not just about CO2





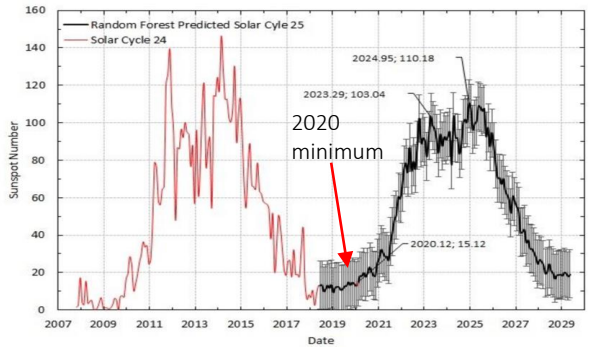


Radiative forcing (RF) is the change in energy flux in the atmosphere due to natural or human caused climate change in watts/meter. 1750-2109 is +2.72

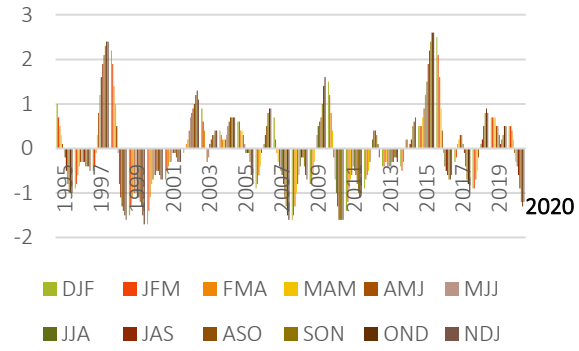
- The two most important factors have been the addition of CO2 in the atmosphere (+) mostly due to combustion of fossil fuels and aerosol pollution (-) from the same process
- From 1900-1990, these two factors largely cancelled each other out
- Increase in other GHG's increase 250% from 1950-1990
- After 1990, pollution (aerosol emission) dropped in Europe and USA replaced in part by pollution in Asia

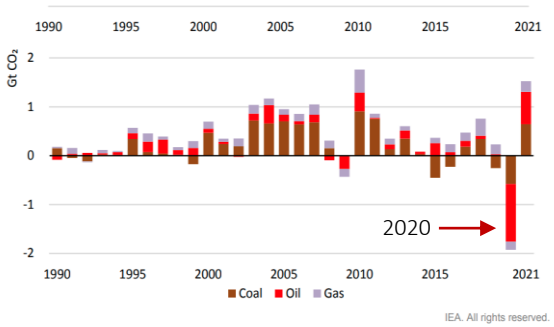
- Cumulatively, these gases can have an effect almost equal to CO2
- Methane (CH4) is most potent but can dissolve in atmosphere within 9 years
- Halogen and ozone levels have flattened and could be reduced
- "Other" includes black carbon from fires, high level pollution from airplanes, land use and natural variations (solar, volcanic)

2020 demonstrated the effect aerosols (or lack of) have on temperatures

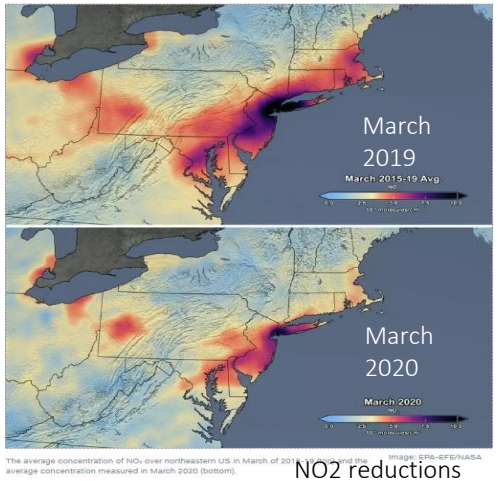


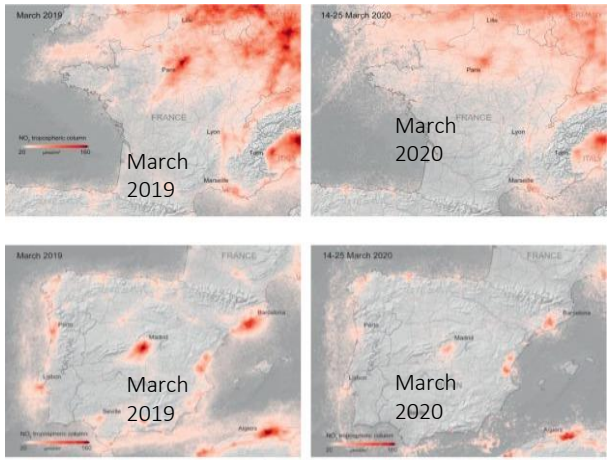
ENSO: El Nino and La Nino 3-month avg. 1995-2020



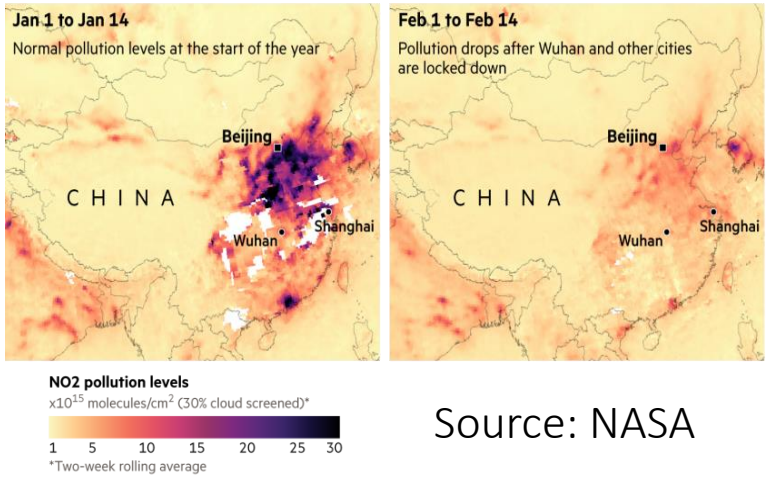


2020 should have been a cool year: solar minimum, la Nina and reduced CO2 emissions!



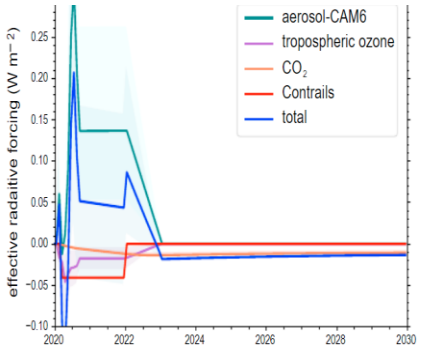


NO2 reductions



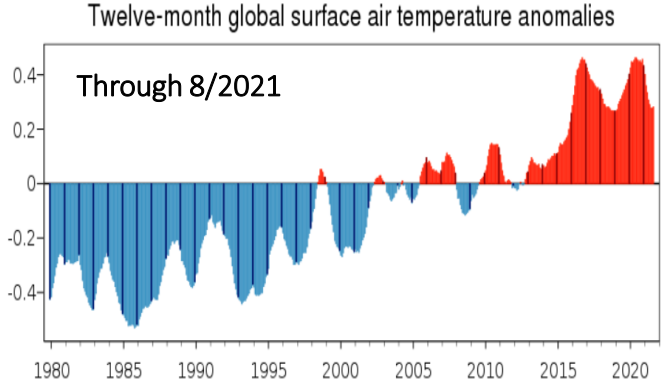
Source: NASA

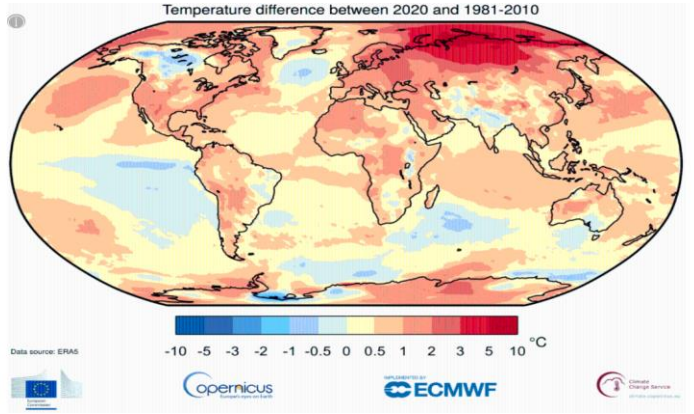
However, lockdowns during 1H 2020 significantly reduced pollution worldwide



NCAR, Gettelman et al, 2021

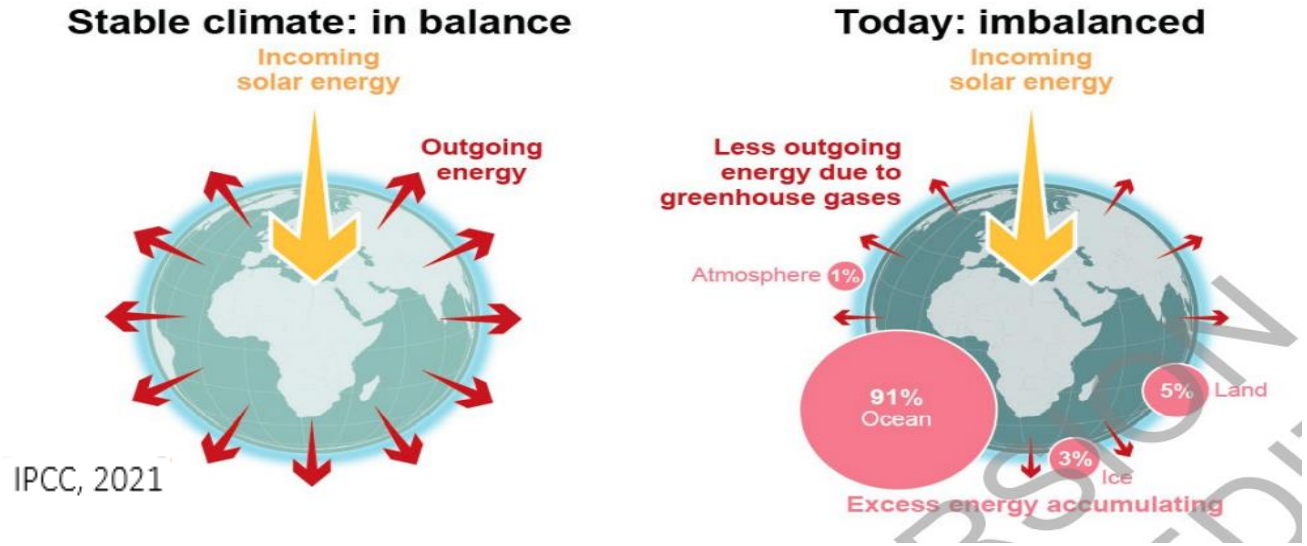
Reduction of aerosols greatly increased RF. Estimated +.3 deg C

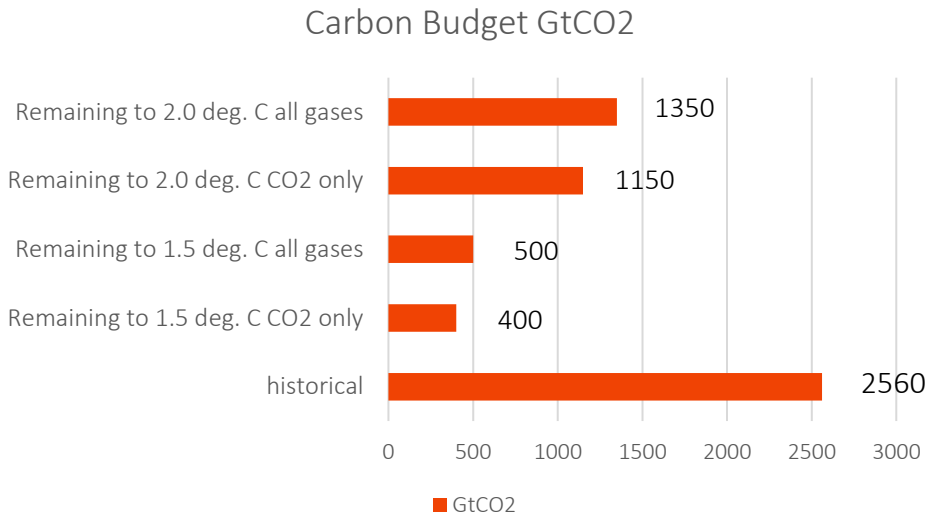


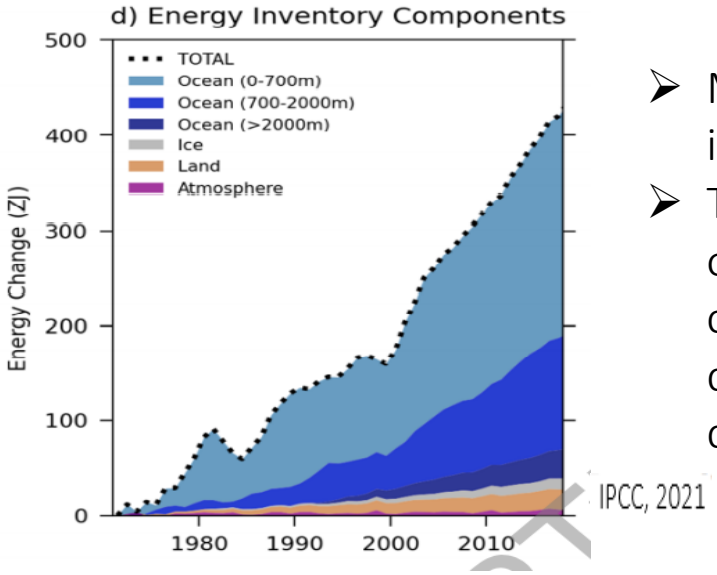


Global temperatures in 2020 tied 2016 as warmest year recorded. Temperatures in 2021 (without lockdowns) are lower.

With a positive radiative flux, how has the earth absorbed the excess energy?

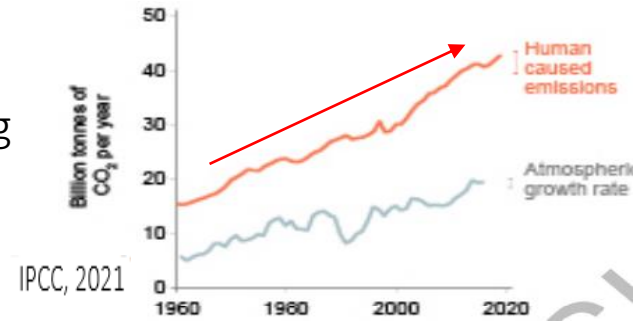






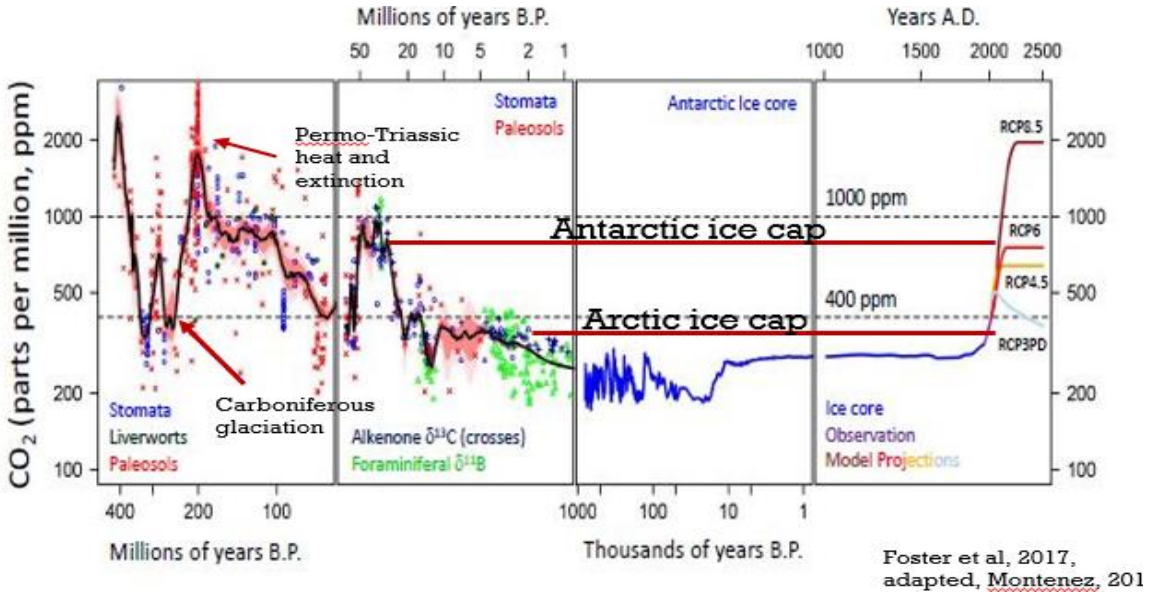
- Most of the excess energy (91%) is being absorbed by the oceans.
- The effects of the heat in the ocean will continue to affect the climate, even if emissions are drastically reduced in the coming decades

- Since 1750, 2560 GtCO2 have been emitted
- We are emitting 41 GT/yr. CO2, 52 GT/yr. all gases
- At current emission levels, we will reach 1.5 degrees C around 2030 and 2.0 deg. C before 2050

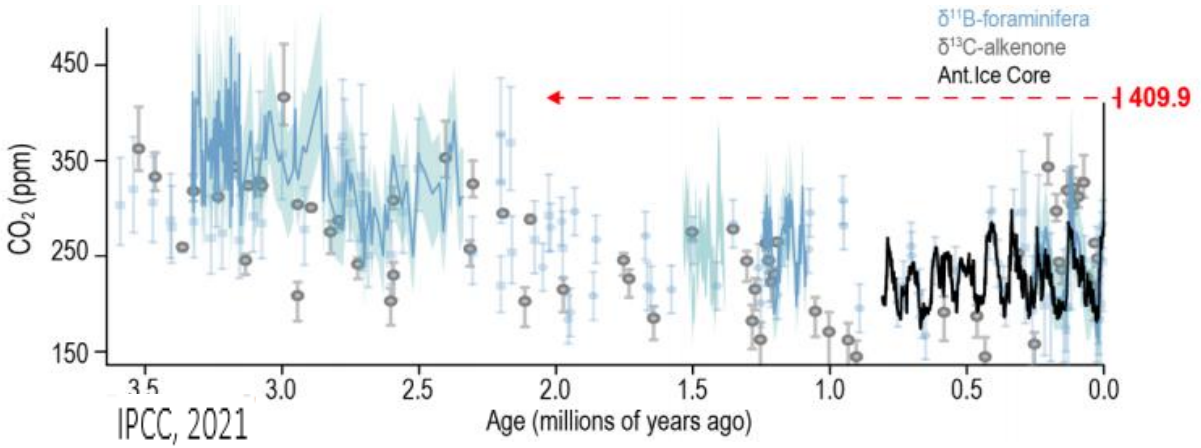


Just reaching a plateau in emissions will be major task

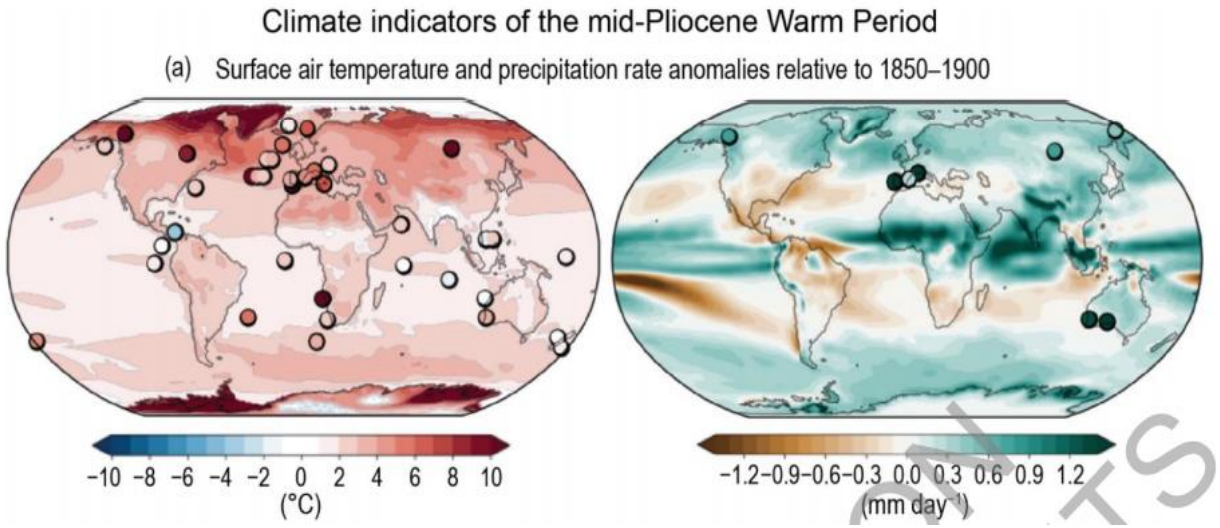
What has happened in the last 50 years needs to be put in context of geologic past



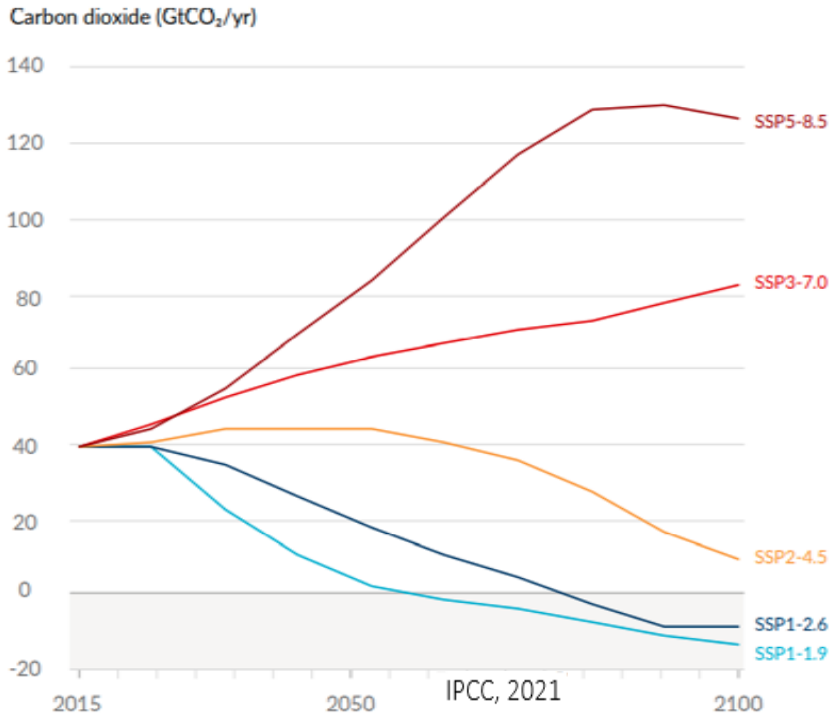
We can measure CO2 levels in the geologic past from the fossil, sedimentary and geochemical record. The current level (417 ppm 2020) is above the formation of the Artic ice cap, which will melt at this level with time

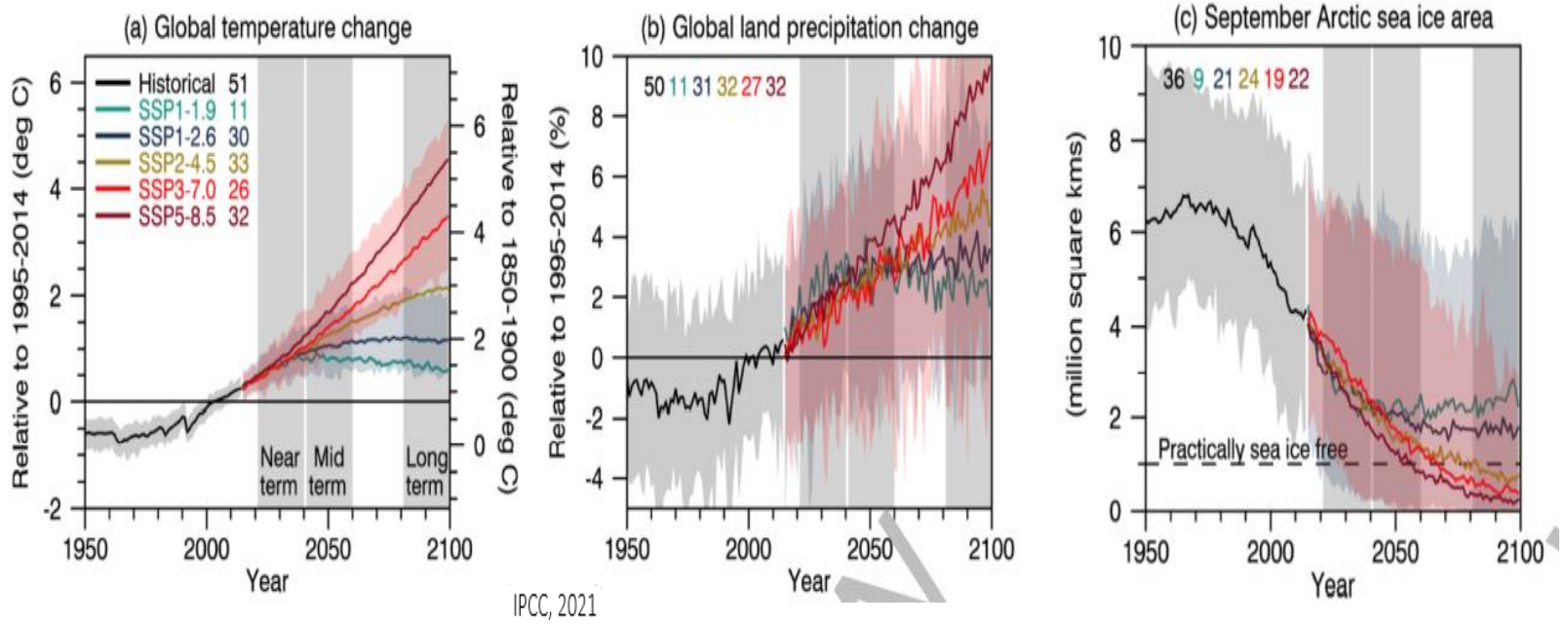


- The last time CO2 levels were this high were about 3 MY ago, in mid Pliocene, a much warmer and wetter world with higher sea levels and no arctic ice cap
- Moving to "net zero" would only establish us at this level, as the earth takes centuries/millenia for the climate to catch up with the atmospheric changes



The 2021 IPCC report presents five potential scenarios for the rest of the 21st century, however, not all are realistic



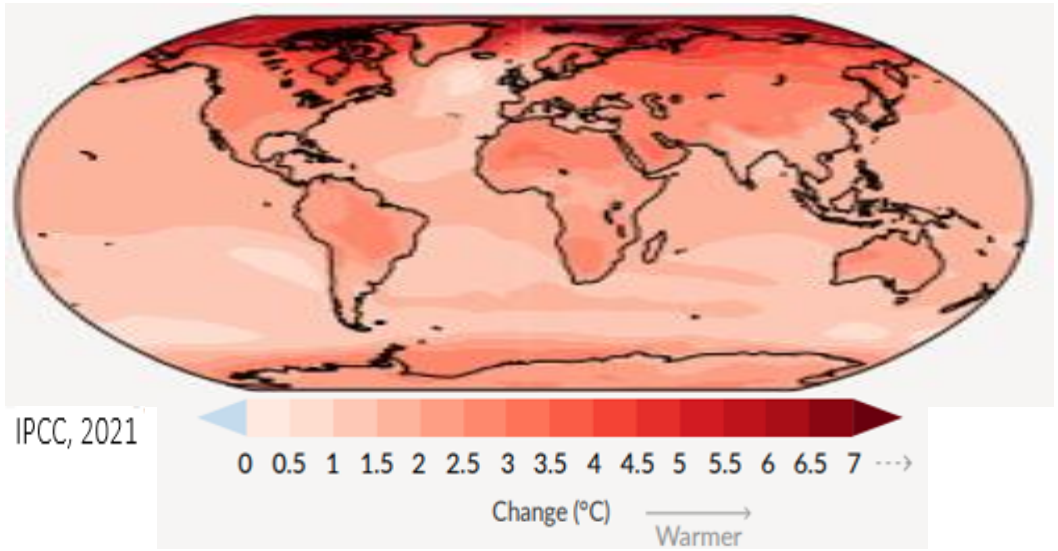


The IPCC admits in the report that the two high and low scenarios are unlikely. In fact, being able to move from the constant increase in carbon emissions to a plateau then decline after 2050 would be a significant achievement. Moving the decline closer to the present (beginning 2025) in SSP1-2.6 is a "stretch" goal.

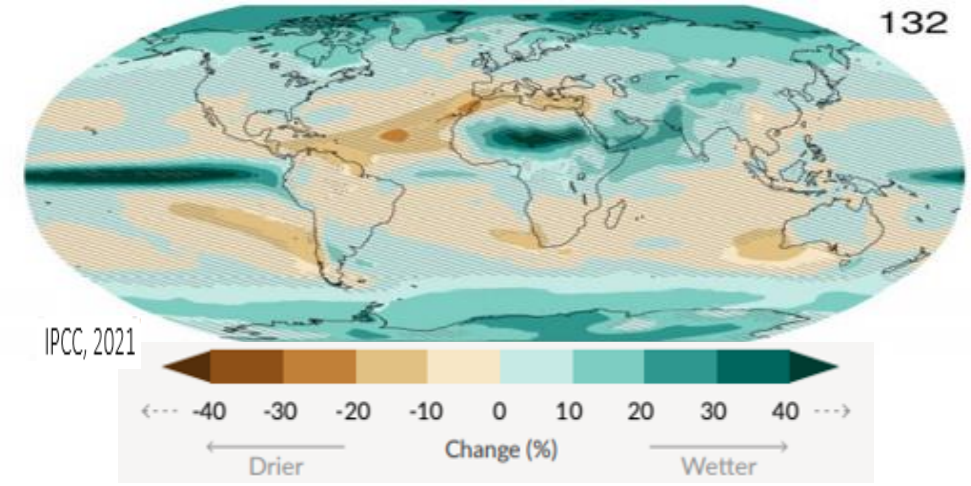
Under most likely scenario **(SSP2-4.5)** the following would occur:

- ❑ Global temperature would rise to 2 deg. C relative to 1900 around 2040 and 3 deg. C by end of century
- ❑ It will be a wetter world in general, precipitation will rise 3% in first half of century, 5% by 2100
- ❑ The arctic will be ice free by late summer in the second half of the century
- ❑ **Through 2040, SSP1-2.6 and SSP2-4.5 have virtually identical results**

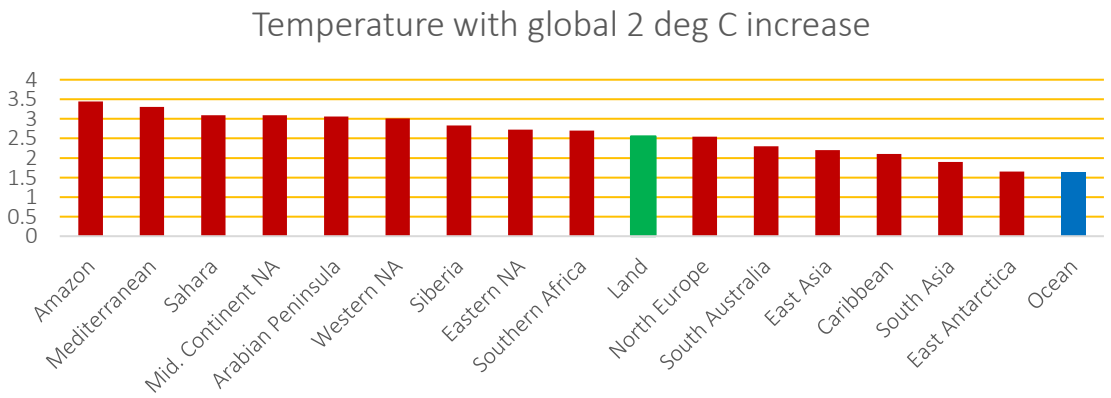
What will the world be like in 2050, with 2 deg. C temperature increase?



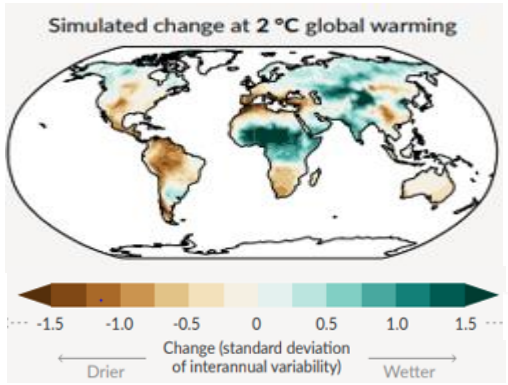
Temperature change at 2 deg warming



Precipitation change at 2 deg C warming



While land will average +2.55 deg C and ocean +1.64 C, certain areas will be much warmer

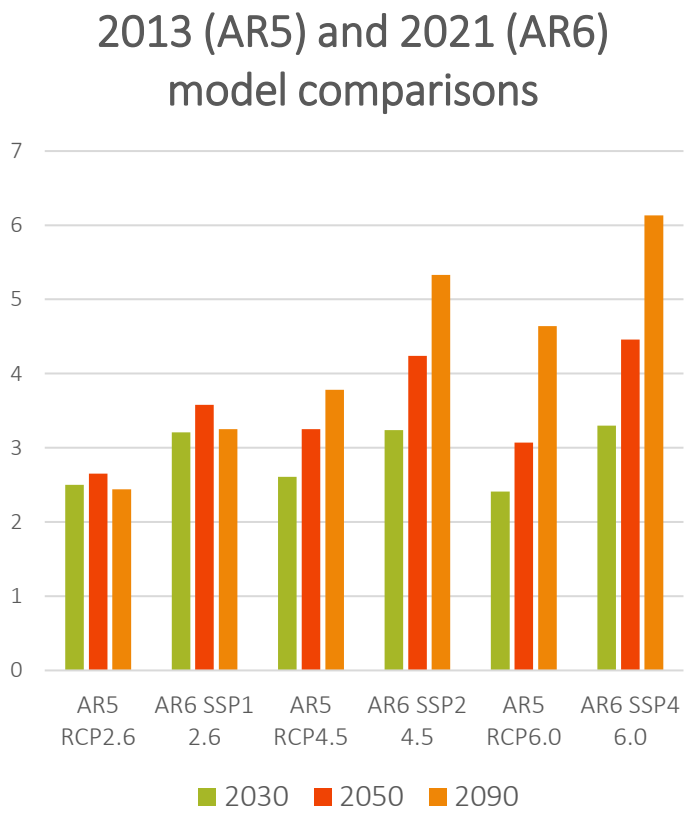


Change in soil moisture

Areas of predicted drought

Combination of temperature increase and reduced precipitation will lead to serious drought

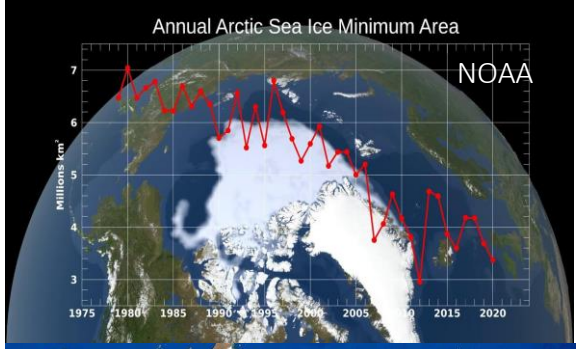
How does the 2021 IPCC report differ from 2013 report in prediction, and why?

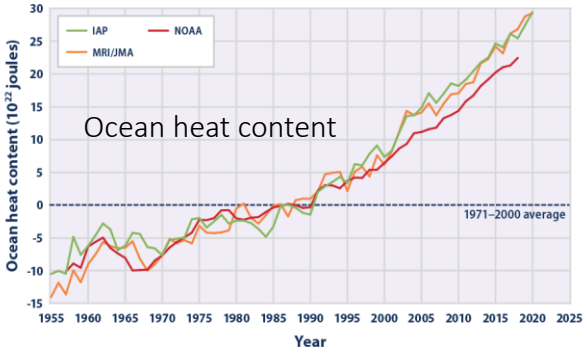


For the 3 plausible cases, results of 2021 report show accelerated climate change as represented by radiative forcing

Main factors in the new results were: data from the past decade, models that fit past performance and understanding of cascading impacts and compound events:

- Arctic amplification: the warming arctic at 3X the global rate affects surrounding land areas, ocean circulation, reflection and absorption of solar energy
- Combined effect of temperature and drought: wildfires increased "black carbon in atmosphere" and accelerated melting of permafrost
- Effect of aerosol emissions (cooling compounds): Reduced emission in Europe and NA after 1990 played role in increased temperatures, demonstrated by high 2020 temperatures during Covid lockdowns
- Impact of melting permafrost: Multiple events are factors accelerating this process
- Ocean warming: Understanding of slower but steady reaction of ocean, which has absorbed most of heat imbalance
- Recognition of combined effect of other GHG gases, collectively comparable to effect of CO2

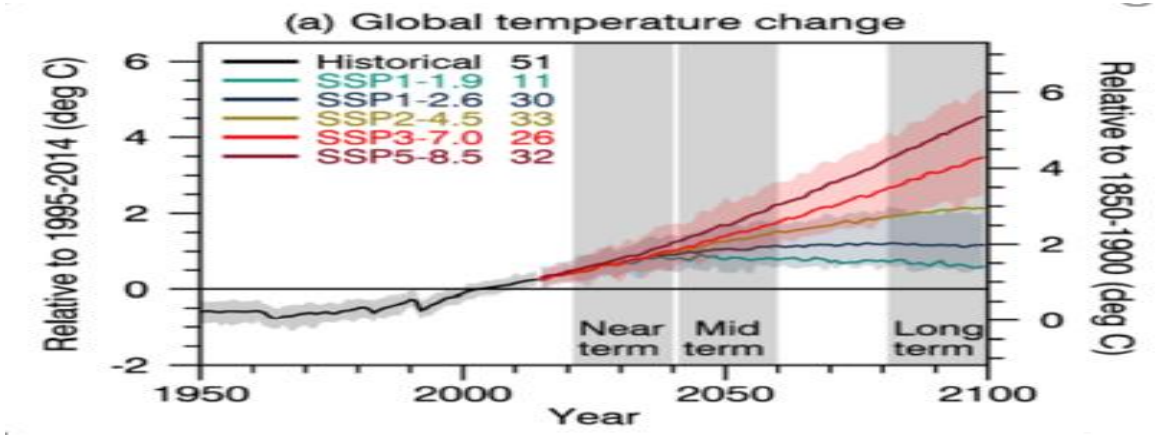




Why will it be virtually impossible to avoid 1.5 deg warming in the 2030's and 2.0 deg C by mid-century

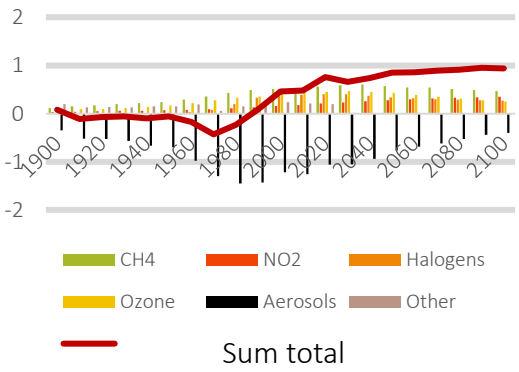
Even the SSP1 2.6 case, which assumes a 50% reduction in global CO2 emissions by 2050 indicates that we will reach those +1.5 and +2 deg C. Before we discuss the anthropogenic difficulties in reducing emissions, the following are physical impediments:

- A major factor in reducing CO2 emissions also reduces pollution. The lockdowns in early 2020 caused a short-term temperature increase of about 0.3 deg. C. Major reduction in pollution will unfortunately result in significant temperature rise, countering any CO2 reductions.
- The excess heat that has built up in the oceans will continue to gradually produce climate results leading to warming
- The earth is in radiative forcing imbalance; even at lower levels it would continue to promote warming. We need to go "net negative" to begin to reverse the process



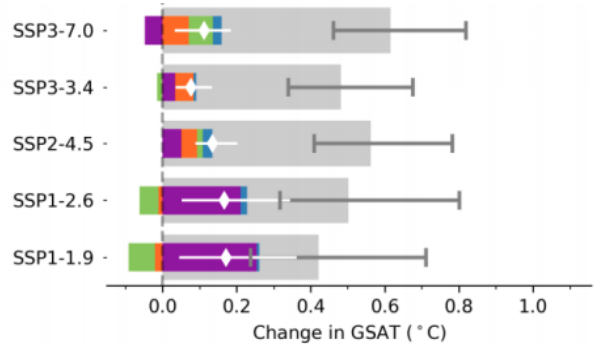
IPCC, 2021

RCP of gases other than CO2 in 4.5 scenario



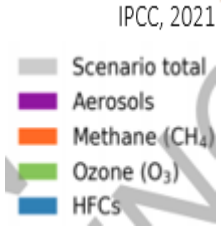
In SSP2-4.5 scenario, pollution is gradually reduced in 21st century, making RCP of non-CO2 gases increasingly positive.

Change in GSAT in 2040 relative to 2019



In SSP1-2.6 scenario, reduced aerosols add 0.23 deg. C by 2040

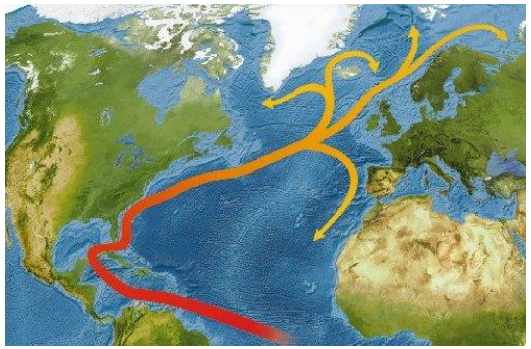
IPCC, 2021

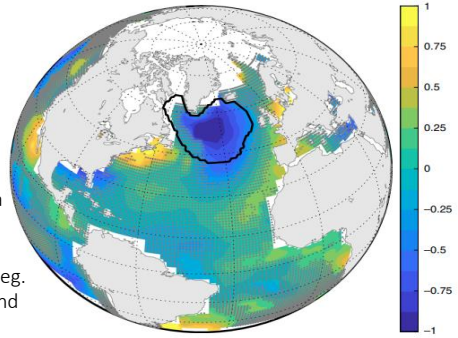


What are potential tipping points that could cause "catastrophic change" in this century?

Once global temperatures rise >2 deg. C, chances for tipping points increase

wikipedia

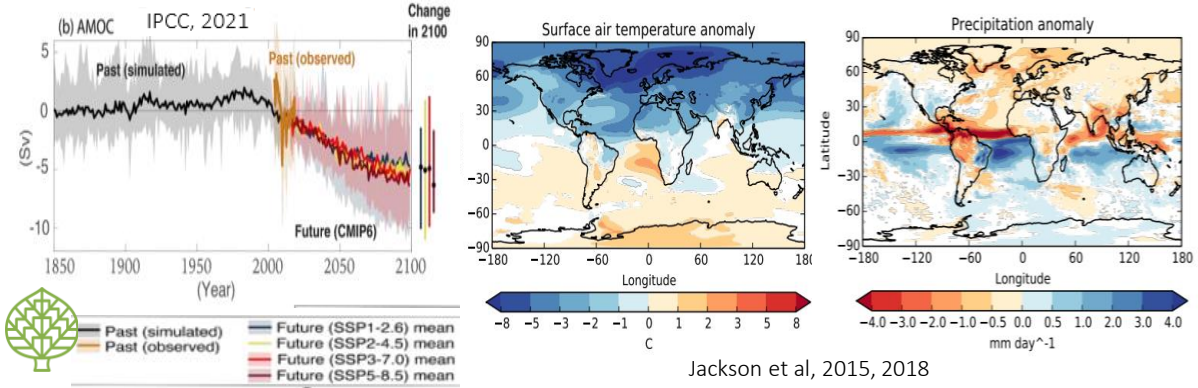




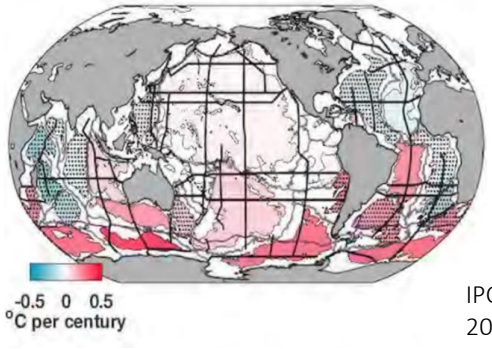
Trends in sea surface temperature 1909-2018 Deg. C (HadISST and Kaplan)

Overturning of Atlantic Meridian (Gulf Stream):

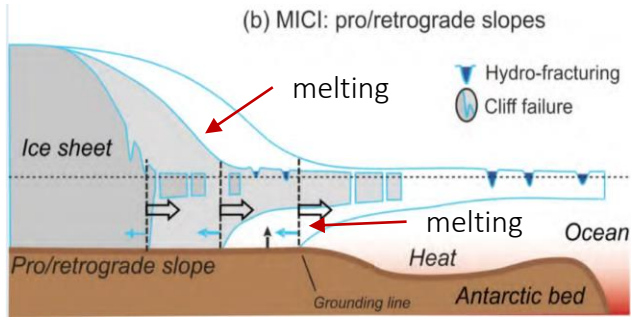
- Increasing freshwater melt from Greenland and Arctic has weakened Gulf Steam by 15%
- This will accelerate under all scenarios and if it reaches 35-40% may overturn, radically changing global climate
- Heat transfer will slow, cooling N Hemisphere, warming S Hemisphere. Effects will be worldwide, especially precipitation.



Jackson et al, 2015, 2018

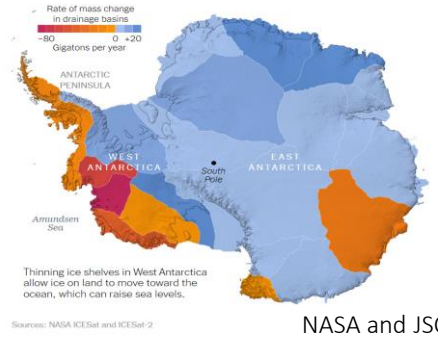


IPCC, 2019

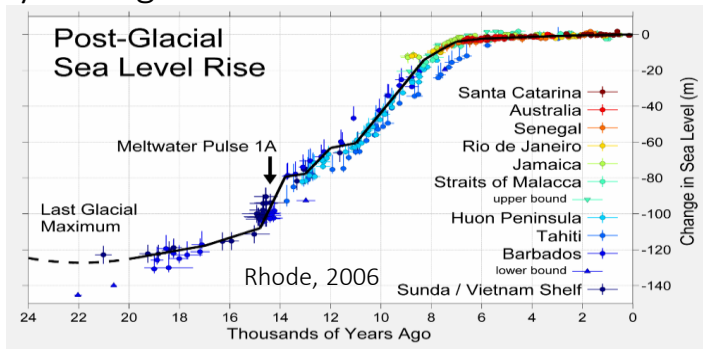


Breaking off of West Antarctic ice sheet:

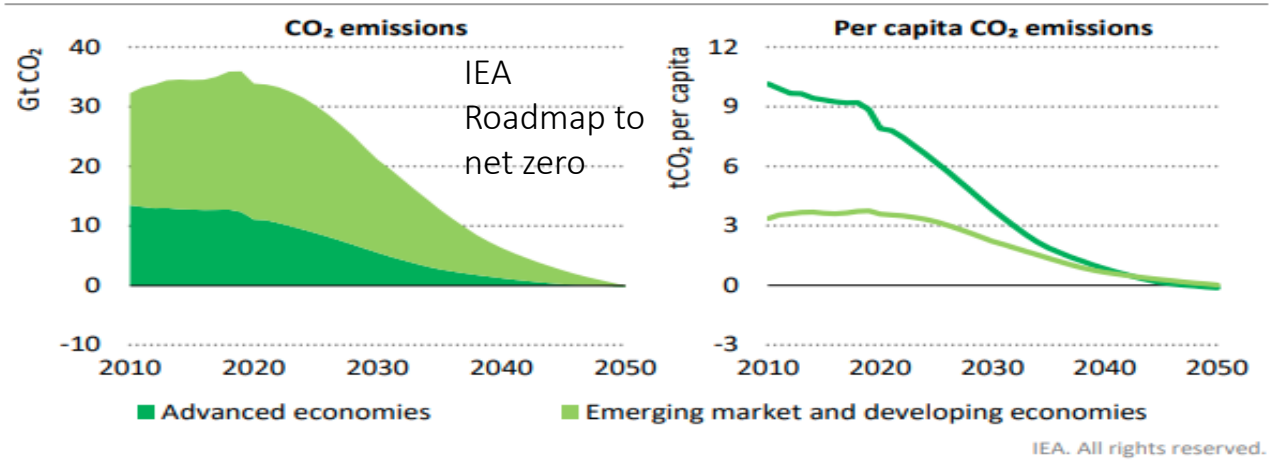
- Much of increased ocean heat is transferred by currents to southern ocean surrounding Antarctica
- Most of Western Antarctica is ice
- Melting due to increased air temperatures and warm currents are making West Antarctic glaciers increasingly unstable
- Breaking off of ice sheet could cause magnitude increase in rate of level rise as happened 14,000 years ago

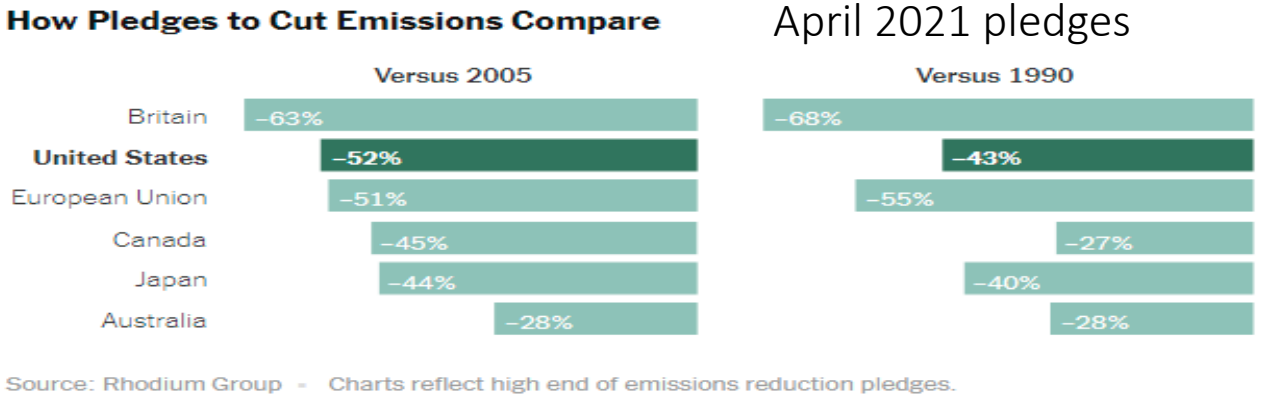


NASA and JSC



With the need for urgent action to address Climate Change to aim for limit of 1.5 deg. C temperature rise, the International Energy Agency issued a report on a "path to net zero by 2050". Some nations made pledges to reduce greenhouse gas emissions in the coming decade consistent with the IEA plan.



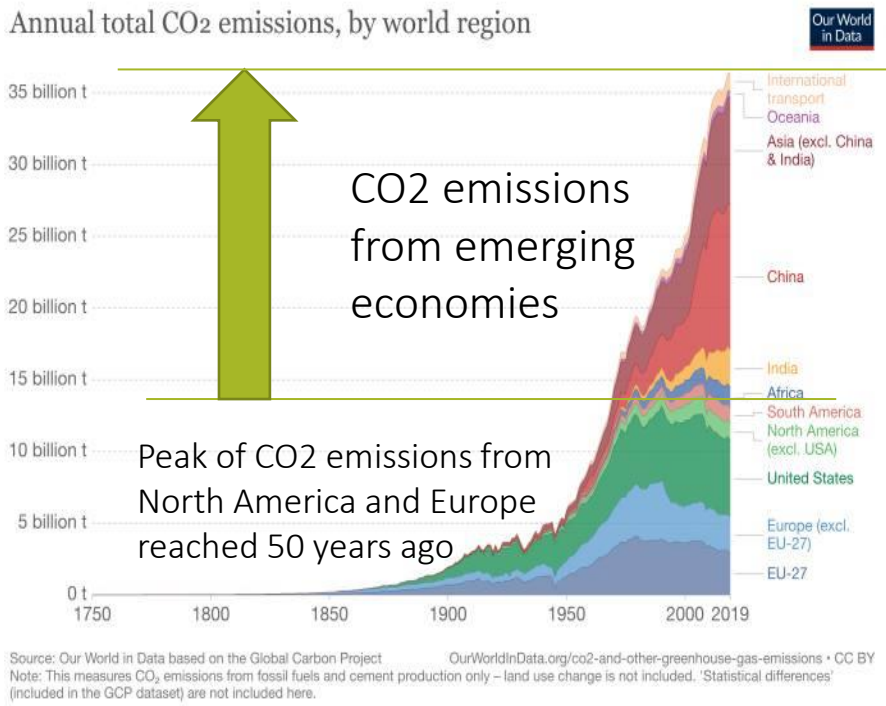


Despite good intentions the IEA roadmap has no realistic possibility of being accomplished

- >70% of world's GHG emissions are outside OECD countries. These countries have no plans to cut emissions in the coming decade and are depending on economic growth to raise living standards.
- The plan depends heavily on continuing exponential growth in renewables. However, renewables require quantities of certain minerals that far exceed current supply and the investment to increase supply has not been made.
- As share of the energy grid increased in specific markets, the lower level of reliability became apparent. The effects of climate change on renewable energy also needs to be addressed.

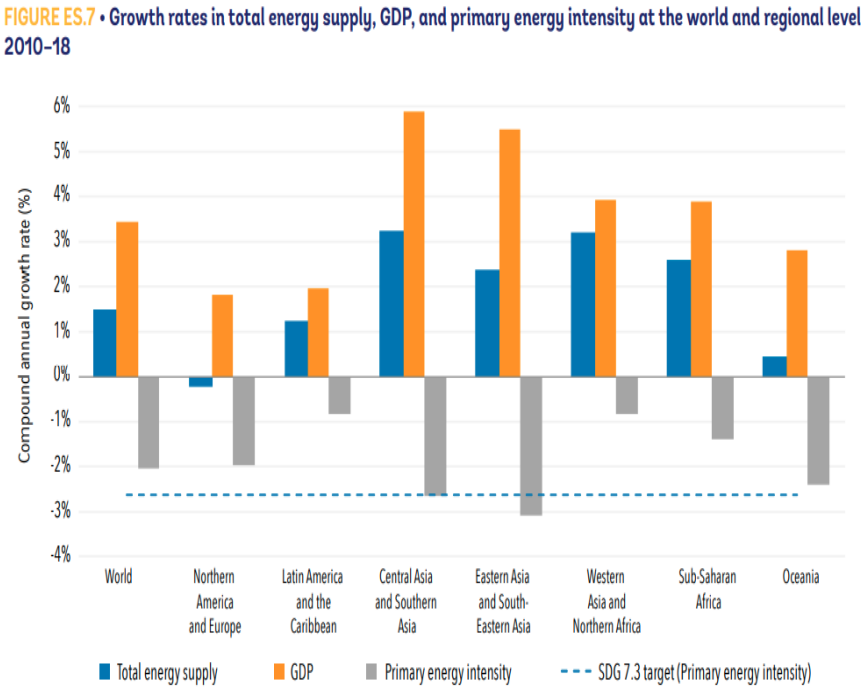
However, there is a recognition of "Climate Emergency" so what is likely to take place in the coming decade?

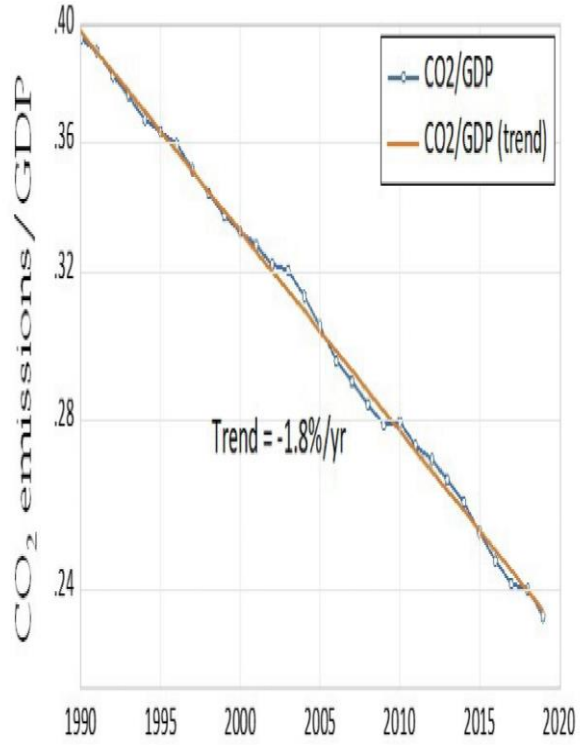
With the obvious urgency of addressing climate change, why is it so difficult to find solutions?



Problem #1: 73% of current emissions come from emerging and developing nations, whose prime concern is improving living standards of their populations. They account for the entire growth of GHG emission of the past 50 years. If developed nations honor their pledges by 2030, they will be only 17% of emissions.

The GDP growth in North America and Europe is balanced by reduction in energy intensity. For the main area of world growth, in Asia, GDP growth is >2X reduction in energy intensity, requiring increased energy supply of 3-4%/year, incompatible with decreasing GHG emissions.





Asian economies, mostly China, are committed to coal

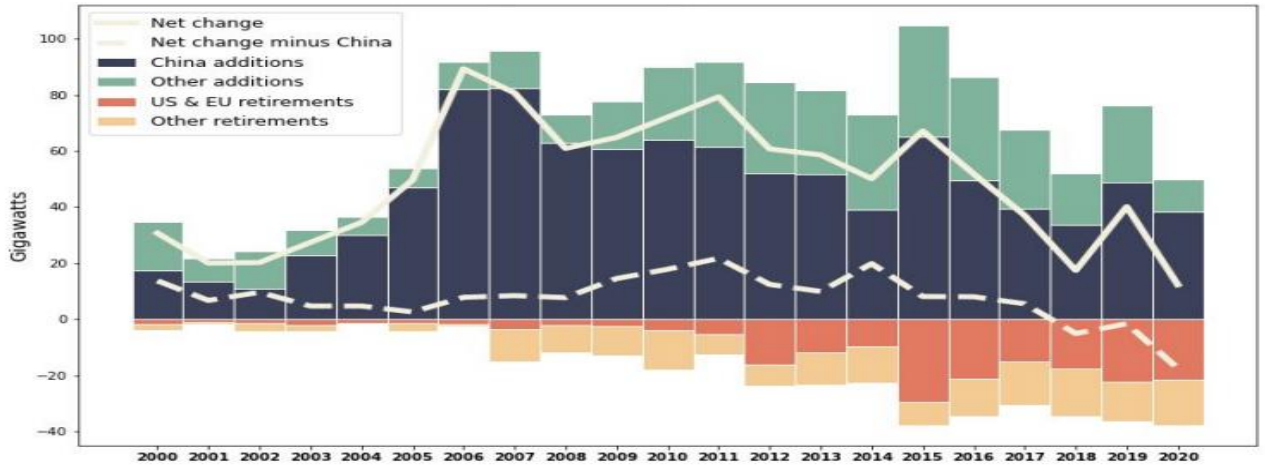
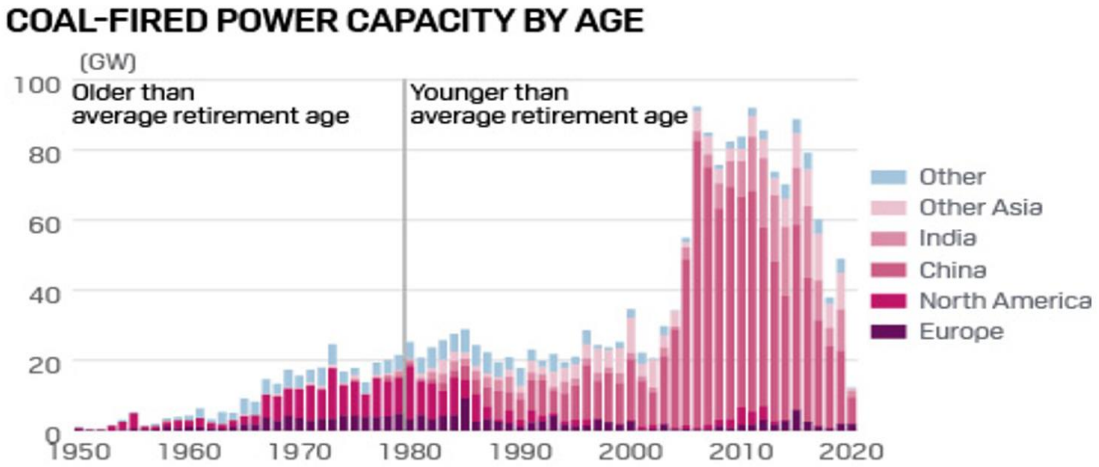
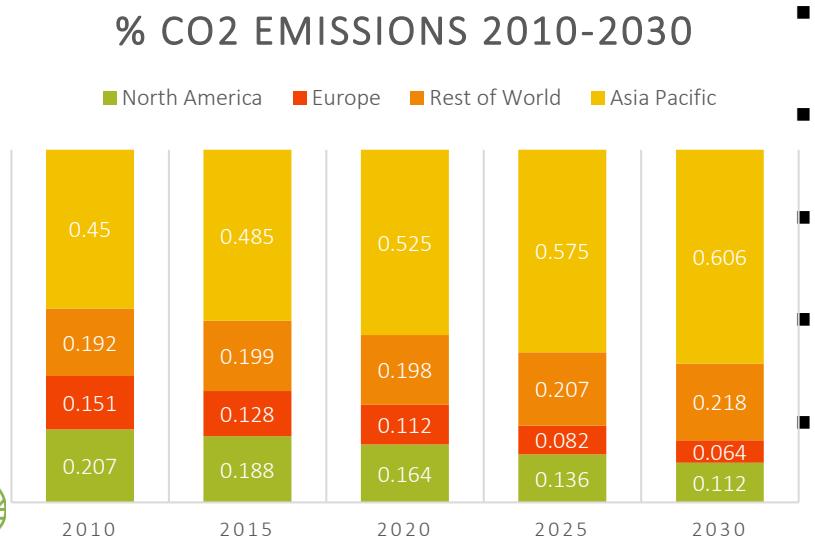


Figure 1. The net change in 2000–2020 global coal power capacity (solid line), and the net change without China (dashed line). Country-by-country additions (positive) and retirements (negative) are shown with coloured columns.
Source: Global Coal Plant Tracker, January 2021.

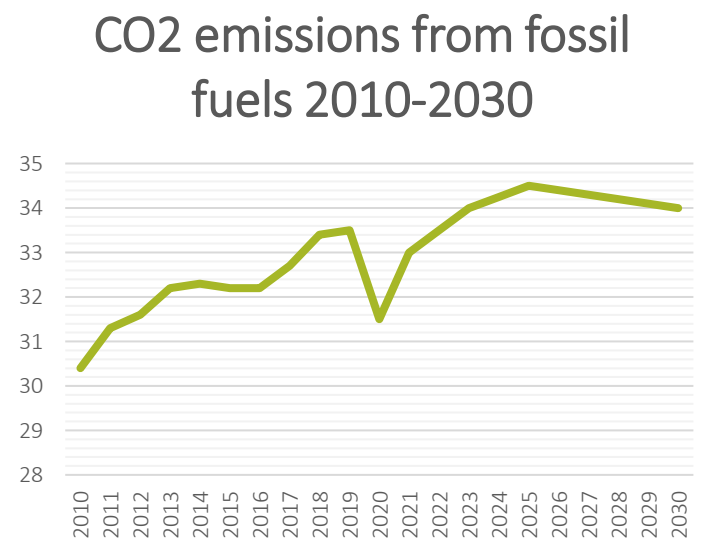


Source: S&P Global Platts Analytics Future Energy Outlooks Global Integrated Energy Model

China continues to build coal fired power plants with 40-year life. They consume more coal than the rest of the world combined. Their "pledge" is to reach peak emission in 2025 and reduce after 2030. India will pass US by mid-decade to be #2 emitter.

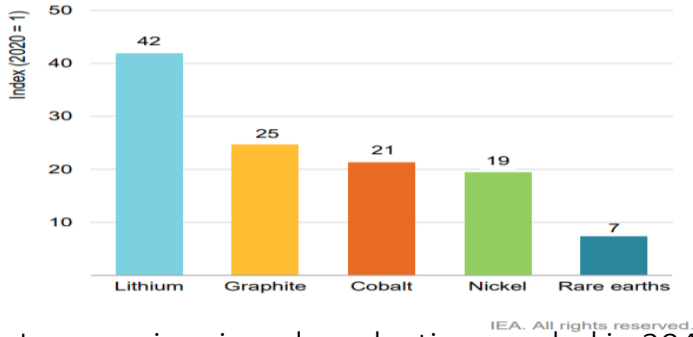


- ***Assume pledges by EU for 50% emission reduction by 2030 fulfilled and US/Canada reduce by 40%***
- *Asia-Pacific and rest of world avg. +2%/yr. through 2025 from 2021 base*
- *Asia-Pacific and ROW incr. +2/1.5/1.0/0.5%/yr. 2026-2029 with no increase in 2030*
- *North American/Europe share of emissions drop from **36%** in 2010 to **27%** in 2020 to **17%** in 2030*
- *Total emissions essentially plateau during decade at level prior to 2020 (34 Gt/yr.)*

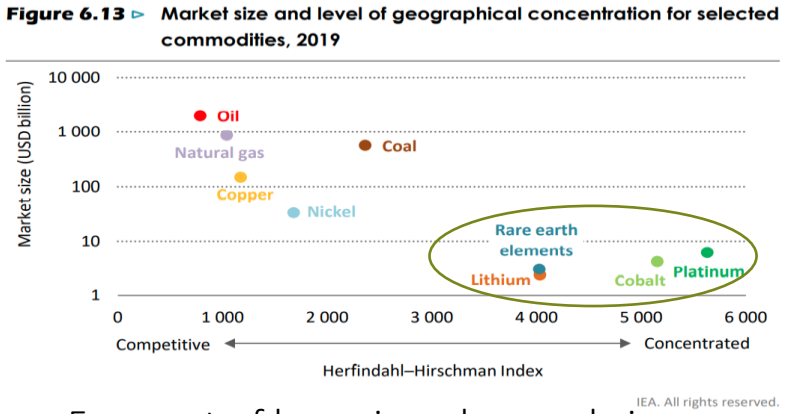


To reach net zero by 2050, share of renewables in electricity and power generation must dramatically increase

Problem #2: Supply of minerals needed for renewables and batteries is far short of what is needed and investment to close the gap is not immediately forthcoming

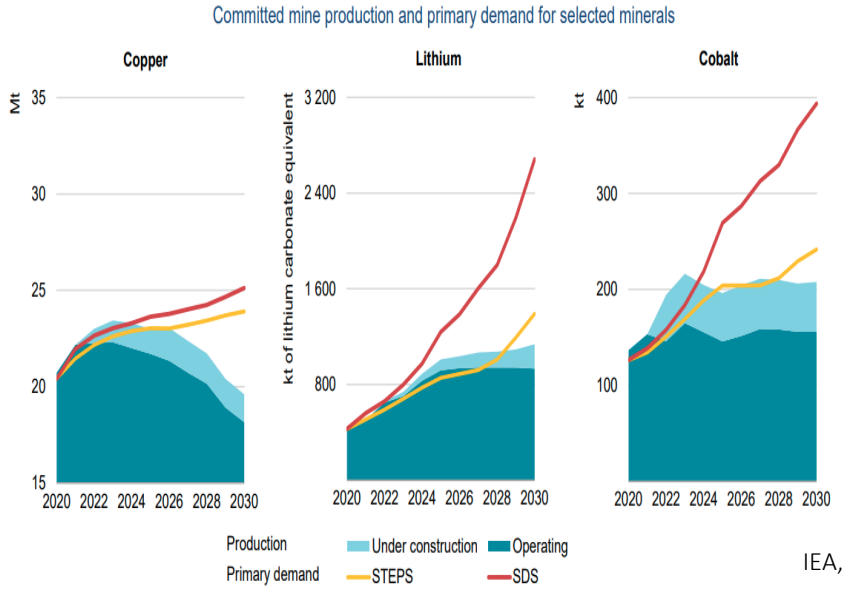


Increase in mineral production needed in 2040 for IEA "sustainable development scenario" (net zero CO2 emissions by 2070, similar to SSP1-2.6)

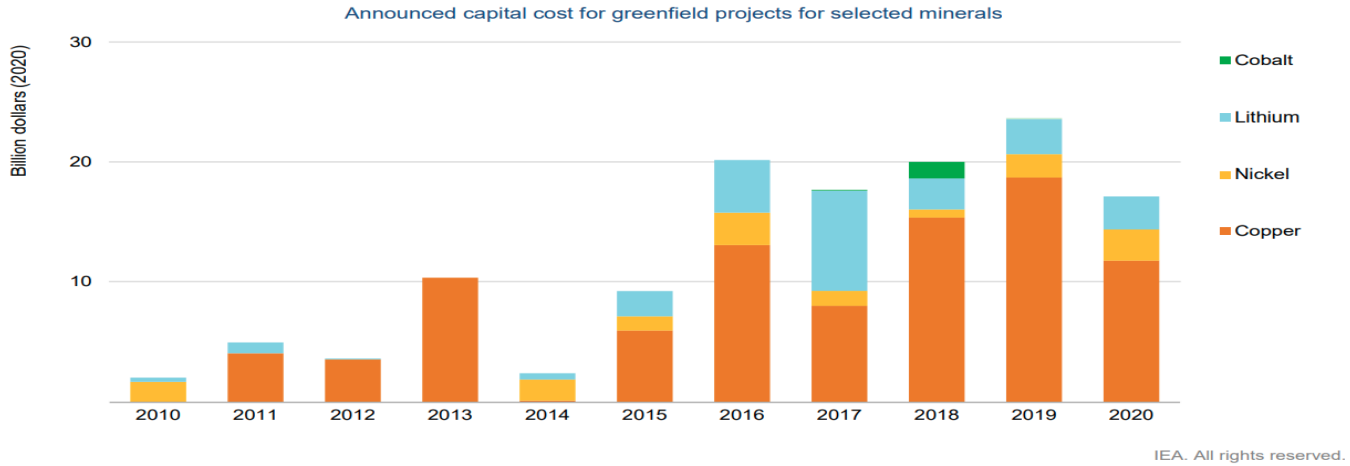


For most of key minerals, supply is concentrated in a few countries

Meeting primary demand in the SDS requires strong growth in investment to bring forward new supply sources over the next decade



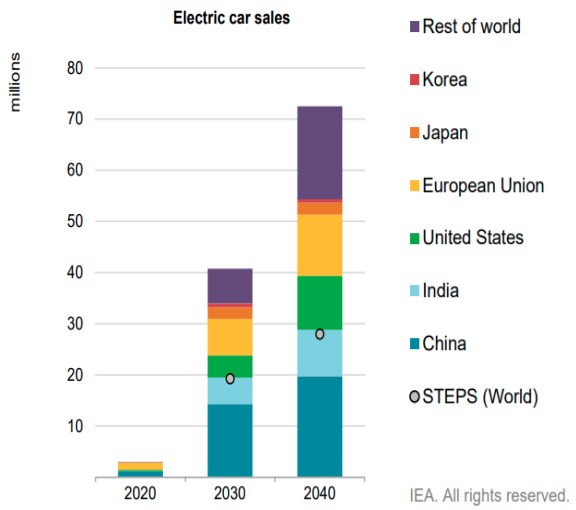
IEA, 2021



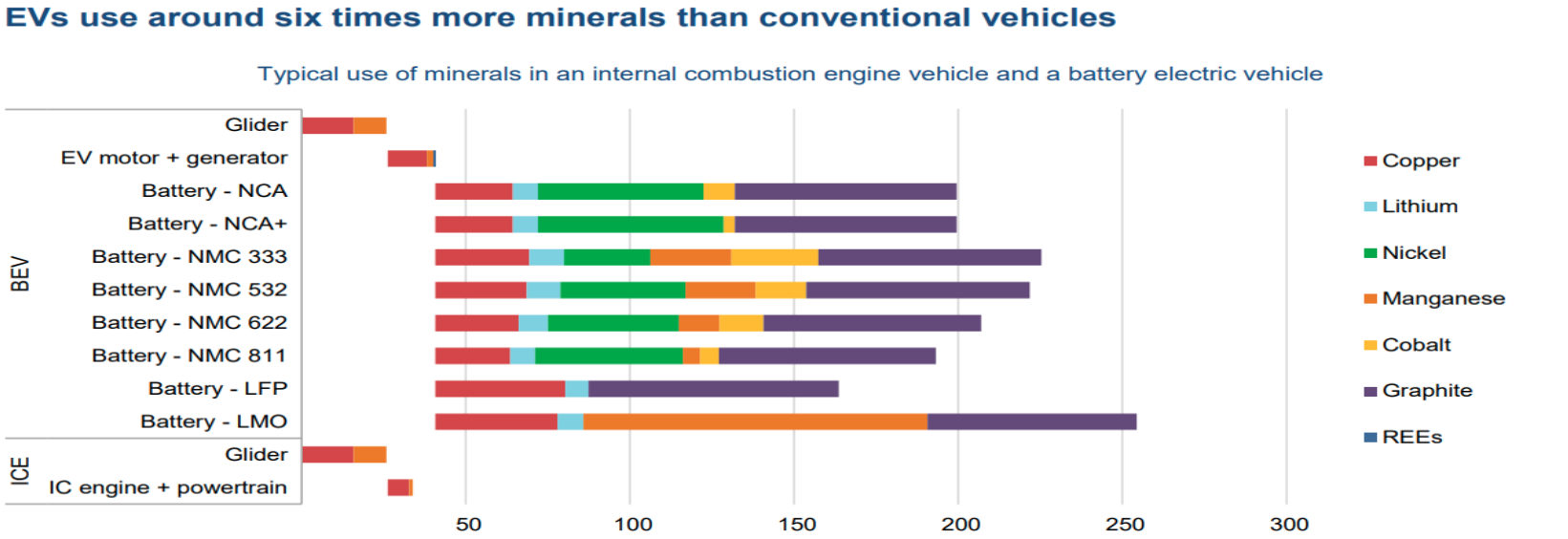
Investment for key minerals has been flat in past five years. It takes 10-15 years from investment decision to production for major minerals projects.

Based on current investment, there will be shortages of copper, lithium and cobalt by 2030

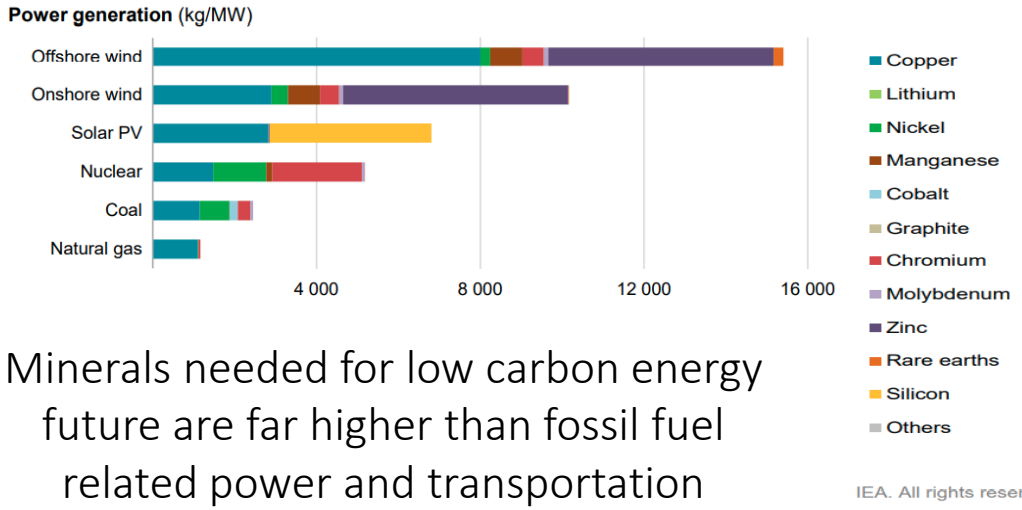
In addition to dependence on solar and wind for power generation, increase in use of electric vehicles for transportation is needed for reduction in oil use



Electric car sales to increase from 2 to 72 MM/year by 2040 in Sustainable Development Scenario (net zero 2070)

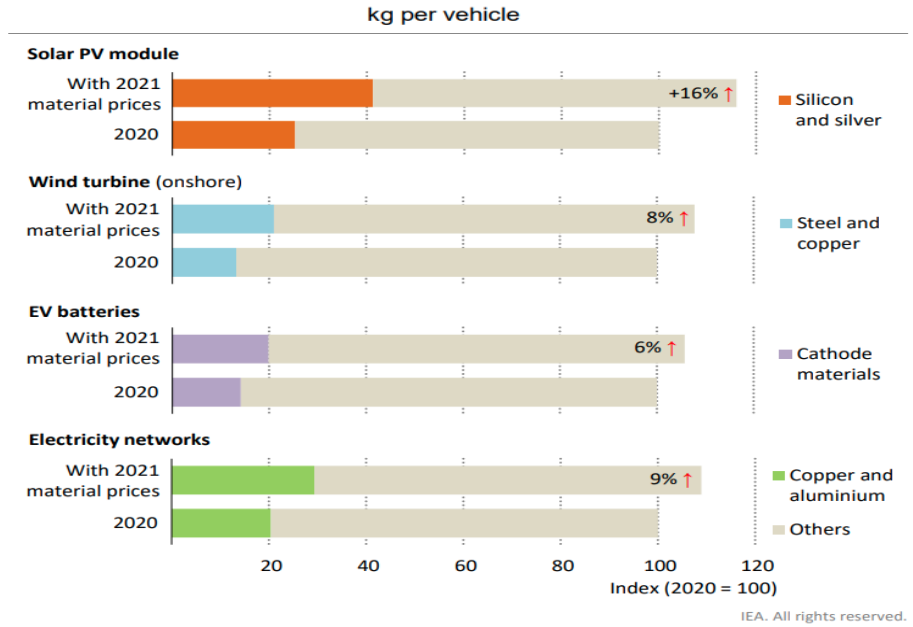


IEA, 2021

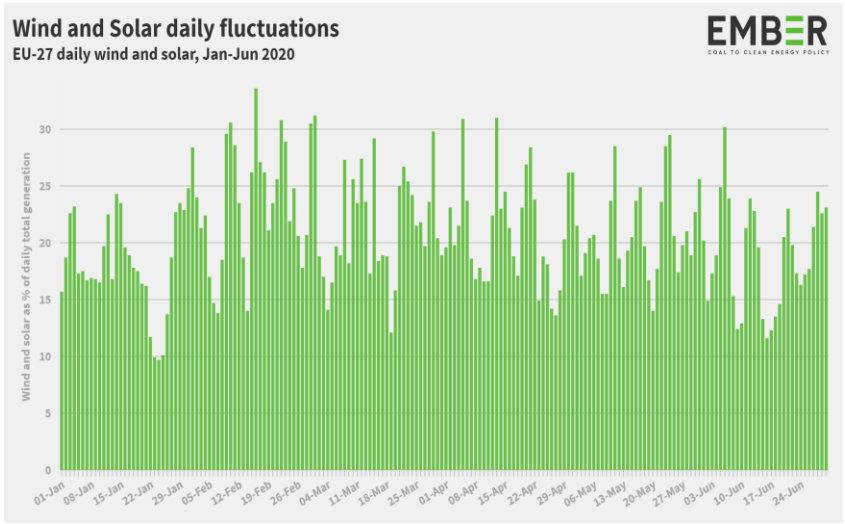


Minerals needed for low carbon energy future are far higher than fossil fuel related power and transportation

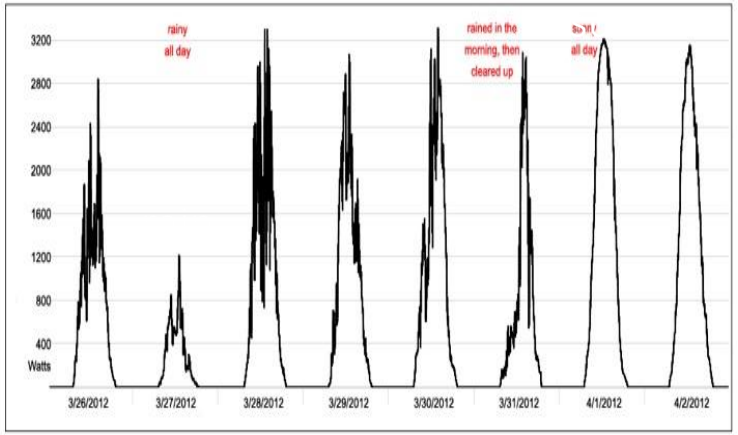
With the increasing shortage of key minerals, the trend of price reductions of renewables may be coming to an end



As share of power grid grows, the reliability factor for renewables becomes more apparent

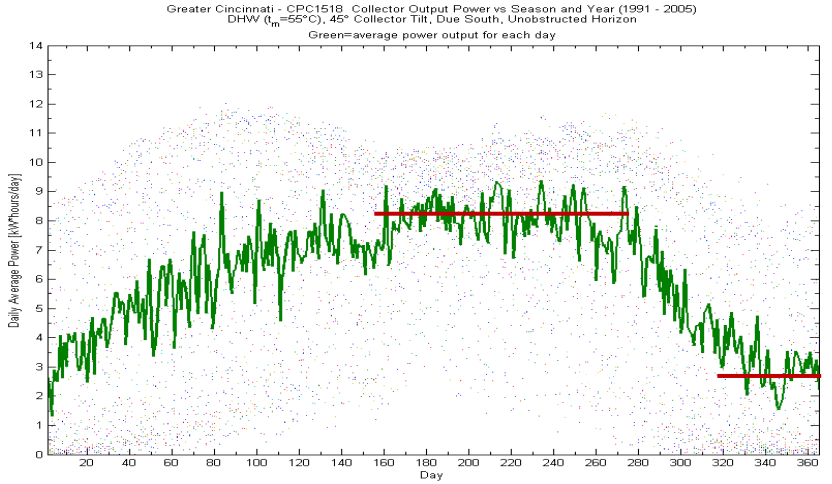


Combined wind and solar power fluctuated to between 10% and 30% of grid on daily basis of EU27 power grid 1H 2020

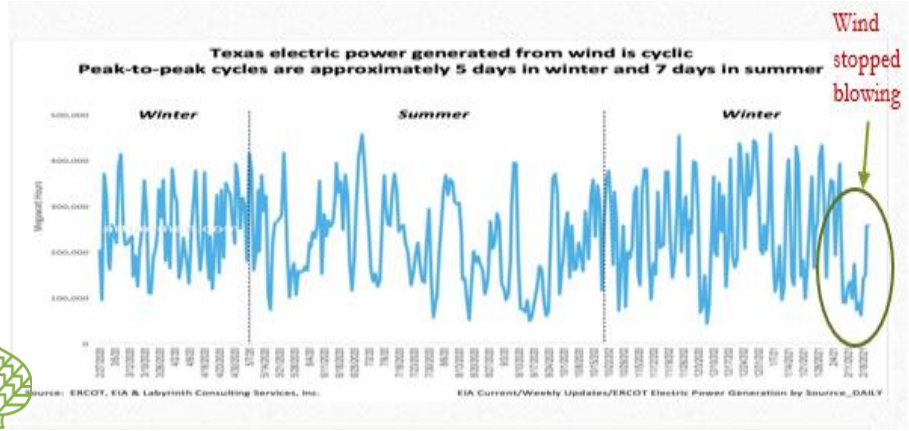


Daily output variation of a large solar power plant in Spain Kumar David

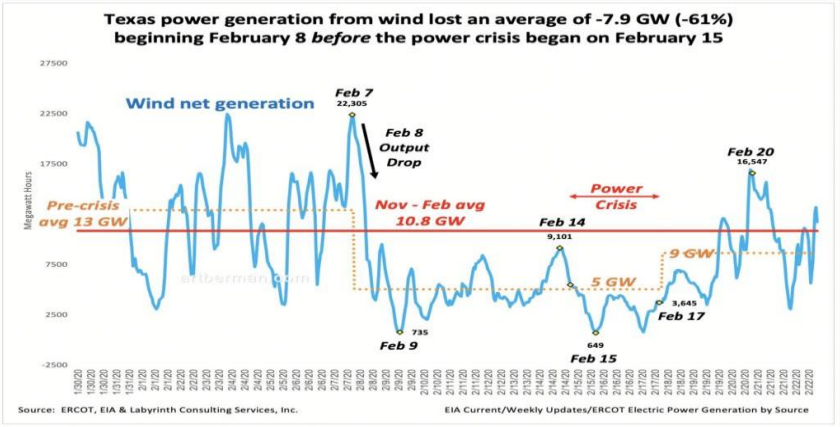
There is an 85% drop in output between a sunny and rainy spring day solar power in large solar plant in Spain



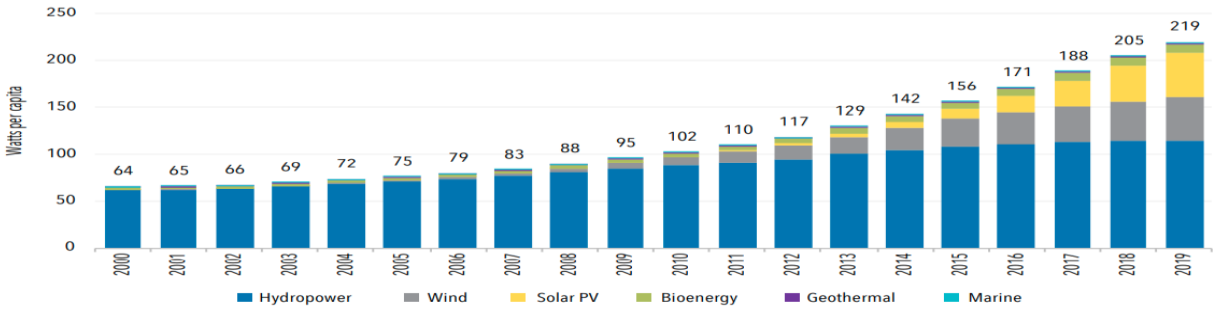
Average solar radiation received only 35% in winter months (when needed most) compared to summer months in Cincinnati USA



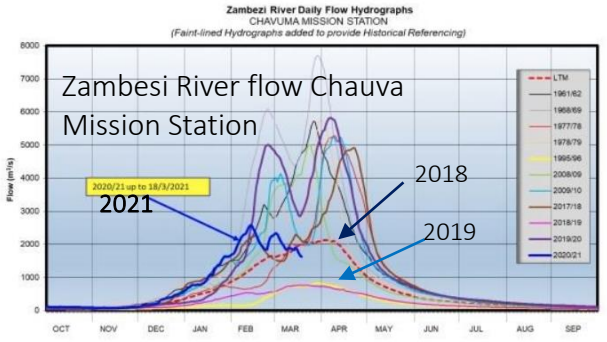
One week prior to "polar vortex" wind stopped blowing in Texas. With wind source of 25% of power supply, this was major cause of power disaster.



Climate change will also affect reliability of hydropower



Source: IEA 2020b; UNSD 2020

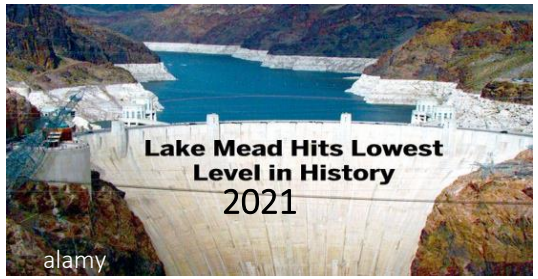


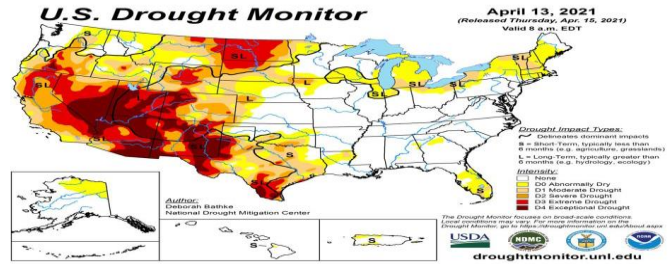
Unprecedented drought reduced flow of Zambesi river and loss of power generation in Africa largest hydroelectric plant

Hydropower currently accounts for half of renewable electricity power and is predicted to provide double the amount of power by 2050. However, climate change will put at risk many of the world's major hydroelectric projects:

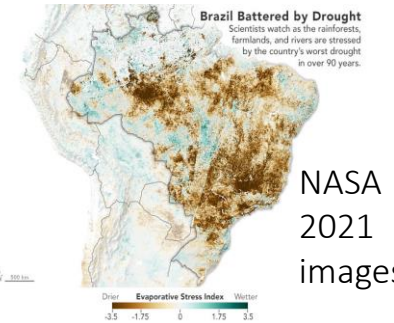
Areas of drought with +2 deg. C temperature increase

- South America receives 52% of electric power from hydroelectric plants, highest proportion of all continents
- Italy and Turkey receive 21% of power from hydro electricity
- Western US and Southern Africa are already suffering from reduced hydro power due to lowered precipitation and drought

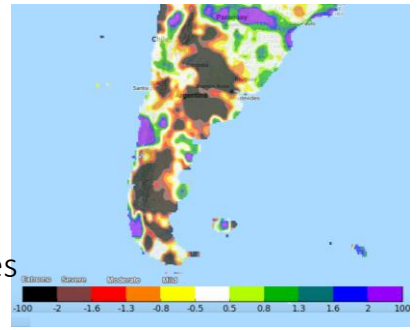




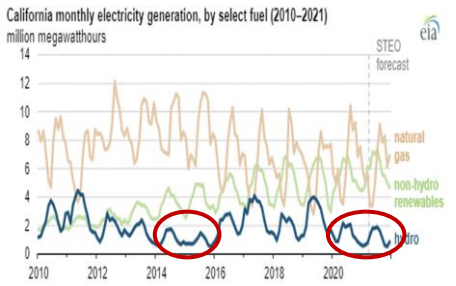
Combination of drought and reduced snowpack puts largest US hydroelectric (Hoover) dam long term viability in question



NASA 2021 images



South America suffering severest drought in century reducing hydropower

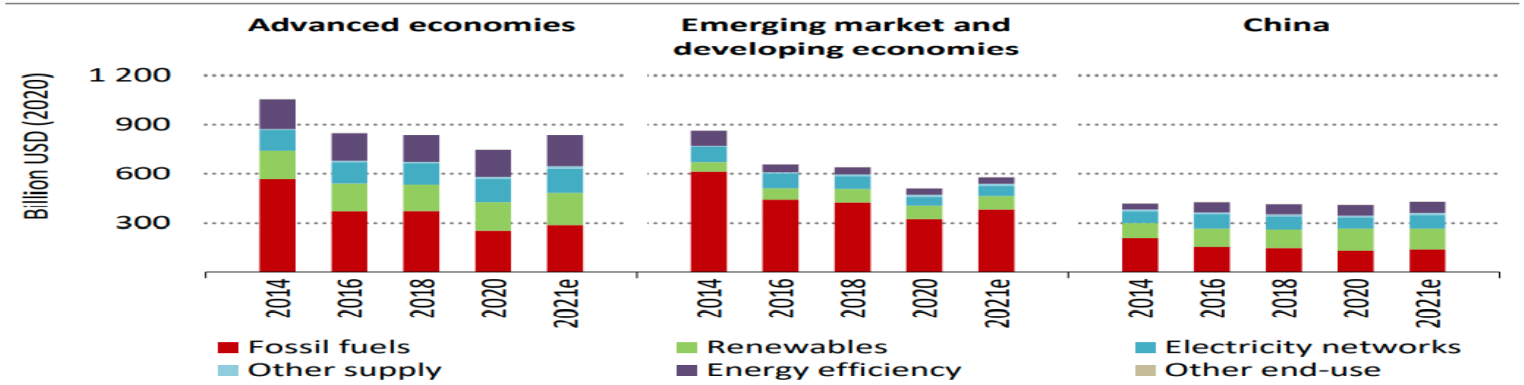


Drought reduces California peak hydroelectric power output by 50%

The energy crisis of 2021 is caused by several interconnected factors:

Underinvestment in the energy, particularly the fossil fuel industry:

- Annual investment in fossil fuels has dropped by approximately 50% since 2014 from $1400 to $700 billion.
- Investment in renewables, efficiency and other supplies have only increased from $950 to $1050 billion



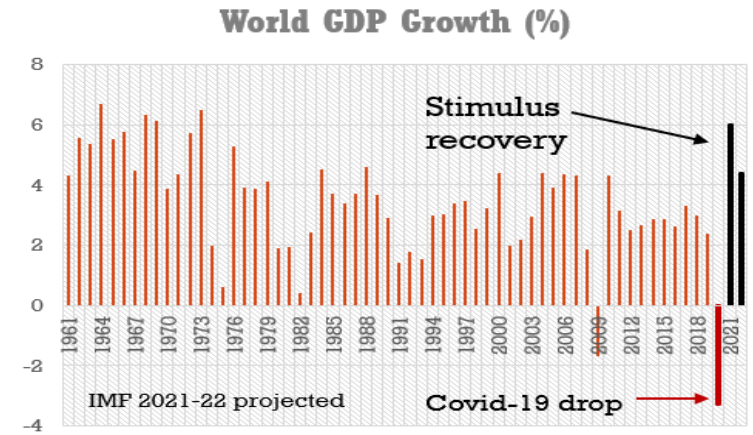
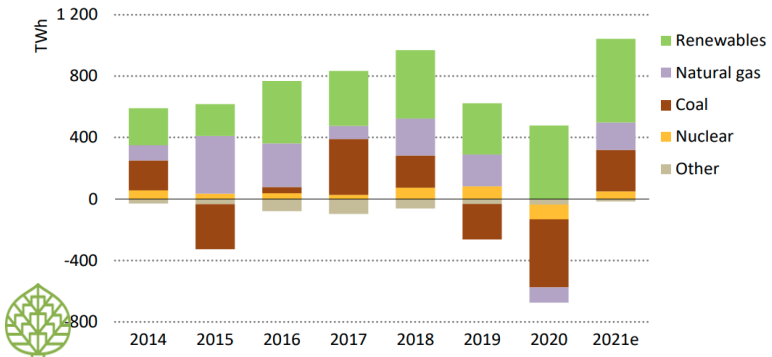
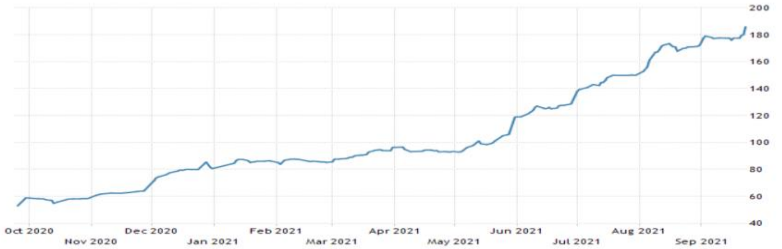
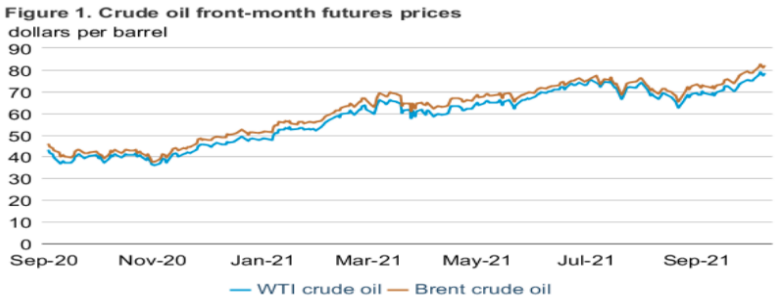


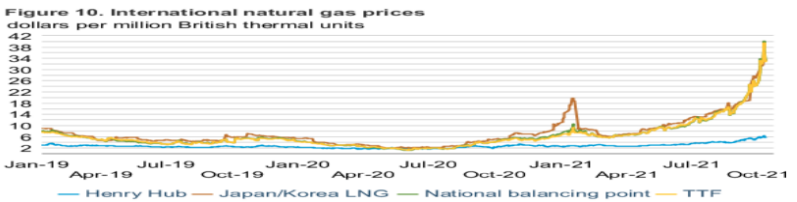
Figure 2.8 ▷ Change in global electricity generation, 2014-2021



With major stimulus injected into economies after Covid recession, GDP and energy growth has resumed in 2021, but without needed increased investment in energy

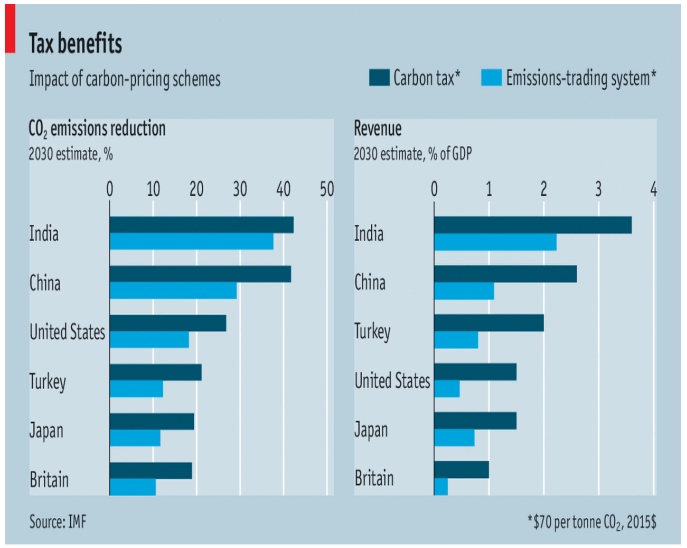




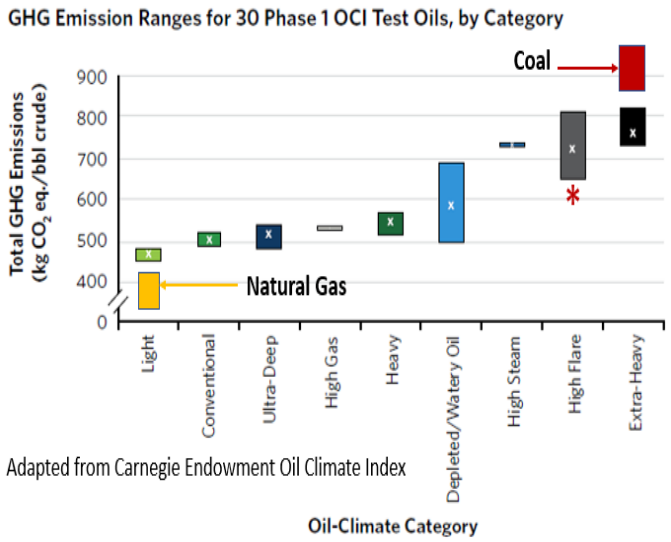


- Coal prices tripled from $60 to 180/ton in one year time
- Crude oil doubled from $40 to $80/bbl. in same time period
- Natural gas rose from $2 to $5 MMBtu in USA and LNG from $5 to $20 MMBtu in Europe and Asia in 2021

What steps need to be taken to begin GHG reduction?

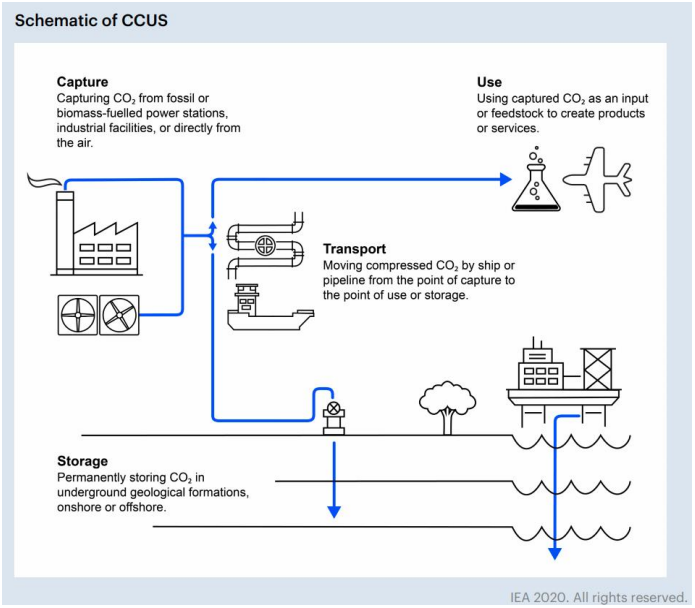


The Economist

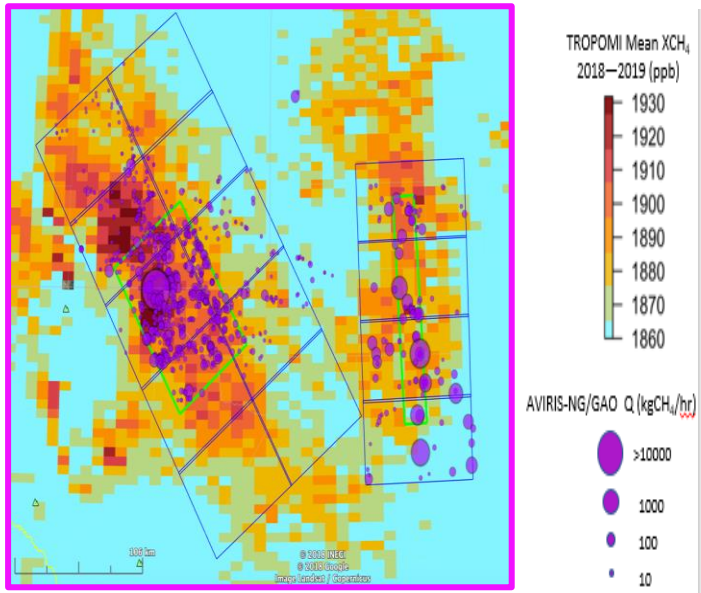


*note, flaring associated gas puts oil production at same level as extra-heavy oil

- **Carbon Pricing:** A market-driven solution to shift to a lower carbon economy necessary. Self- imposed country quotas have not worked. It will accelerate shift to lowest CO2 emitting sources of power.
- **Carbon capture (use) and sequestration:** This technology is known and could be implemented on a major scale quickly. Fossil fuels will still account for >60% of power generation. With carbon pricing, CC(U)S will become economic.
- **Natural gas as transition fuel:** While not the ultimate solution, natural gas emits ½ CO2 per unit of energy compared to coal. It was the major factor in EU and USA emission reduction this century. It can make the biggest difference now when reduction of CO2 emissions is urgently needed.
- **Methane emission reduction:** A concerted effort to identify "super emission centers" of methane, which account for up to 50% of O&G emissions, with remediation. Elimination of gas flaring and venting can play significant role. Methane is 80x more potent than CO2 in short term as GHG and can accelerate warming if rise is not curbed.

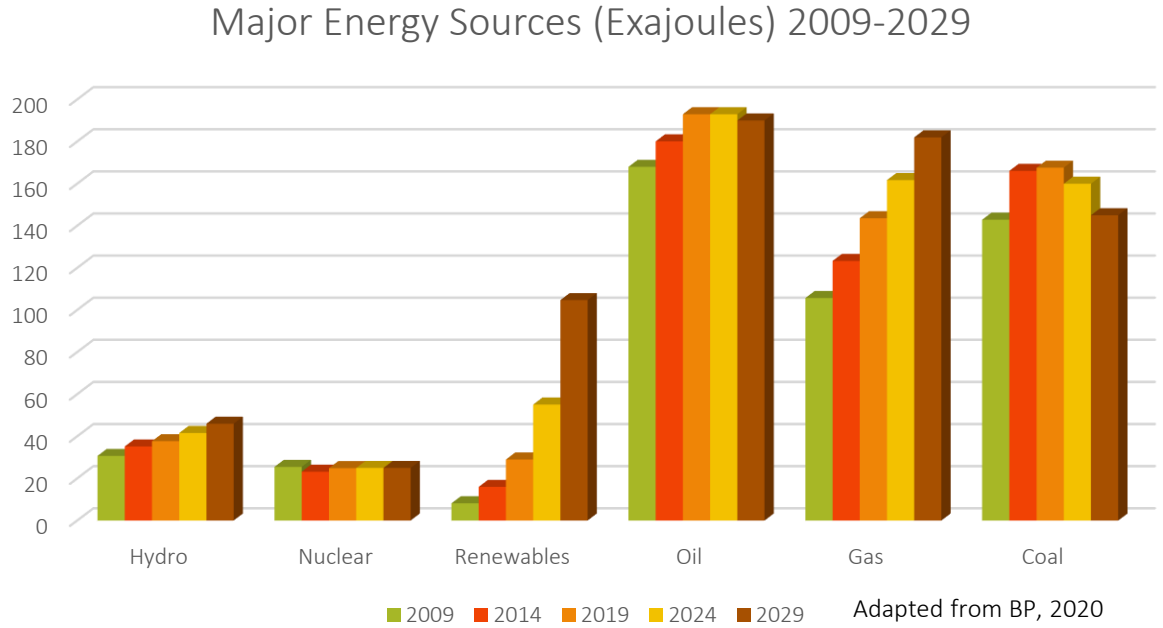


Methane emissions from Permian Basin



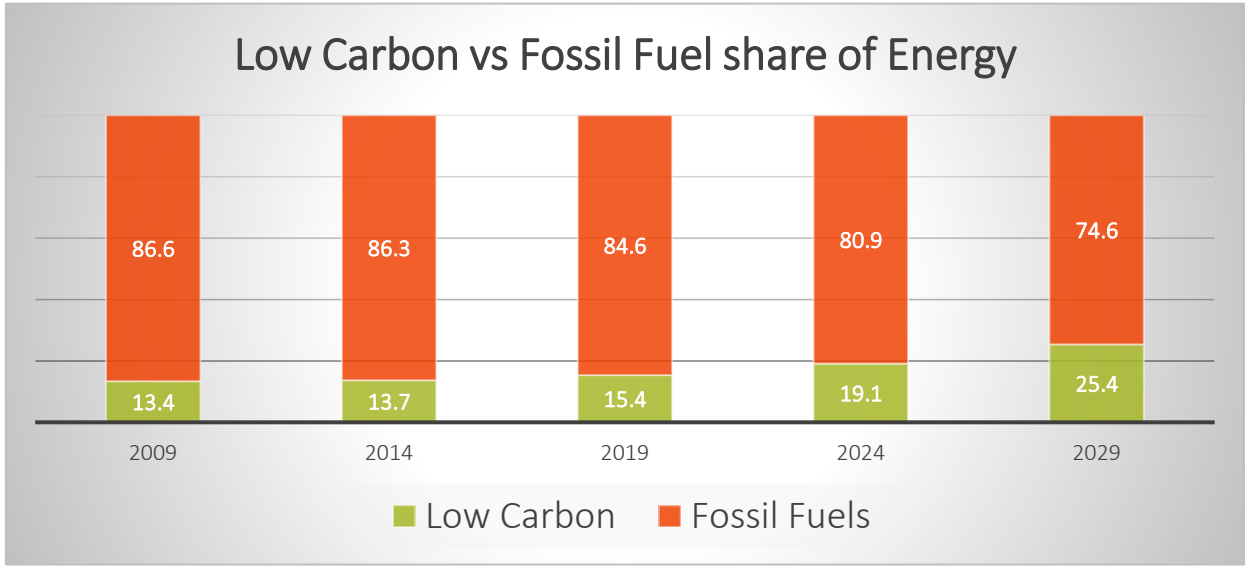
AVIRIS-NG/GAO 2019

The coming decade will finally see the beginning of a shift away from fossil fuels

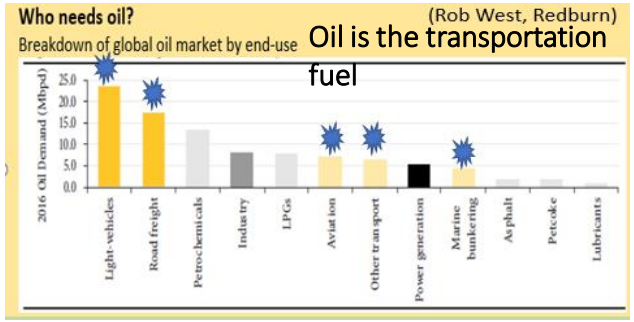


Adapted from BP, 2020

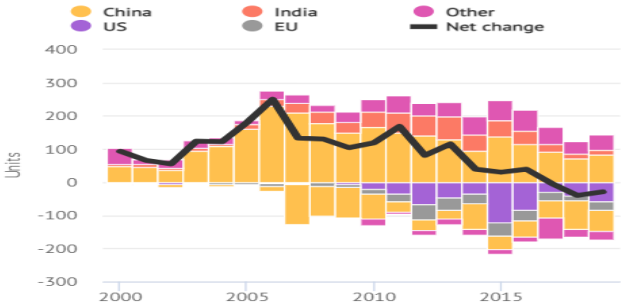
- After recovery from 2020, world energy use growth at 1.5%/yr.
- Steady hydro growth rate of previous decade continues
- No growth in nuclear power as plant retirements in US and EU balanced by new plants in Asia
- Growth rate of renewables in past decade continues (14%/yr.) with biggest growth in offshore wind
- Oil demand plateaus and begins to decline by end decade as electric vehicles gain widespread use
- Continued 2.4%/yr. gas growth, with higher LNG growth rate
- Coal begins significant decline with shift to gas



Low carbon energy share, which had minimal increase since 2000, increases during 2020-2029, from 15.4% to 25.4%



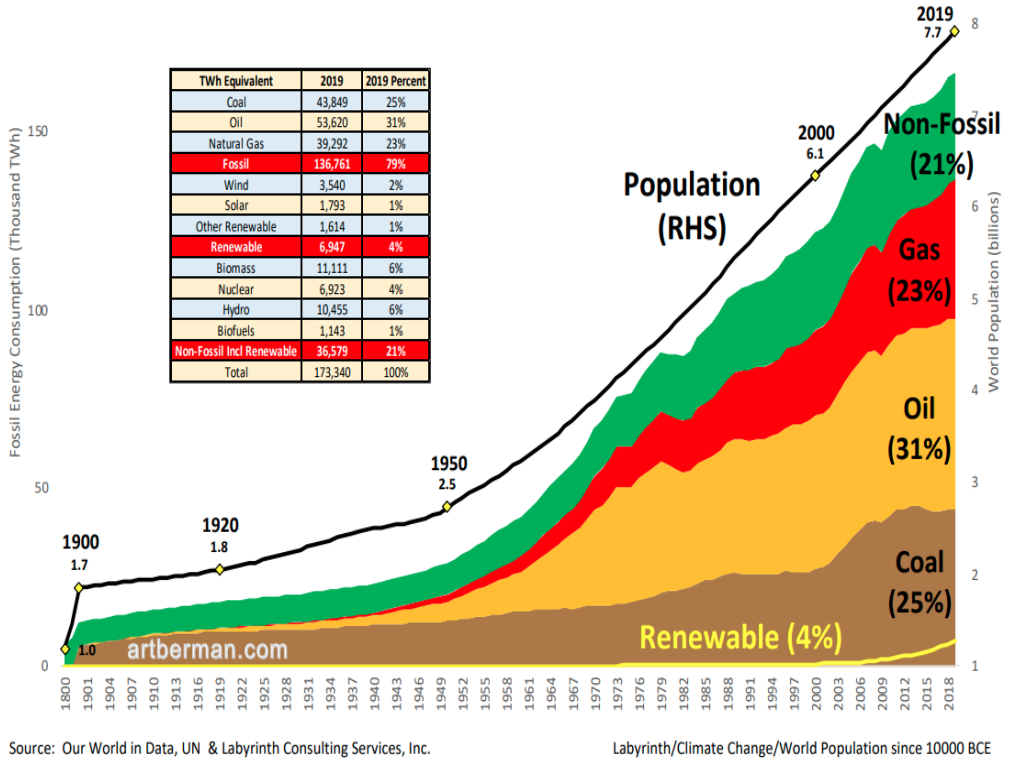
In 2020, global car sales decreased 15%, electric car sales increased 40%
After pandemic, 30% of white collar likely to work from home, compared to 10% before



IEA. 2020

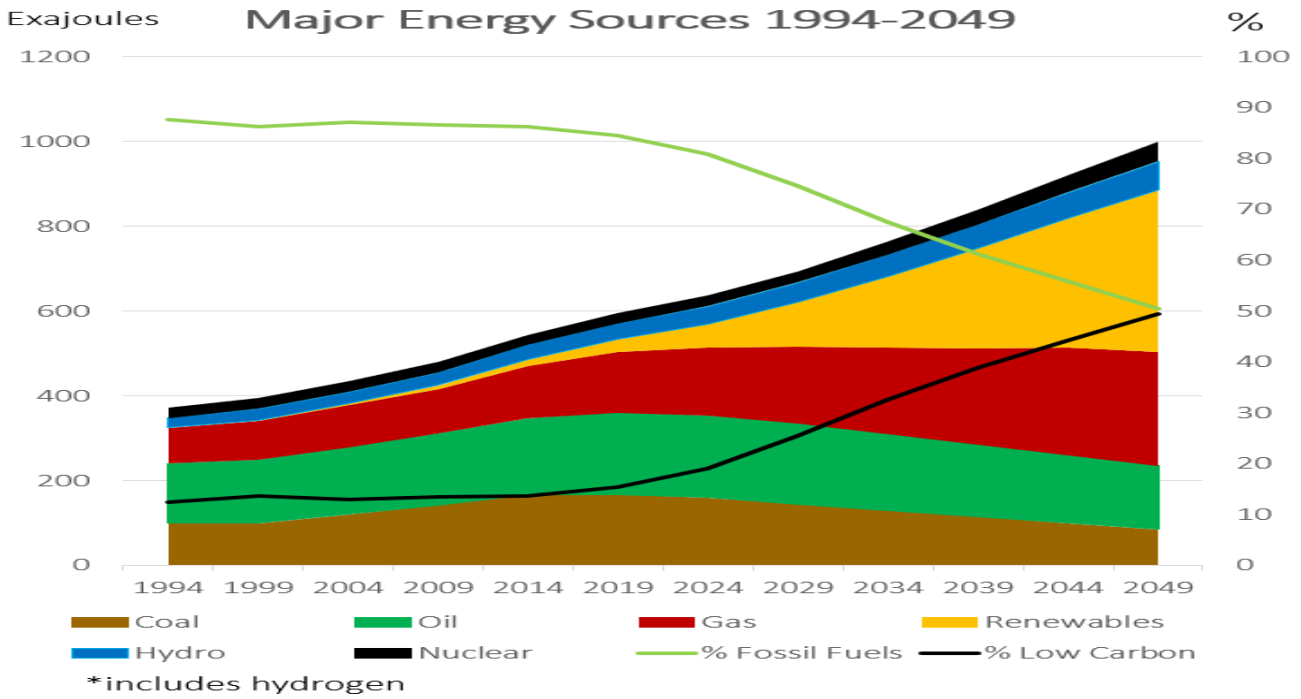
The global number of operating coal plants began to decline starting in 2018

The attempt to reduce CO2 emissions before 2050 will be challenging



Source: Our World in Data, UN & Labyrinth Consulting Services, Inc.

Labyrinth/Climate Change/World Population since 10000 BCE



- Energy use has closely paralleled population growth
- Average annual world energy growth of 2%/yr. in past decade unlikely to dramatically change
- Fossil fuels have consistently supplied about 80% of energy for the past 50 years
- Renewables (mainly solar + wind) grew at 14%/yr. in past decade

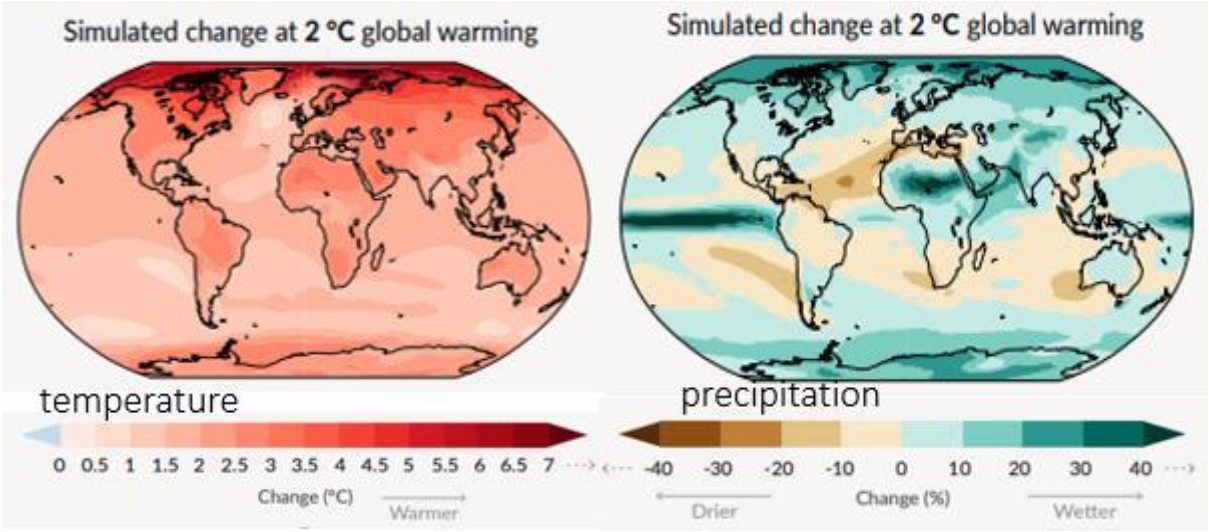
In order to flatten overall emissions, an optimistic but realistic scenario would include the following:

- Total fossil fuel use flat from 2020-2050*
- World energy growth 1.5%/yr.
- Energy increase covered by growth mainly in renewables (continue 14% increase/yr.) with some hydro and nuclear
- Fossil fuel share of energy reduced to 50% by 2050

*Coal use declines at 15% per decade
Natural gas increases 2.4%/yr.
Oil use plateau until 2030 then drops 1%/yr. after 2030

The Reality of Climate Change: Summary and Conclusions

- The planet is headed for a 1.5 deg. C temperature increase around 2030 and 2.0 deg. increase by mid-century. We need to prepare for it.
- How we respond in the coming decades will tell if the ultimate temperature increase is closer to 3 degrees C than 2, and if tipping points occur
- Based on current plans and commitments, the world is headed for the SSP2-4.5 scenario, or 2.7 deg C warming by end century
- Steps that can be taken to reduce the ultimate increase are clear: carbon pricing, carbon capture and sequestration, natural gas as transition fuel and methane reduction. Implementation of these policies on a global scale could result in GHG emission reduction beginning earlier than 2050.



The world at +2 deg C increase from 1900

Comparison of global emissions under scenarios assessed in the Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5 °C with total global emissions according to nationally determined contributions