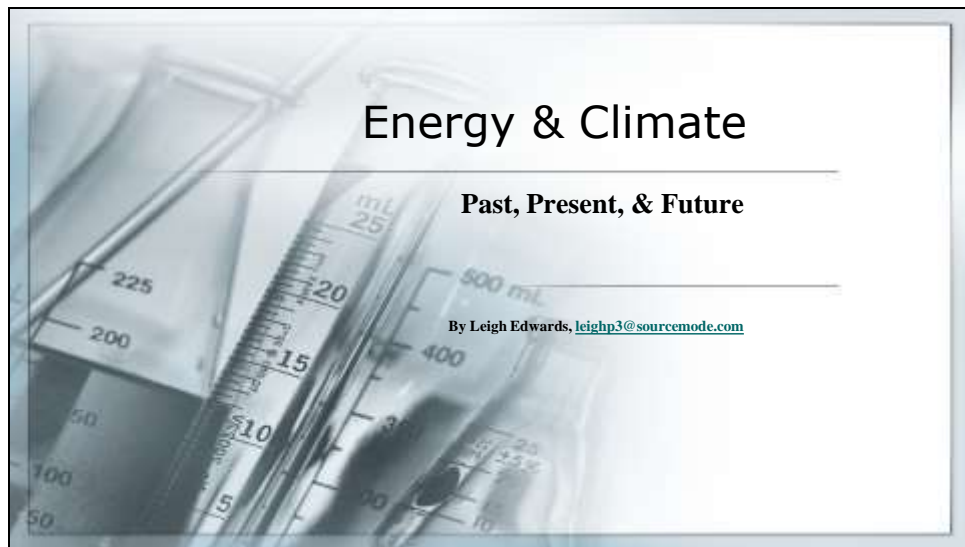
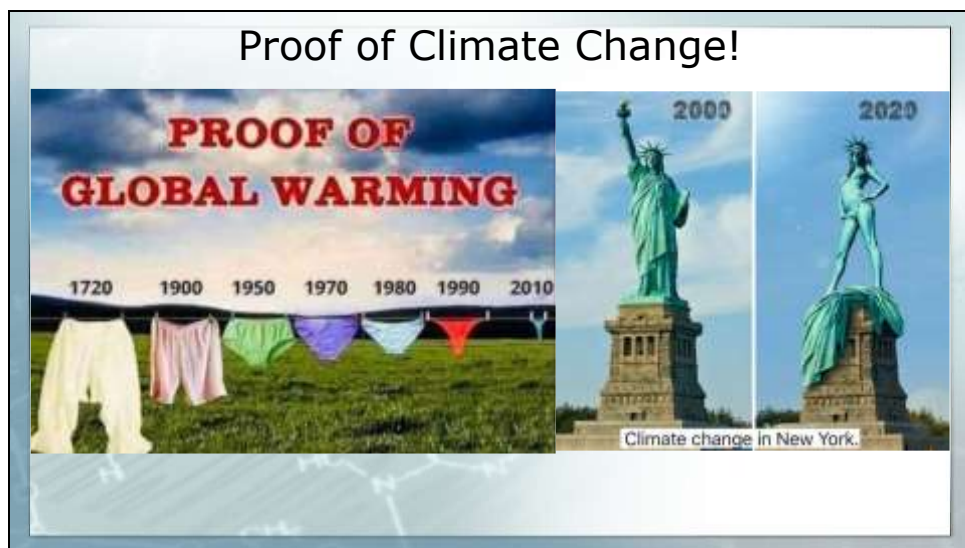


Slide 1



Slide 2



Climate – The Evidence

But seriously climate change is real

Apart from actual measurements of surface temperature rises, one of the most obvious signs are in global ice

Mountain glaciers are shrinking everywhere, in the Peruvian Andes, Puncak Jaya on the island of New Guinea, the Alaskan ranges, the Himalayas, in the Alps

In Chile, a glacier called HPS-12, retreated eight miles between 1985 & 2017

Sea ice has receded drastically; & as it does so less solar radiation is reflected back into space, & the heat is absorbed by the ocean, disrupting currents & ecosystems; Arctic Ocean sea ice has reduced by 40% since the 1980's

The great ice sheets on Greenland & Antarctica are melting adding enormous volumes of water to the world's oceans

Every year 400 billion tons of ice melting, adding 1mm to global sea levels each year; we are losing huge areas of land

In the vast boreal (forested) regions of the Arctic, permafrost is thawing, upending homes, buildings & other infrastructure, releasing CO₂ & CH₄, a particularly potent greenhouse gas

What is the meaning of boreal region? Definition: A forest that grows in regions of the northern hemisphere with cold temperatures. Made up mostly of cold tolerant coniferous species such as spruce and fir.

Greenland has lost 15 trillion tonnes of ice since the 1880's and half of that since the 1970! – Dr Zeke Hausfather

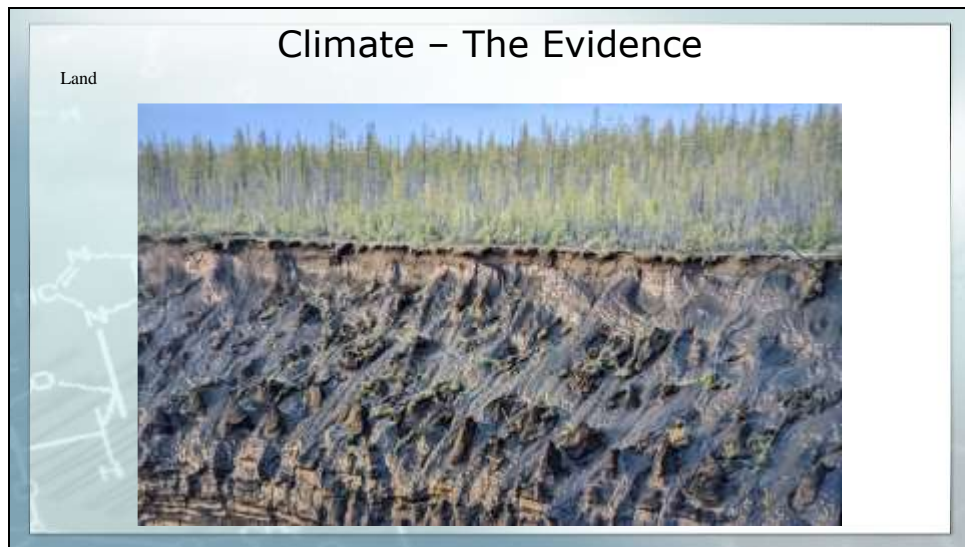
Climate – The Evidence

Land

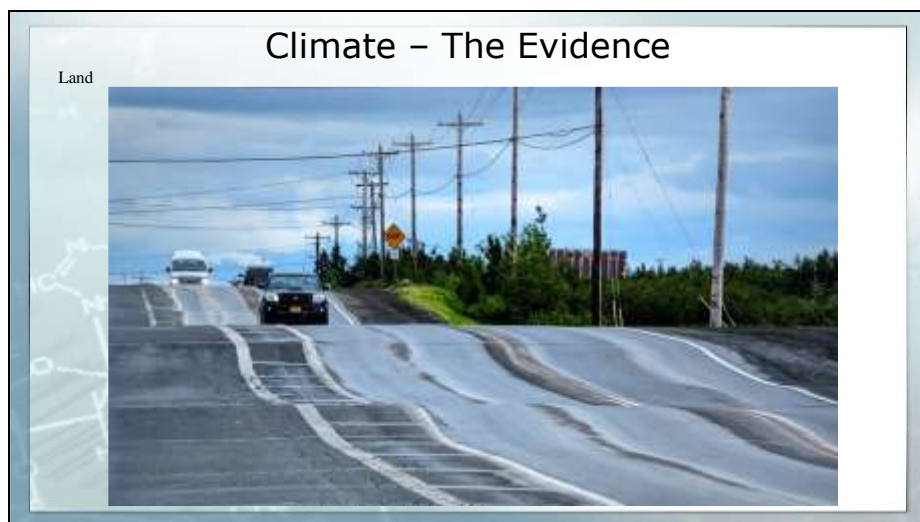
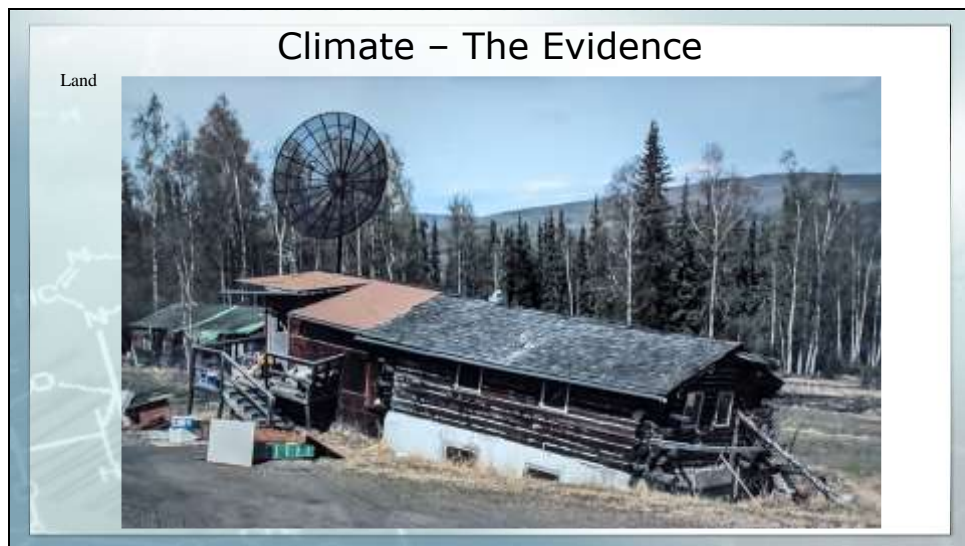


The image shows a large, dark, textured rock formation in a grassy field. The rock has a rough, layered appearance, suggesting it might be a remnant of a permafrost feature or a glacial deposit. The surrounding landscape is green and hilly, with a clear blue sky in the background.

Slide 5

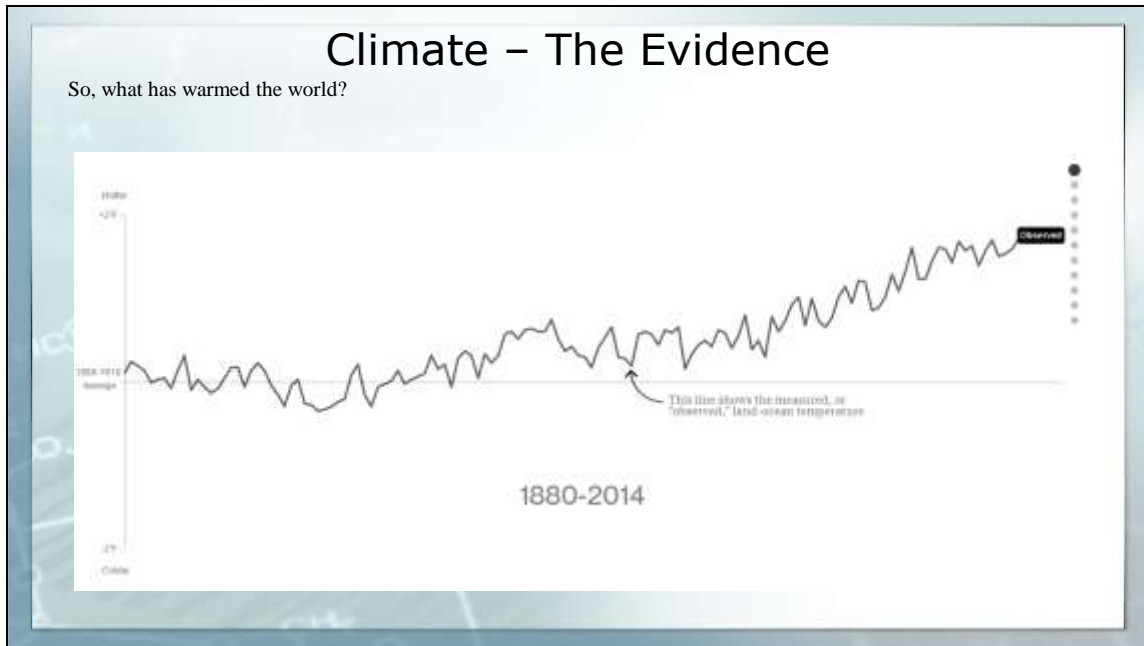


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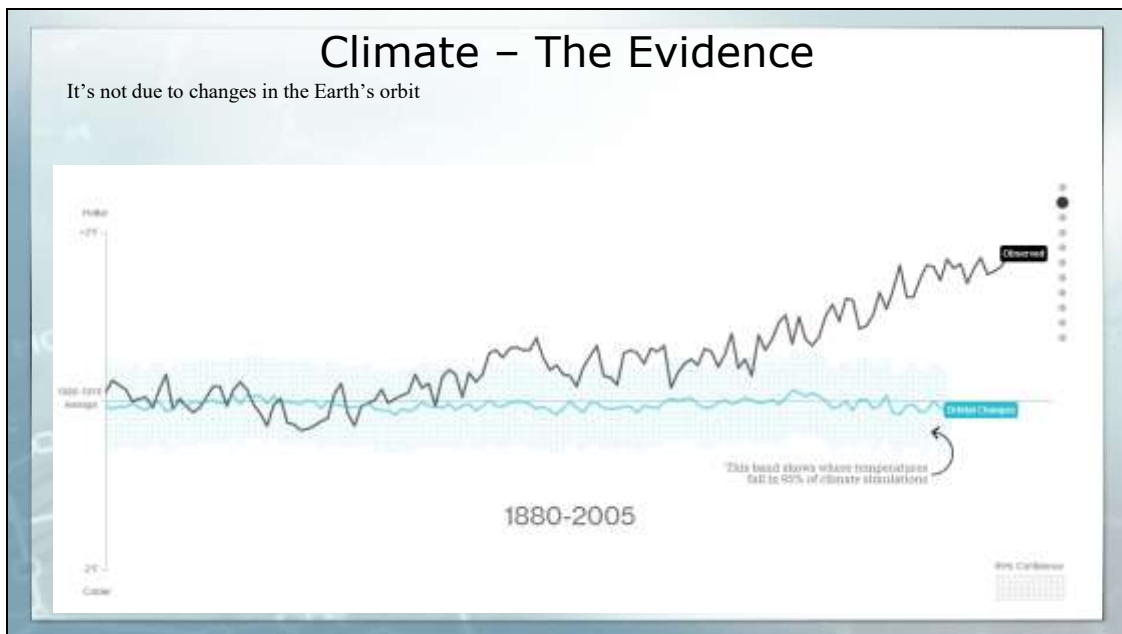


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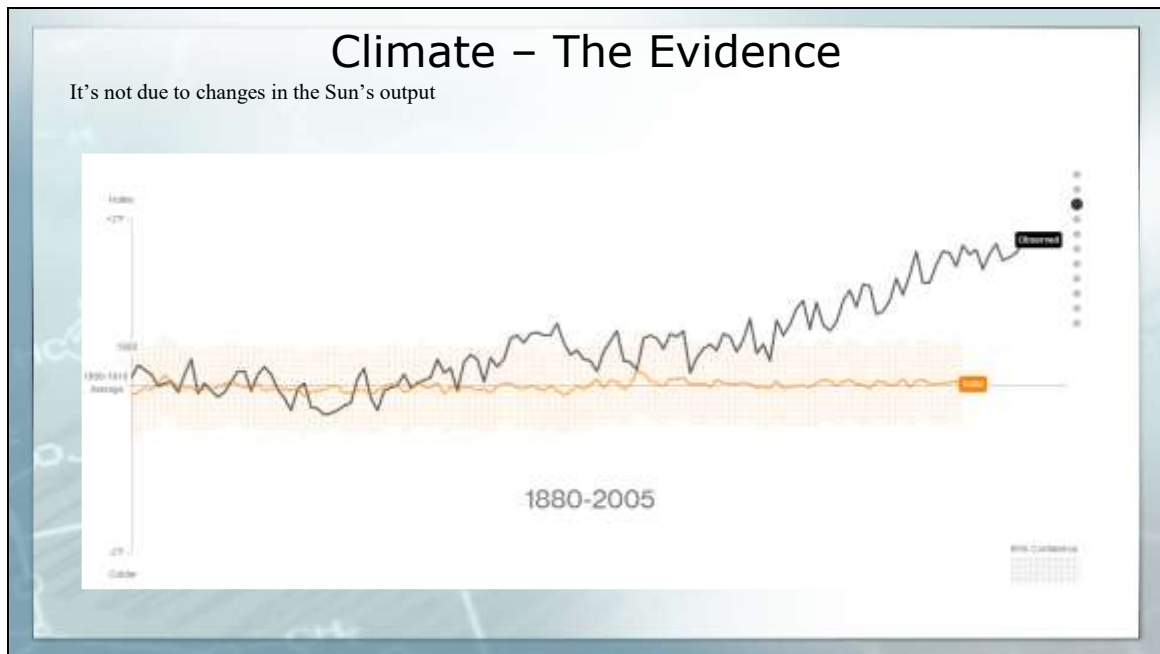
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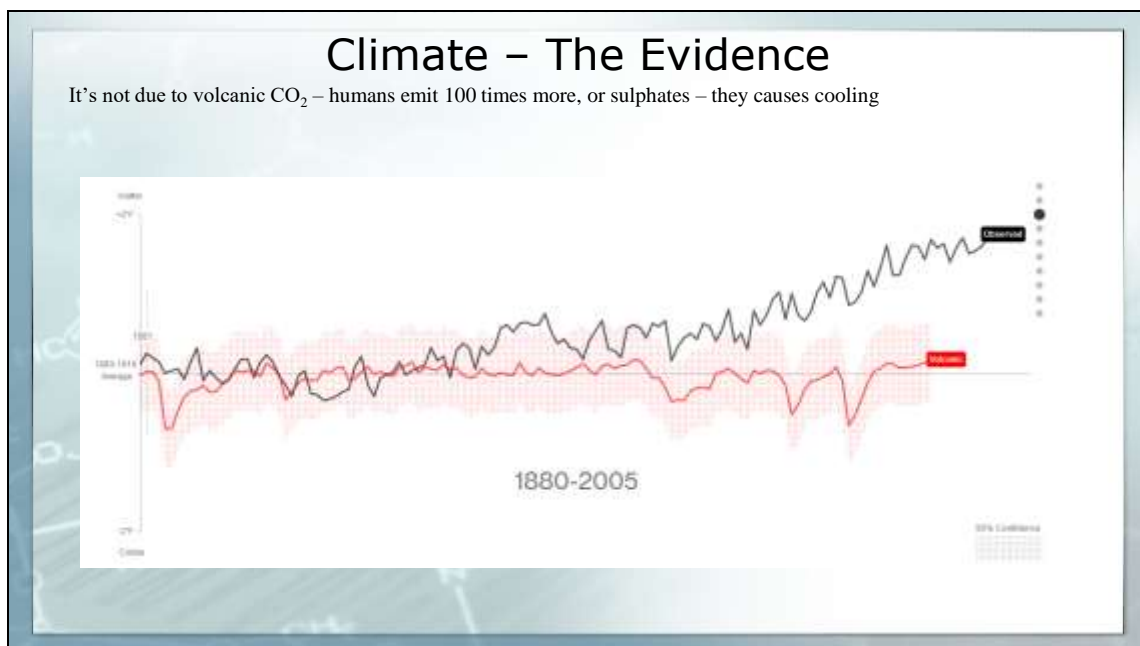
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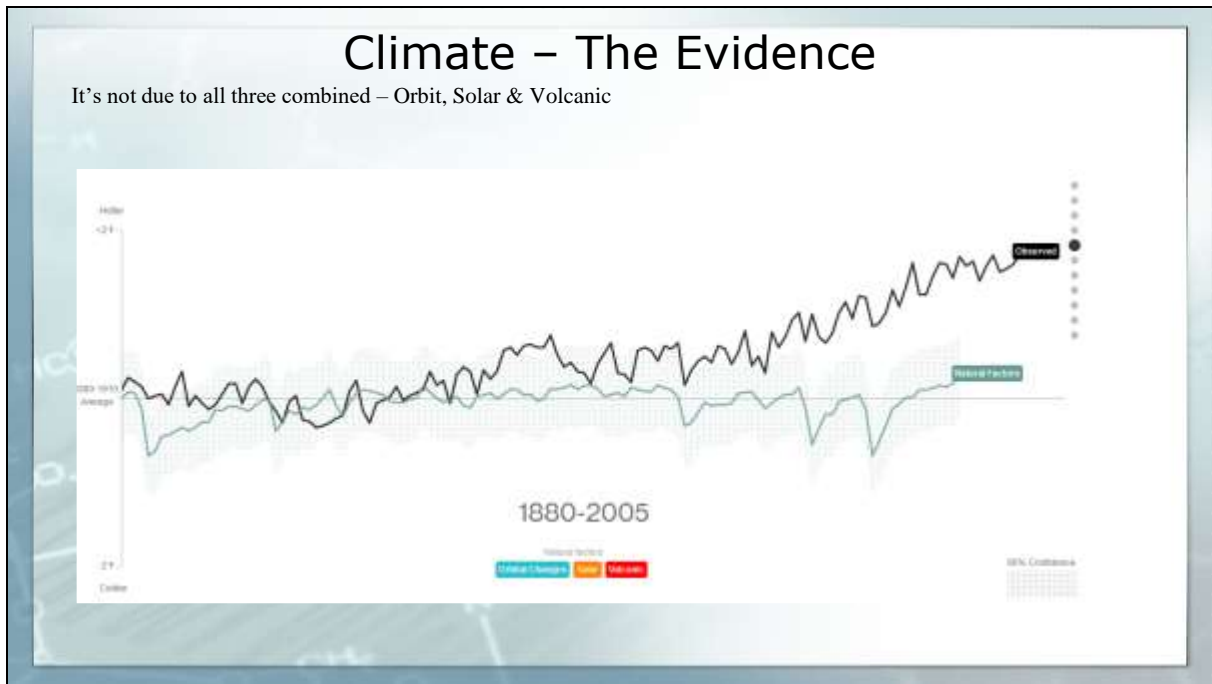
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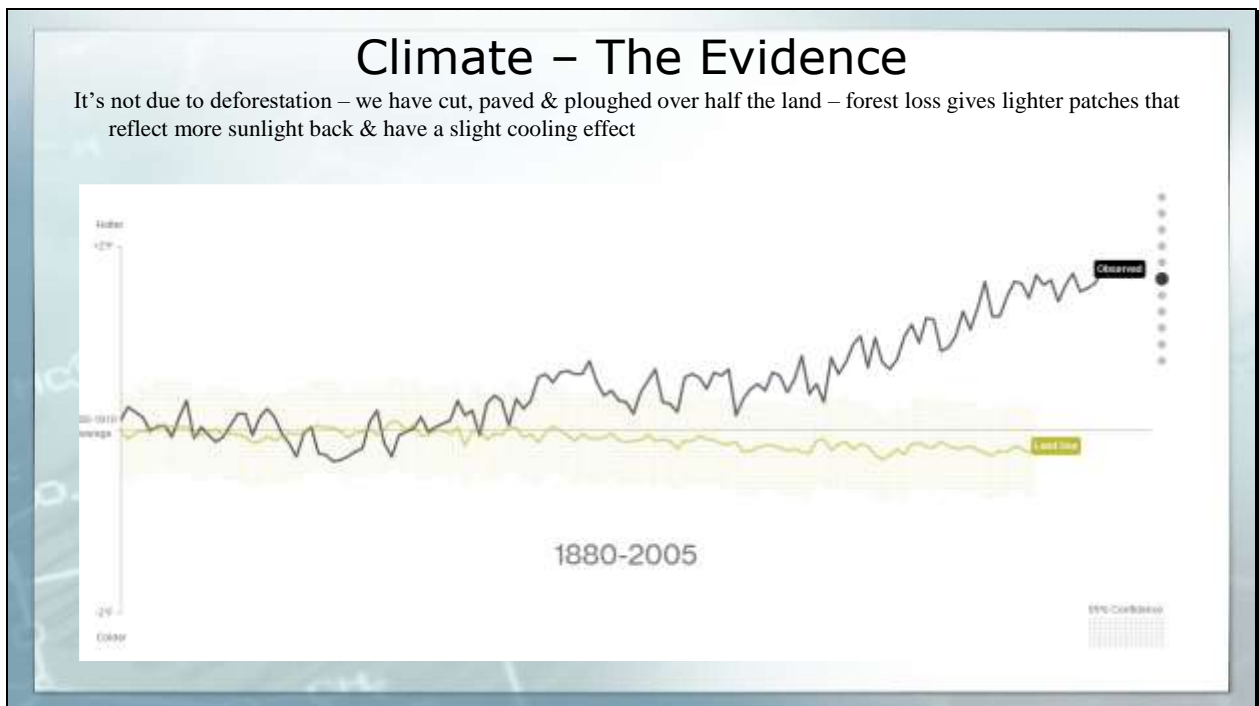
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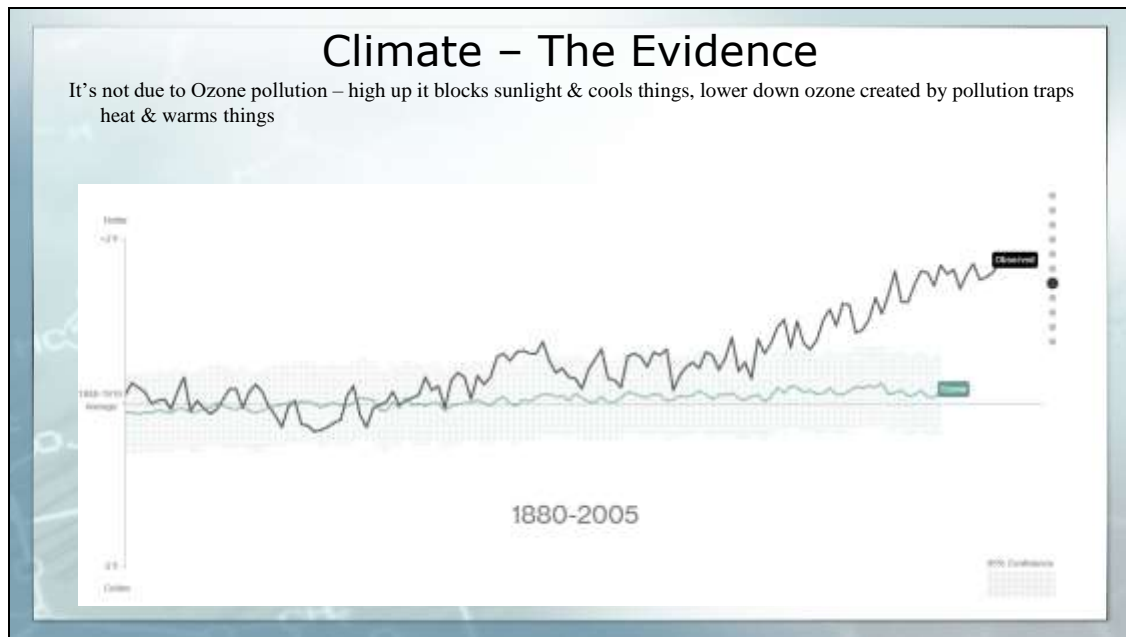
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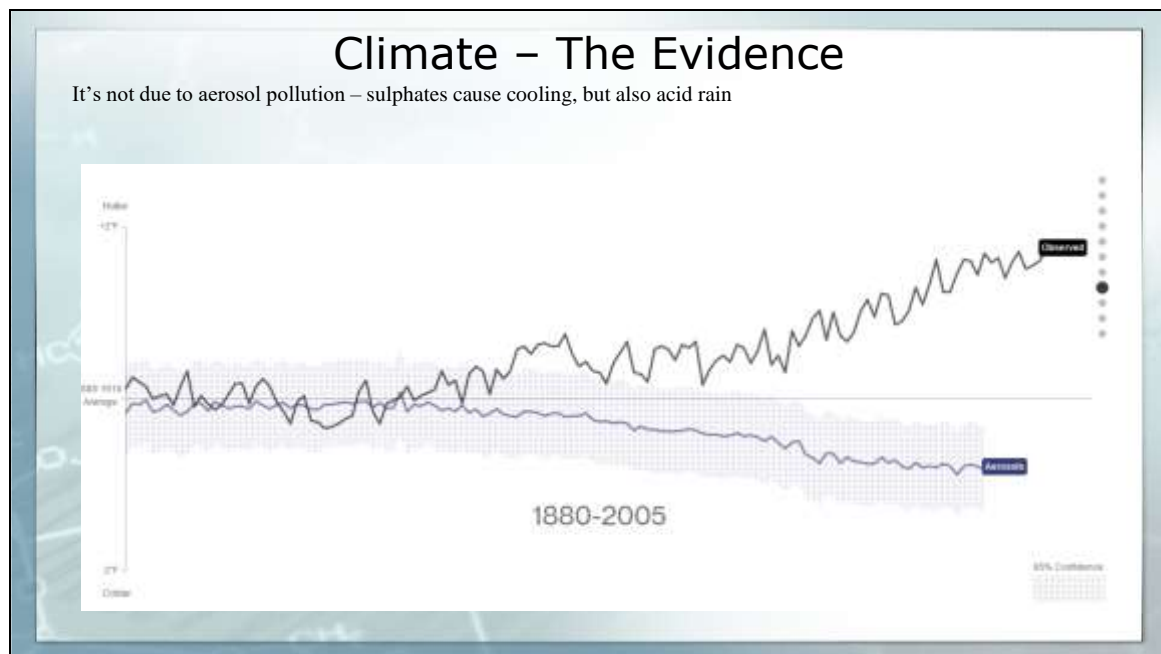
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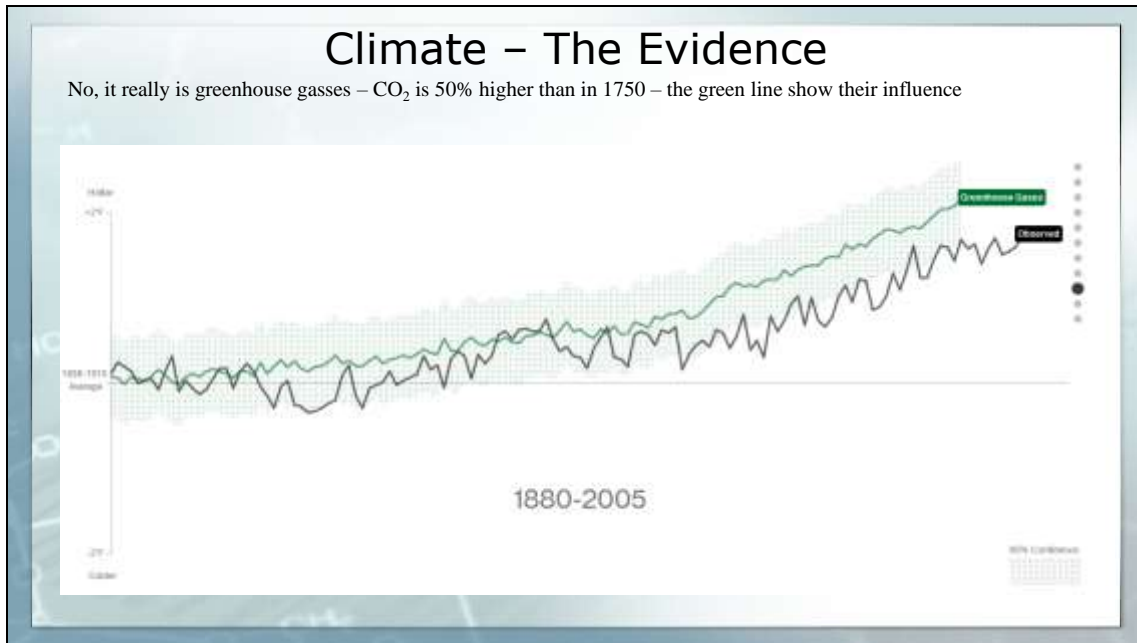
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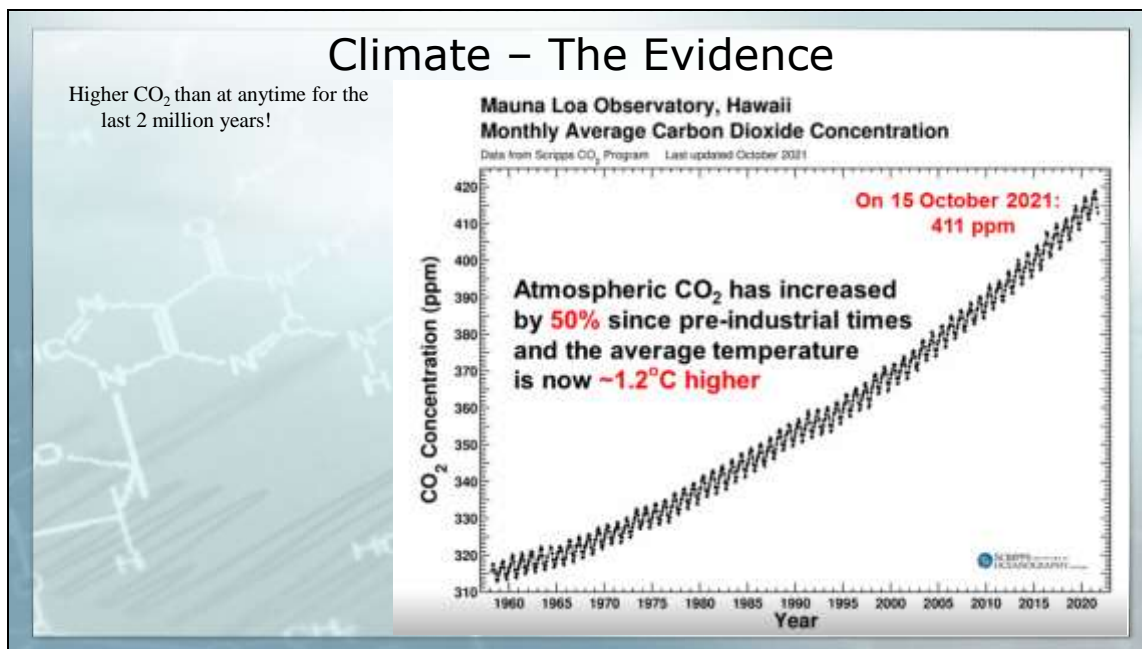
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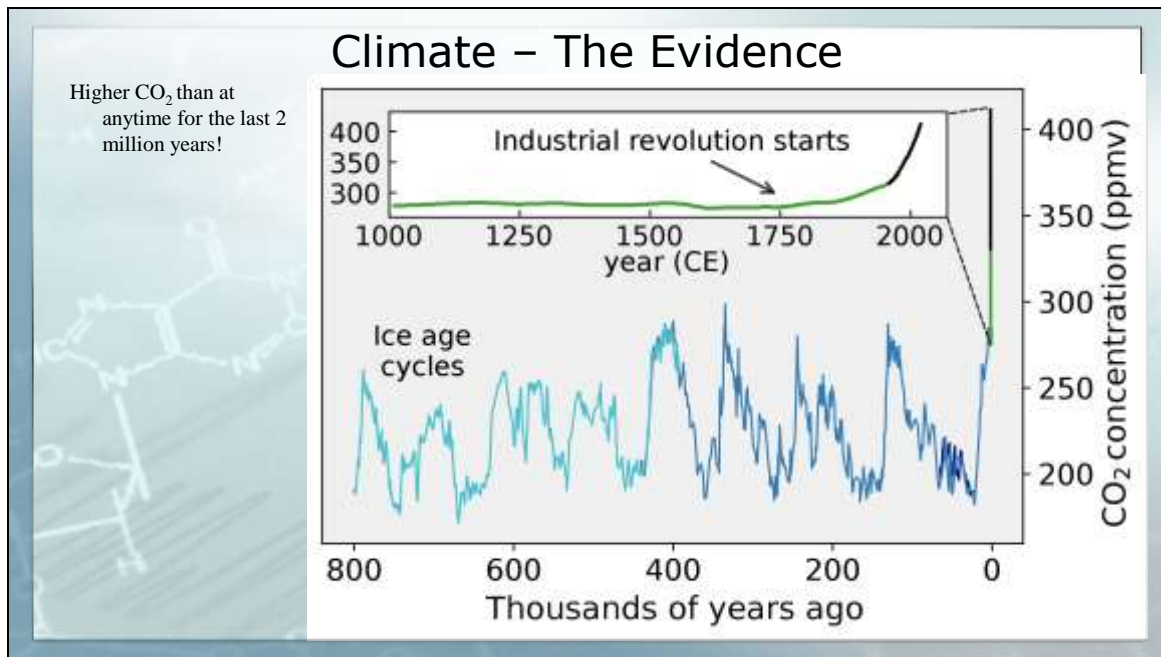
Slide 16



Slide 17



Slide 18



Slide 19

Weather vs Climate

Weather is not climate – the difference is ...

- Weather is how you choose your outfit; climate is how you choose your wardrobe
- Weather is the mix of events that happen each day in our atmosphere, including temperature, rainfall, & humidity; it's not the same everywhere & depends on where you live
- Climate, in your place on the globe, controls the weather where you live, & is the average weather pattern in a place over very many years

Weather vs Climate

Weather prediction is difficult, but getting better, but chaos theory sometimes plays a role, & destroys our predictions

E.g., The major storm / cyclone 15-16th October 1987 defied all weather predictions at the time – 122 mph winds!
Too many Navier-Stokes equations of fluid dynamics to solve, & the sheer scale of the computational task
Bigger computers, ensemble forecasts now, plus probabilistic information about the conditions to come

Climate change prediction is difficult

If we can't accurately predict the weather, then how can we predict the climate?

“The theory of global warming is a gigantic weather forecast for a century or more. However interesting the scientific enquiries involved, therefore it can have almost no value as a prediction.” Charles Moore – The Telegraph 6th April 2014

And his qualifications? – a 2.1 BA in English & History!

He is a Trustee of:

The Global Warming Policy Foundation (GWPF) is a lobby group in the UK whose stated aims are to challenge "extremely damaging & harmful policies" envisaged by governments to mitigate anthropogenic global warming
The GWPF, & some of its prominent members individually, are practicing climate change denial!

Exaflop (10¹⁸) computers now

Energy & Climate

On the other hand:

New York Times – 8th November 2019, “How Scientists Got Climate Change So Wrong”
“Few thought it would arrive so quickly. Now we’re facing consequences once viewed as fringe scenarios.”
By Eugene Linden

Climate change is almost certainly brought about by human activities – this now the consensus of most scientists – IPCC Report of August 2021 (4000 pages!)

Due to our past, & ever-increasing, need for fuel & energy

So, in the rest of this presentation we’ll:

- Look at climate modelling, & why we should take its predictions seriously
- Look at human energy sources & usage in the past & up to the present time
- Look at future predictions of the climate, depending on what actions we take?
- Also, at what actions could make a difference, & some of which cannot?
- Then we’ll look at human energy usage, & options in the future, for generation methods & energy economies

NYU Physicist Prof Emeritus Steve Kunin’s recent book ‘Unsettled’ – was assessed for its scientific merit by a review panel of experts and assessed to be of very low scientific merit. He’s cherry-picking data and studies and not considering the others!

Slide 22

Climate - Modelling

Modelling has gone on for over 40 years; very simple initially with few factors considered & monitored e.g., radiation from the sun, convection, dynamics – very simple, but it turned out the models could tell us things about the climate, even though it was much more complicated than the models in use

Gradually got more sophisticated incorporating many more factors about a lot more of the Earth's systems

For example, ice sheets, solar radiation, sea ice, the carbon cycle, atmospheric composition, volcanic aerosols, the ozone layer, the deep ocean, the soils, the biosphere, the mountain bases, topography, orbit of the earth, all of these things, & more are now incorporated

Plus, we have gathered so much more data, & measurements, & plus incredible global surveillance going on by numerous satellites looking at the Earth & the Sun

Around the world there are around 40 or so research groups in more all major countries who have written around 61 climate models

Each takes a slightly different approach to the elements of the climate system, such as ice, oceans, or atmospheric chemistry – but they are all approximations – but provide results that are very valuable

Dr Zeke Hausfather - models are not right or wrong; they're always wrong. They're always approximations. The question you must ask is whether a model tells you more information than you would have had otherwise. If it does, it's skillful.

1993 sea level measurements became very much more accurate due to satellite altimetry measurements.

Slide 23

Climate - Modelling

As they've expanded the scope of their models, they have become more skilful, by putting more in, so the outputs have become even more realistic

Now have models that can explain what we see in the weather, or in the climate, & in the changes over the past 100 years

Plus, they're able to project things going forward in a skilful way, & have been able to test those projections

By varying the boundary conditions e.g., the amount of forest cover, or atmospheric composition, or ozone levels, they can make accurate predictions of future conditions

For example, increasing atmospheric greenhouse gases, such as CO₂, will increase surface temperatures, this will lead to ice melting at the poles & in glaciers – ensemble modelling

Or varying the physics of specific aspects of the model e.g., effects of cloud cover, or ocean uptake - ensembles

We can't predict the weather beyond about ten days, but we can predict the statistics of the weather over much longer periods, according to how those boundary conditions might change

For example, the intensity of rainfall, floods & storms, higher frequency of heatwaves, droughts, rising temperatures & wildfires & the damage to the crops & land

We can see changes in the ecosystems – sea level rises, coral reef reduction, extreme weather, ocean acidification, loss of biodiversity etc., etc.

Drought as far as crops are concerned there are two key factors – how much rainfall there is and how hot it is – and even if the rainfall has not changed much the moisture in the soil may be too low for the crops due to increased temperatures!

Climate - Modelling

We know that the planet has warmed more than a degree C over the last hundred odd years & most of that warming has come in the last 60 years – this is based on detailed measurements & records

But how do we determine the actual cause?

How can we really say it is due to CO₂, & not due to changes in the Sun's output, or something else?

Well, the patterns are different!

If it were due to the sun's output increasing, then yes, the surface would have warmed, but the whole atmosphere would have warmed up too – but that's not the case

If it were due to CO₂ then that causes the surface to warm, but anything above the troposphere & the stratosphere causes it to cool, because carbon dioxide is more efficient in those areas at emitting than it is at absorbing due to the way spectral absorption works, & so you have a very different pattern for carbon dioxide driven change than you do for solar driven change

All other likely causes have been considered & ruled out

Solar radiation peaked in the 1950s & it's been slightly decreasing ever since, & it's not a very big effect anyway, & even if we got it wrong by an order of magnitude it would still have the wrong pattern of change

Maybe the ocean is putting lots more heat into the atmosphere, but if that was the case the ocean should be cooling, but instead the oceans are warming!

Layers of the atmosphere – from bottom to top Troposphere, Stratosphere, Mesosphere, Thermosphere, Exosphere

Climate - Modelling

Ocean warming tells us that something is changing at the top of the atmosphere, by conservation of energy

If more energy is coming into the system, then it must be coming in at the top

What changes the radiation balance at the top, things like greenhouse gases, or the sun, or atmospheric aerosols

They have looked at each of those things

The quantity of aerosols in the atmosphere have decreased

The amount of greenhouse gases have increased, so is that expected to cause more energy to be come in than is leaving, & yes, it is!

So where is that additional energy going - it's going into the oceans

Now they have the data for the heating of the oceans, they saw it was exactly at the level & the rate that was expected, because of the increases in greenhouse gases

So, they've made real predictions, that have been verified, & that demonstrate that they have understood what's going on, & for the right reasons

CO₂ is largely transparent to Visible & UV radiation from the Sun, but it is opaque to outgoing Infrared radiation!

Three key uncertainties in climate modelling are – human uncertainty what we do and don't do e.g., cutting tree, burning fossil fuels etc, **climate sensitivity** – how the planet will react to what happens and what humans do, and **carbon cycle feedback** – how the planet will deal with carbon and absorb it or not in the oceans and atmosphere and plants and other sinks

Climate - Modelling

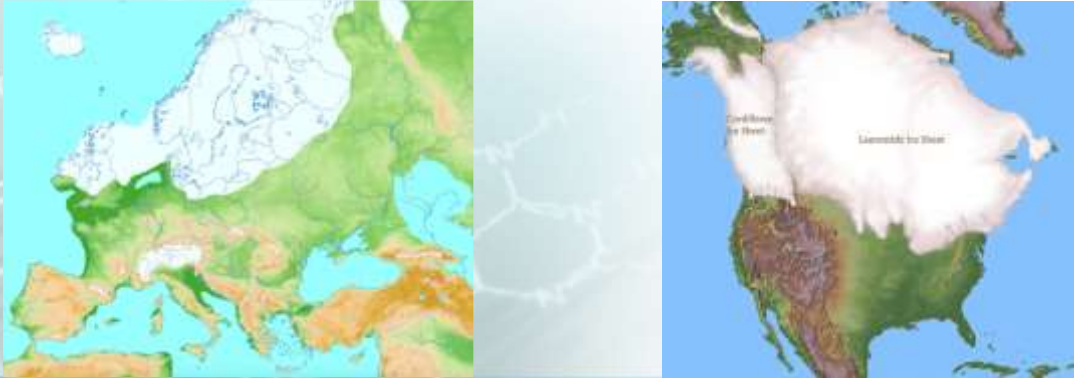
Why is 1 or 2 degrees warming so worrying?

Last ice age was about 20,000 years ago & there were glaciers & ice sheets all over the UK, Scandinavia, North America

Massive amounts of water were locked up on land & the sea levels were around 120 metres (390 feet) lower than now

But the temperature change between then & now was only about 6 degrees Celsius!

So, if we do nothing, then the planet could be warmer by the same amount than the ice age was colder!



Greenland has lost 15 trillion tonnes of ice since the 1880's and half of that since the 1970! – Dr Zeke Hausfather

Climate - Modelling

We have measured just over 1 degree C of warming to-date

The land is warming more than the Oceans, & the Arctic is warming more than anywhere

The statistics of weather are already apparent now – more extremes

We are trying to change our behaviours, but are we doing enough, quickly enough

Models are not perfect & have uncertainties & different models (around 40) have different uncertainties

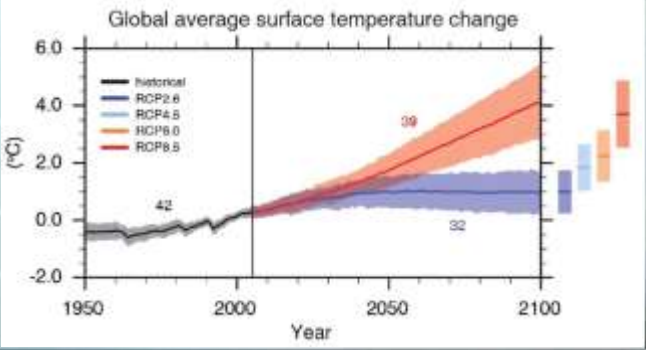
There are ways to reduce the uncertainties

Better data & new measurements about the past

Better data & new measurements about now

Improved, more detailed models

Increased computational power



Representative Concentration Pathway (RCP) is a greenhouse gas concentration (not emissions) trajectory adopted by the IPCC. Four pathways were used for climate modeling and research for the IPCC fifth Assessment Report (AR5) in 2014.

The pathways describe different climate futures, all of which are considered possible depending on the volume of greenhouse gases (GHG) emitted in the years to come.

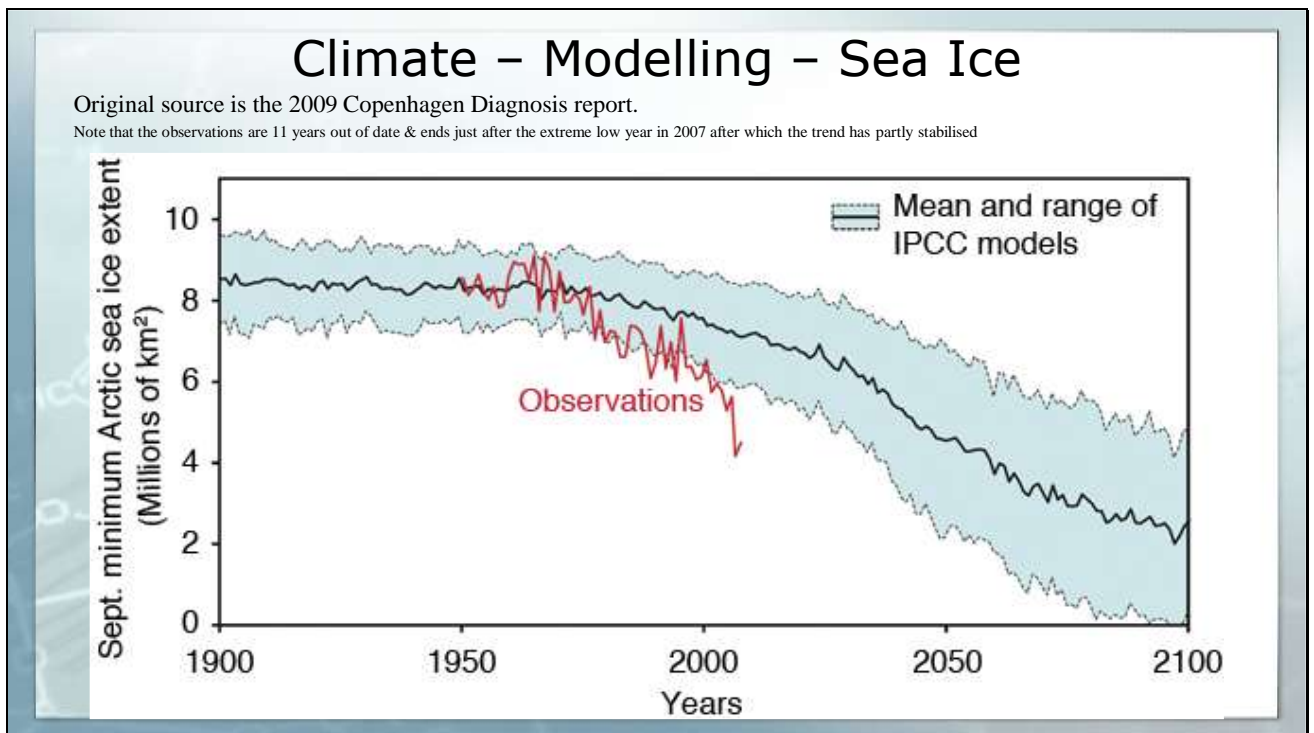
The RCPs – originally RCP2.6, RCP4.5, RCP6, and RCP8.5 – are labelled after a possible range of radiative forcing values in the year 2100

Between 2010 and 2020, 15 times more people died from floods, droughts and storms in very vulnerable regions including parts of Africa, South Asia and Central and South America, than in other parts of the world.

Nature is already seeing dramatic impacts at the current level of warming.

Coral reefs are being bleached and dying from rising temperatures, while many trees are succumbing to drought.

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Climate - Modelling

Future warming is just a function of future emissions, so that means that we still control of how much it's going to warm in the future, & that's quite an empowering message?

However, there are some potential amplifiers of our carbon emissions!

Water vapour, clouds, carbon cycle & vs oceans, ice albedo vs sea water, methane

So, for how long will we be in control?

If the warming goes too far, we risk releasing all the methane locked up in the permafrost, & in clathrates in the oceans
That would lead to a tipping point & an irreversible runaway greenhouse effect

Methane (CH₄) already contributes to 30% of the warming, so rapid & sustained reductions called for in August 2021 IPCC report

Great video from the Bad Boy of Science
<https://youtu.be/jvsLkxho3Pg>
 Great website
<https://www.carbonbrief.org/>

Methane comes from many natural sources, rice production (equal the whole of aviation) landfills, leaks from fossil fuel systems – accidental or deliberate

Energy & Climate

Look at human energy & power sources & usage in the past & up to the present time

Human effort, the Sun, animal power, water & wind, dried dung, wood

Then coal – particularly from around 1769 onwards – steam engines

Fuels – tallow for candles, then Whale oil – by 1850 whale oil was America's fifth biggest industry

Then a shortage of whales raised prices & competition from kerosene & gas, both synthesised from coal, took over

In 1859 Drake struck oil in Pennsylvania, & in less than a decade whale oil was in steep decline – thank goodness!

Gas for lighting from 1812, & then by 1879 electric light was rapidly taking over, hydro-electricity from 1878

November 1973 the Arab Oil Embargo rocked the major economies of the world

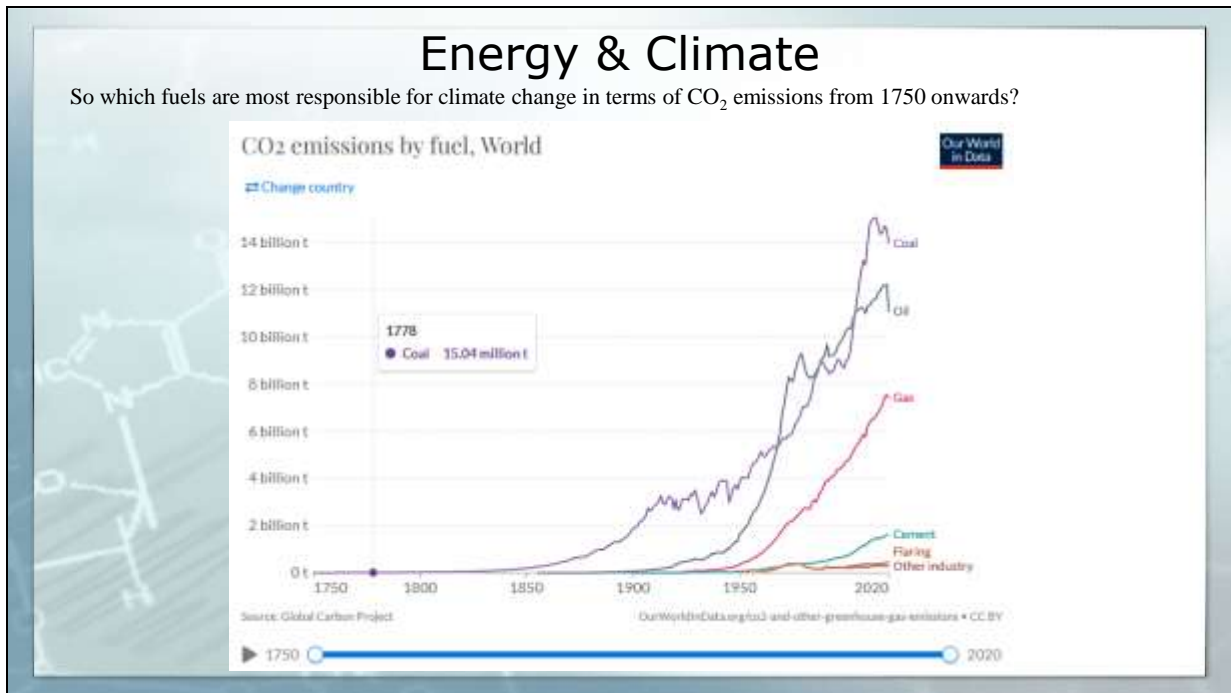
By 2009 the US economy was using 60% less oil, 50% less energy in total than in 1975, but there is much scope left

For example, in the US 71% of all oil used is in transportation, so the scope for reduction is huge!

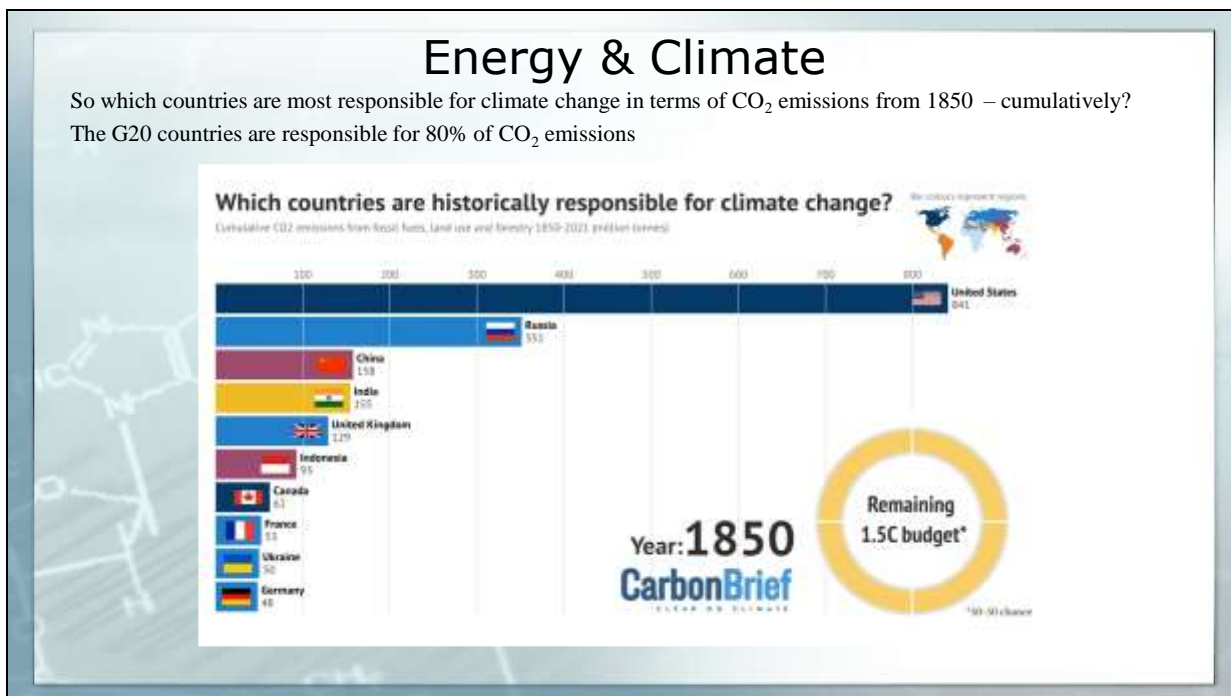
Whale oil is oil obtained from the blubber of whales. Whale oil from the bowhead whale was sometimes known as train oil, which comes from the Dutch word traan ("tear" or "drop"). Sperm oil, a special kind of oil obtained from the head cavities of sperm whales, differs chemically from ordinary whale oil: it is composed mostly of liquid wax. Its properties and applications differ from those of regular whale oil, and it is sold for a higher price.

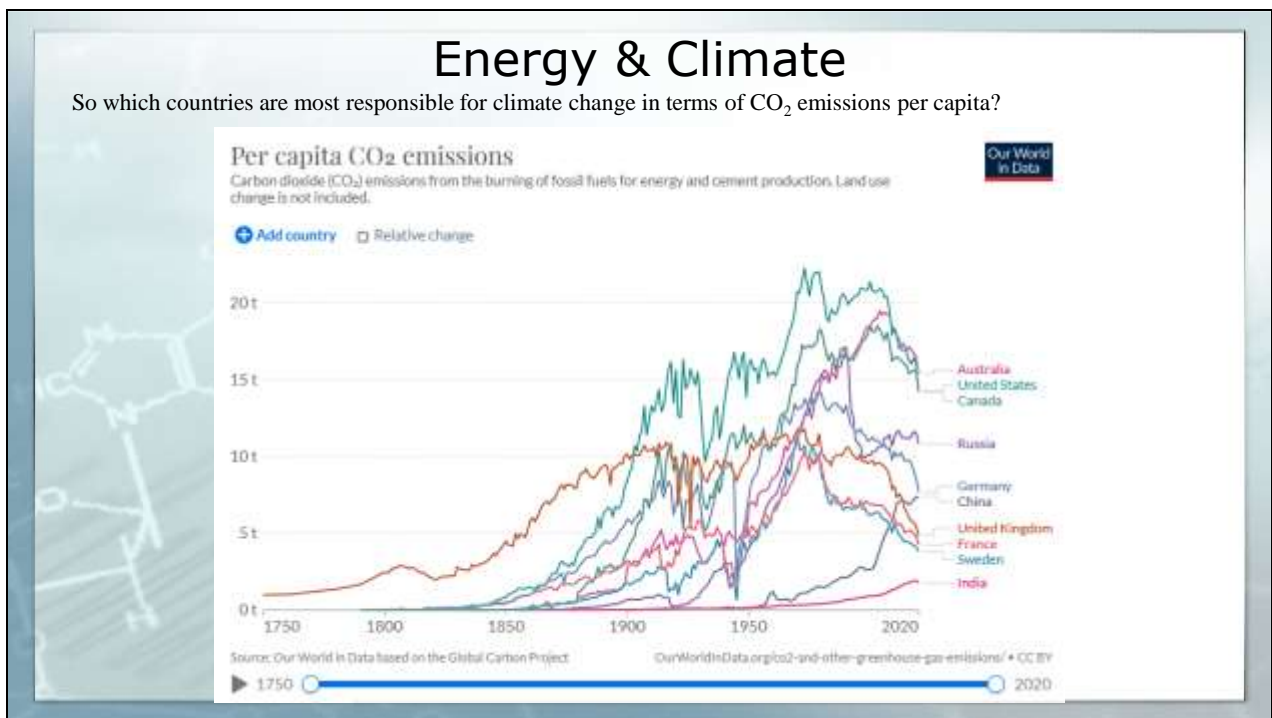
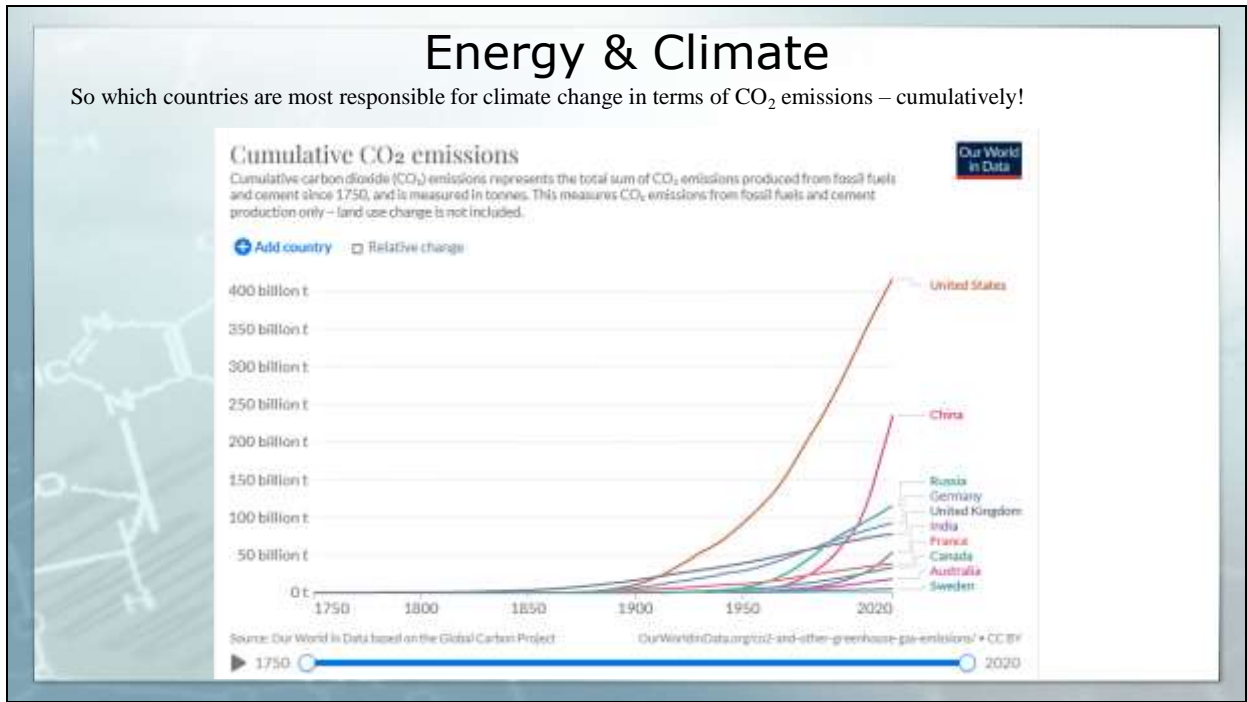
This is the well near Titusville, Penn., that pumped the petroleum industry into existence 100 years ago. The picture was taken four years after **Col. Edwin L. Drake** struck oil on Aug. 27, 1859.

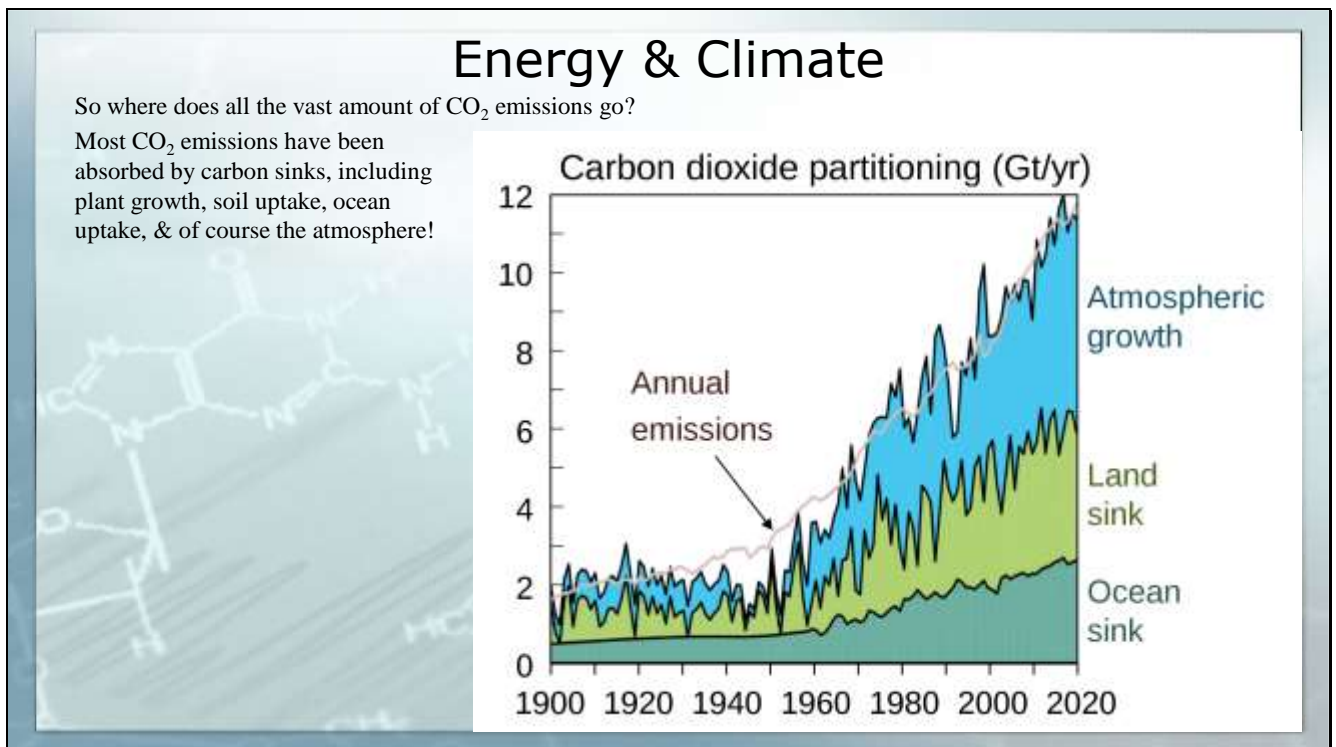
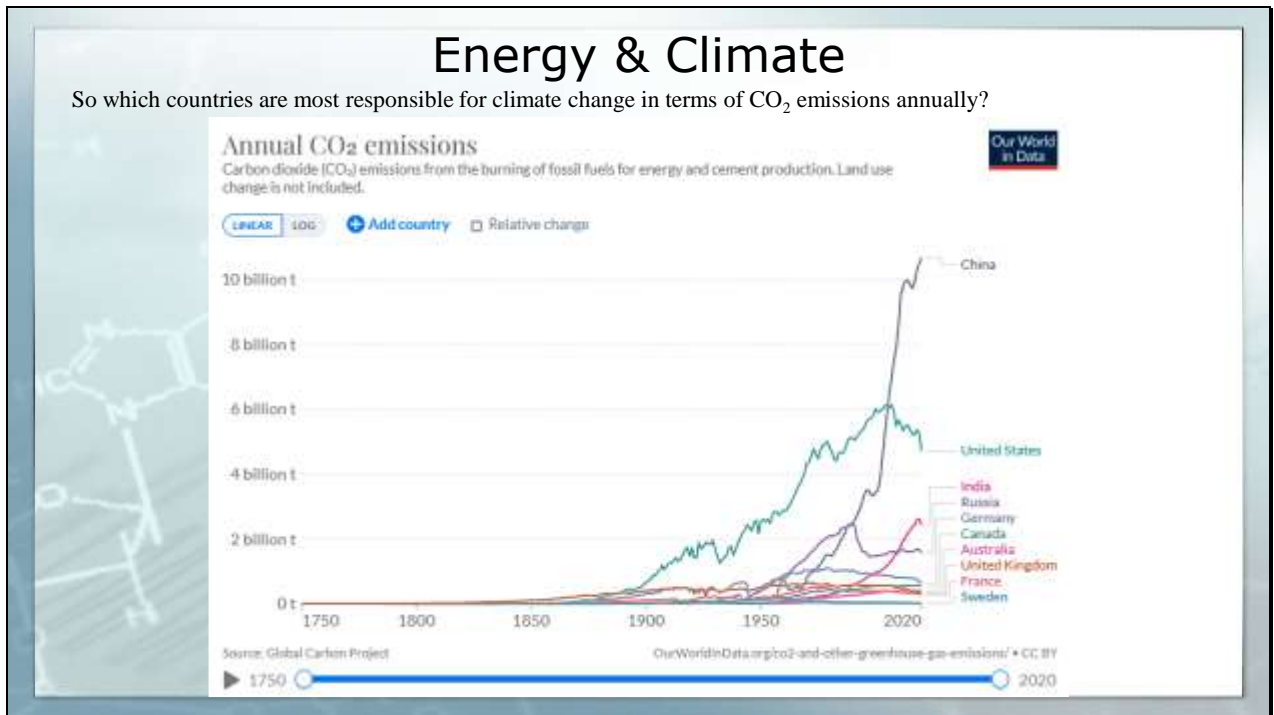
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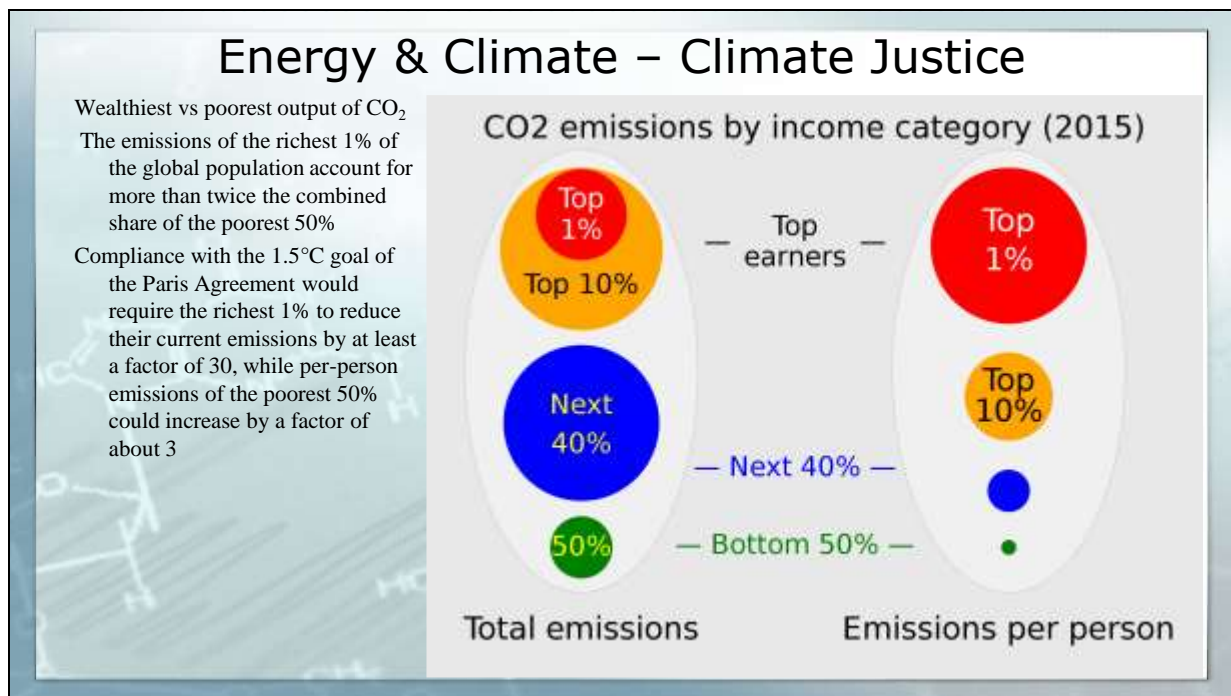


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Energy & Climate – United Nations

United Nations IPCC – Intergovernmental Panel on Climate Change – the body responsible for assessing the science related to climate change

Climate change has been brought about by the richer developed countries & the developing countries are the worst hit

United Nations Climate Change Conference 2021 (2022) COP26

Keep 1.5 Deg C alive – was the aim

Pledges made on methane, deforestation, coal, finance & so on

If all the pledges made at COP26 are met, then we might limit warming to something like 1.8 or 1.9 degrees, so, there's still very big gap between doing that & 1.5 – few countries are sufficient Gabon & Bhutan

Ratchet mechanism, every five years countries must come back with greater ambitions

So, all countries are to come back by the end of 2022 & strengthen their pledges as necessary to meet the goals of the Paris agreement (2015) of 1.5 or well below 2 Deg C

Best estimates from the IPCC suggest we need to cut emissions by 45% below 2010 levels, by 2030, however under current commitments, global emissions are set to increase by almost 14% over the current decade!

Rich countries pledged to provide poorer countries with \$100 billion worth of climate finance every year from 2020, the report basically said sorry we haven't done it

The Glasgow climate pact urges rich countries to deliver what they promised as soon as possible, & to do that every year through to 2025

Also sets in place this process through which a new target of climate finance is going to be worked out which is going to kick in from 2025

The reporting requirements on progress & emissions & on promises met have been made far more stringent for all

During the coronavirus pandemic CO2 emissions were reduced by 7% for 2020!

Energy & Climate – United Nations

COP26 & Climate Justice

The question about finance for loss & damage, the World's already warmed by more than 1 Deg C, we're already seeing increases in extreme weather around the world, storms, flooding & such

Some of the most vulnerable countries don't have the financial resources to quickly bounce back & rebuild after they've faced disaster, so they have been asking for a long time for specific financial support, separate climate finance, to help them meet their climate pledges, which would actually help address this loss & damage

They didn't get that, they got what's called 'the Glasgow dialogue', effectively a talking shop to think about how finance for this problem might be provided in the years ahead

The provision of climate finance hasn't reached that \$100 billion p.a. target, as promised, & the majority of the money's been going towards mitigation, in other words helping countries to cut emissions

It is easier to fund a project for a wind farm, or to help someone install efficiency measures at industrial plants, whereas Adaptation Funding is less defined i.e., such as building sea defences, or early warning systems to help people prepare for extreme weather events, or mechanisms to help farmers shift the kinds of crops they are growing etc.,

Glasgow agreed add to double Adaptation Finance, from a specific baseline of 2019, so that over the next few years countries are going to have to make a significant increase in provision

Energy & Climate – The Kaya Identity

The Kaya identity was developed by Japanese energy economist Yoichi Kaya

It is the subject of his book Environment, Energy, & Economy: strategies for sustainability co-authored with Keiichi Yokobori as the output of the Conference on Global Environment, Energy, & Economic Development (1993 : Tokyo, Japan)

What determines total CO₂ emissions?

The 'Kaya Identity' breaks down total emissions into the key elements driving them.

Total CO₂ emissions = Population x CO₂ emissions per person

Income
Goods and services per person in a country

↓

GDP
Population

x

Technology
CO₂ emissions per \$

↓

Energy intensity
Energy consumed per \$

↓

Energy
GDP

x

Carbon intensity
CO₂ emitted per unit of energy consumed

↓

CO₂
Energy

↓ energy intensity by:

- Improving energy efficiency
- Switching to low intensity industries

↓ carbon intensity by:

- Switching to renewable energy
- Switching to nuclear energy
- Switching gas for coal gas fuel
- Capturing & storing fossil CO₂ (CCS)

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Energy & Climate – The Kaya Identity

Developed by Japanese energy economist Yoichi Kaya - total emissions, in the simplest description, are determined by:

Population: number of people

Per capita impact: average emissions per person

Per capita emissions are determined by:

Income: GDP per capita – richer people tend to emit more CO₂

Technology: how much CO₂ is emitted per dollar spent

Technology is determined by two factors:

Energy intensity: the amount of energy consumed per unit of GDP

Carbon intensity: the amount of CO₂ emitter per unit of energy

This means that total emissions are driven by the equation:

$$Emissions = Population * GDP * Energy\ intensity * Carbon\ intensity$$

$$Emissions = Population * GDP * \frac{Energy}{GDP} * \frac{CO_2}{Energy}$$

Energy & Climate

Sector by sector: global greenhouse gas emissions

Energy (electricity, heat & transport): 73.2%

Energy use in industry: 24.2%

Transport: 16.2%

Energy use in buildings: 17.5%

Unallocated fuel combustion (7.8%)

Fugitive emissions from energy production: 5.8%

Energy use in agriculture & fishing: 1.7%

Direct Industrial Processes: 5.2%

Cement (3%)

Chemicals & petrochemicals (2.2%)

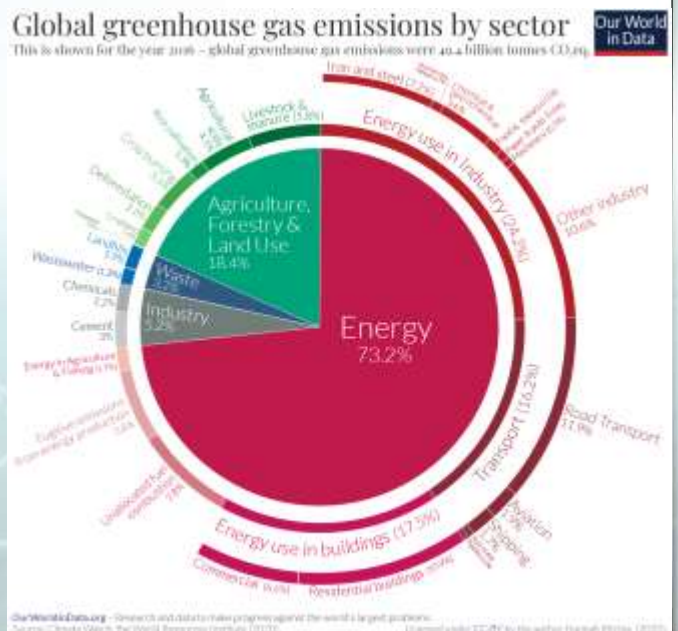
Waste: 3.2%

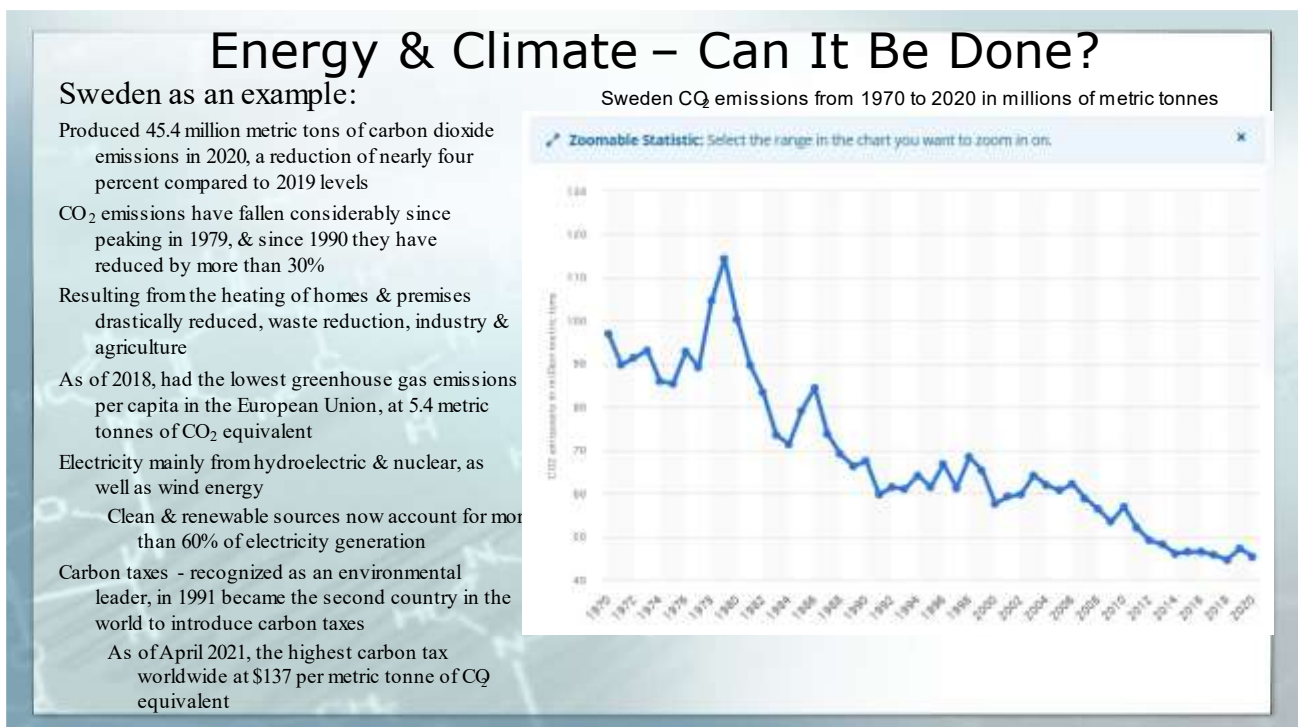
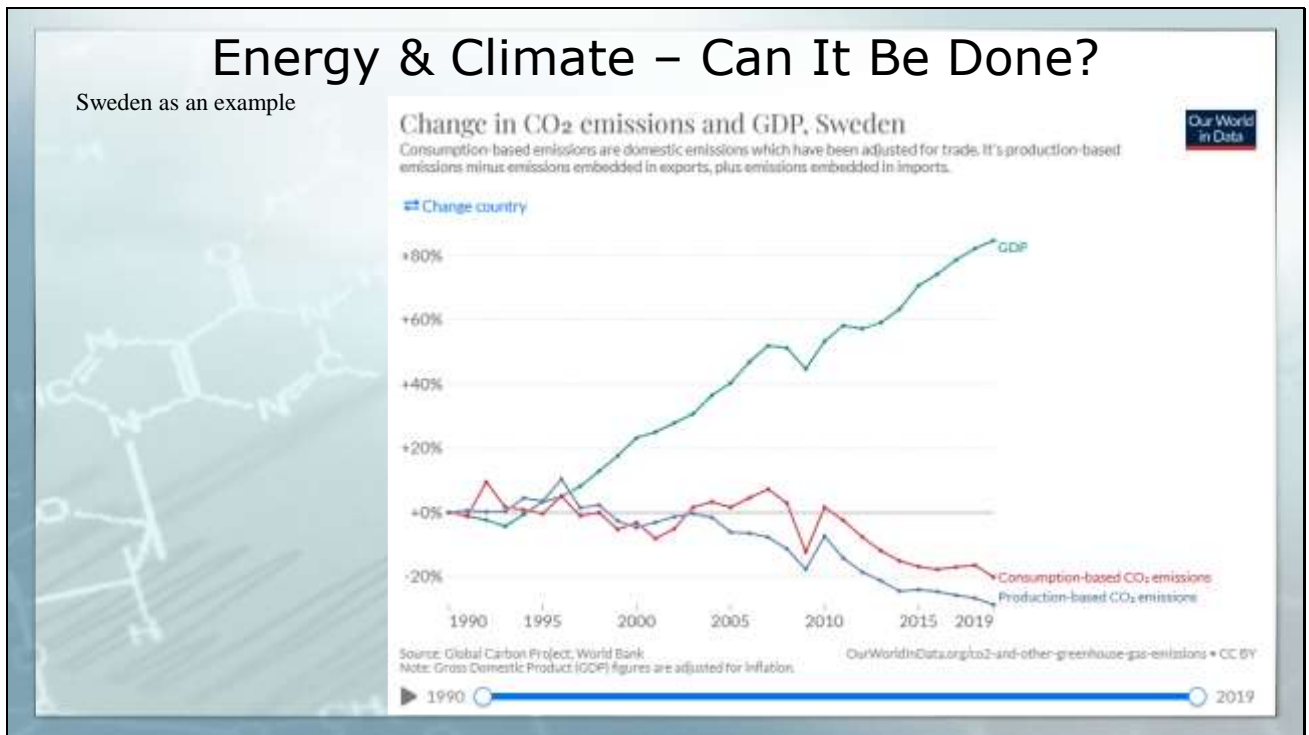
Wastewater (1.3%)

Landfills (1.9%)

Agriculture, Forestry & Land Use: 18.4%

Grassland (0.1%), Cropland (1.4%), Deforestation (2.2%), Crop burning (3.5%), Rice cultivation (1.3%), Agricultural soils (4.1%), Livestock & manure (5.8%)





Energy & Climate – What Can Be Done?

What actions could make a difference, & which cannot?

David JC MacKay – Energy Without the Hot Air, 2009 – free online

“We are inundated with a flood of crazy innumerate codswallop

The BBC doles out advice on how we can do our bit to save the planet

For example, “switch off your mobile phone charger when it’s not in use;”

If anyone objects that phone chargers are not actually our number one form of energy consumption, the mantra “every little helps” is wheeled out

A more realistic mantra is: if everyone does a little, we’ll achieve only a little!”

Energy & Climate – What Can Be Done?

Decarbonize our energy & fuel systems

Shift towards low-carbon electricity (reduce carbon intensity- carbon per unit energy)

Renewables

Nuclear energy

Shift from coal to gas (which emits less CO₂ per unit energy) as an interim step

Use biomass

Carbon capture & storage

Ideally needs to be at source where it is most concentrated – but it costs more fuel/energy to do it

Taking it out of the atmosphere is very difficult, biomass capture, direct capture is very energy consumptive

Shift sectors such as transport, towards electricity

Some energy sectors are harder to decarbonize – for example, air travel & transport

Develop low-cost low-carbon energy, plus energy storage technologies

To do this quickly, & allow lower -income countries to avoid high -carbon development pathways, low -carbon energy needs to be cost-effective & the default choice

Change from storing/using energy as fossil fuels to green hydrogen or ammonia storage/usage

Improve energy efficiency– energy per unit GDP

Energy & Climate – What Can Be Done?

Reduce emissions from food production & agriculture

Reduce meat & dairy consumption, especially in higher -income countries

Shift dietary patterns towards lower-carbon food products, this includes eating less meat & dairy generally, but also substituting high-impact meats (e.g., beef & lamb) for chicken, fish, or eggs

Innovation in meat substitutes could also play a large role here

Promote lower-carbon meat & dairy production

We are not going to cut out meat & dairy production completely any time soon (& doing so is unnecessary – large reductions would be sufficient)

This makes the promotion of lower-carbon production methods essential

Improve crop yields

Sustainable intensification of agriculture allows us to grow more food on less land

This could help to prevent deforestation from agricultural expansion, & frees up land for replanting, or giving back to natural ecosystems

Reduce food waste

Food waste is responsible for 6% of global greenhouse gas emissions

Food lost in supply chains & wasted by consumers accounts for around 25% of greenhouse gas emissions from food

Improving harvesting techniques, refrigeration, transport & packaging in supply chains; & reducing consumer waste can reduce emissions significantly

The world now produces more than three times the quantity of meat as it did fifty years ago. In 2018, production was around 340 million tonnes.

Pork is the most popular meat globally, but the production of poultry is increasing most rapidly. 80 billion animals are slaughtered each year for meat. The average person in the world consumed around 43 kilograms of meat in 2014. This ranges from over 100kg in the US and Australia to only 5kg in India.

Meat consumption increases as the world is getting richer.

The world now produces around 800 million tonnes of milk each year – more than double the amount fifty years ago. Richer countries tend to consume more milk per person.

The amount of meat produced for a given animal varies significantly across the world based on production systems.

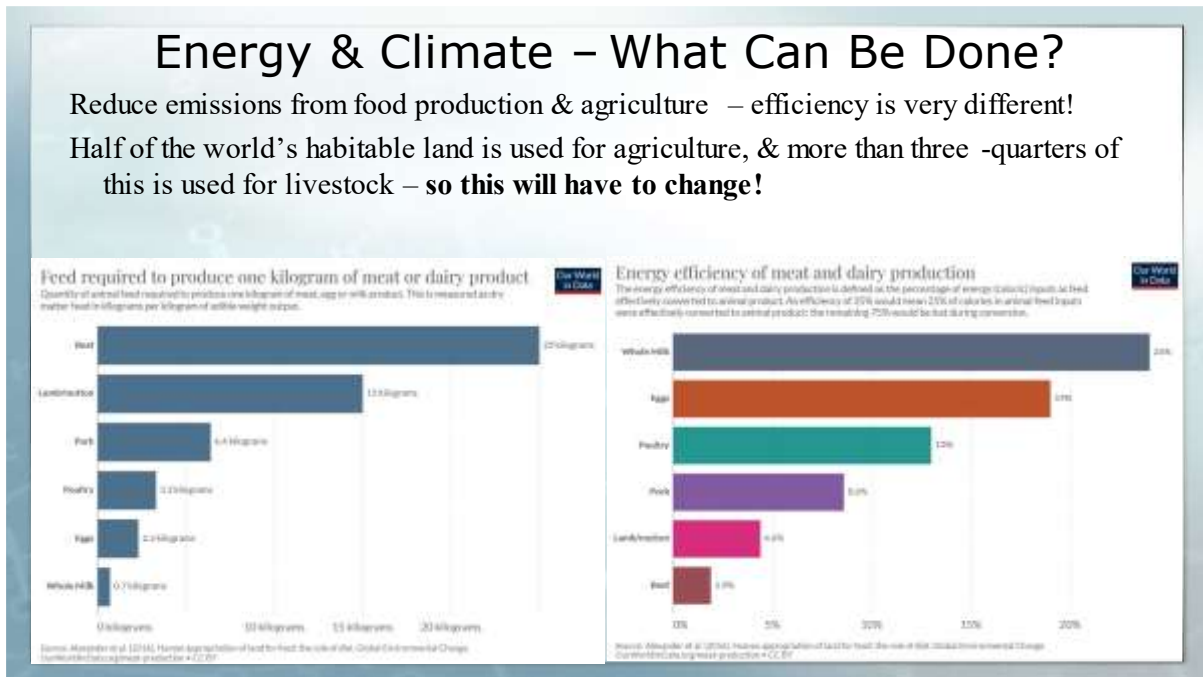
Livestock production has large environmental impacts on greenhouse gas emissions, land and water use. Beef and lamb have much larger environmental impact than pork and poultry.

Seafood production – fish and seafood is another key source of protein and nutrition for populations across the world. How much fish do people eat, and what are the environmental impacts?

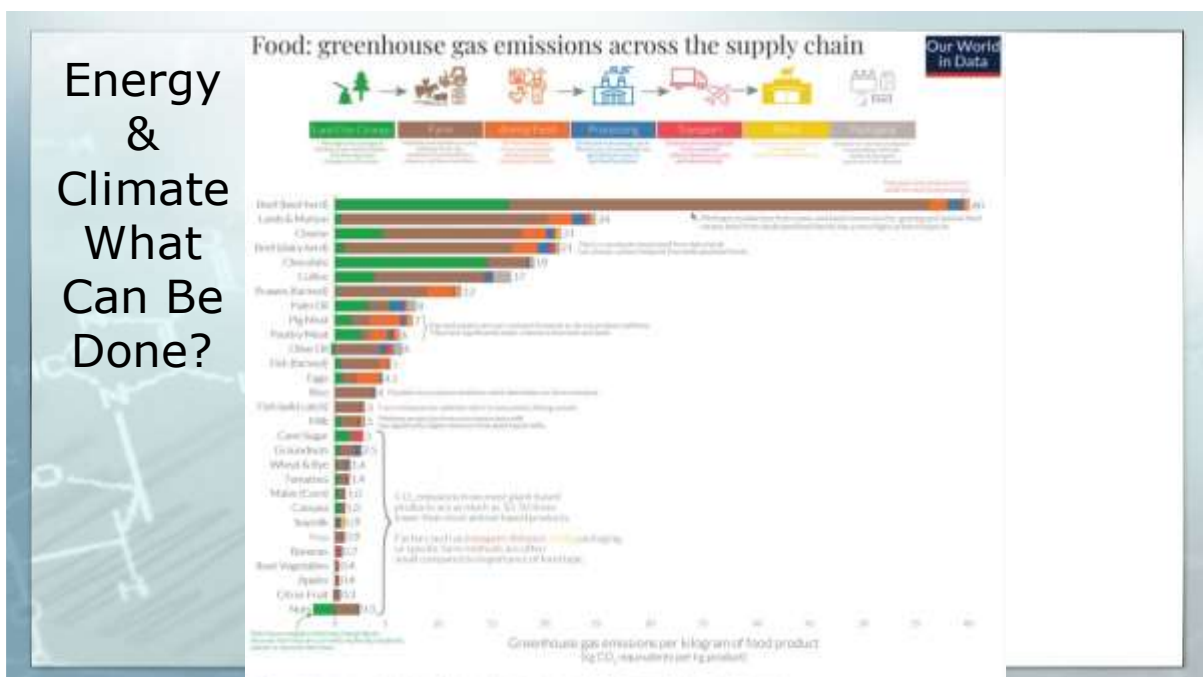
Diet compositions – varied diets are essential for good health and nutrition. But the quality and diversity of diets varies significantly across the world. What do people eat?

Micronutrient deficiency – poor dietary diversity means many people lack the essential vitamins and minerals they need for good health. How common is micronutrient deficiency and who is most at risk?

Land use – half of the world's habitable land is used for agriculture, and more than three-quarters of this is used for livestock.



Around 57% of food emissions come from animal-based foods, although they make up only 18% of the world’s calories, and 37% of its protein. And as people across the world grow richer, they want more meat. Traditional diets in most cultures were primarily plant based with a little meat on top. But with the rise of industrial style meat production and factory farming, meat has become a staple food, a regular indulgence in developed countries and a symbol of status and wealth in developing countries.



Energy & Climate – What Can Be Done?

What can you do?

Save energy, insulate your house, fix draughts, turn the thermostats down, switch to renewable energy, use LED lights & turn things off, reduce water usage – especially hot water

When replacing household electricals etc., buy the most energy efficient units, especially heating systems, use heat pumps?

Don't fly, or at least do as few miles as possible, holiday nearer to home, buy carbon offsets

Don't drive, unless you must, but try to reduce your annual mileage year on year, buy an electric car, do you really need a car, or more than one?

Walk or cycle more, use public transport

Work from home where possible

Reduce all forms of waste, especially food

Reduce, re-use, recycle, reduce

Avoid single use plastics & disposables, use a personal water bottle

Consume less, & replace everything less frequently, repair rather than replace?

Eat less meat & dairy, go plant based - consider vegetarianism, or veganism, buy foods in season, & buy locally sourced foods avoiding food miles (air miles) – but far more important, is what you eat!

But the sad reality is that personal contributions are totally dwarfed by those from global emission sources!

Except for one - having fewer children!

If you eliminated 100% of your emissions for the rest of your life, you would save one second's worth of emissions from the global energy sector. Even the most motivated person can't even make a tiny dent!

Carbon offsets come from certified green-energy projects such as solar power projects, wind farms and methane-recapture operations at landfills or dairy farms, and projects that plant trees or work toward forest preservation. Though customers still receive liquid fossil fuels, purchasing carbon offsets helps keep these projects running and allows project owners to create more of them, which helps lead to cleaner air and reduced carbon emissions.











They estimated that if the average household substituted their calories from red meat and dairy to chicken, fish or eggs just one day per week they would save 0.3 tCO₂eq. If they replaced it with plant-based alternatives, they would save 0.46 tCO₂eq. In other words, going 'red meat and dairy-free' (not totally meat-free) one day per week would achieve the same as having a diet with zero food miles. There are also a number of cases where eating locally might in fact increase emissions. In most countries, many foods can only be grown and harvested at certain times of the year. But consumers want them year-round. This gives us three options: import goods from countries where they are in-season; use energy-intensive production methods (such as greenhouses) to produce them year-round; or use refrigeration and other preservation methods to store them for several months. There are many examples of studies which show that importing often has a lower footprint.

Hospido et al. (2009) estimate that importing Spanish lettuce to the UK during winter months results in three to eight times lower emissions than producing it locally. The same applies for other foods: tomatoes produced in greenhouses in Sweden used 10 times as much energy as importing tomatoes from Southern Europe where they were in-season.

The impact of transport is small for most products, but there is one exception: those which travel by air.

Energy & Climate – What Can Be Done?

What can you do? **Top options for reducing your carbon footprint**
 Average reduction per person per year in tonnes of CO2 equivalent

 Live car-free 2.04	 Refurbishment/renovation 0.895
 Battery electric car 1.95	 Vegan diet 0.8
 One less long-haul flight per year 1.68	 Heat pump 0.795
 Renewable energy 1.6	 Improved cooking equipment 0.65
 Public transport 0.98	 Renewable-based heating 0.64

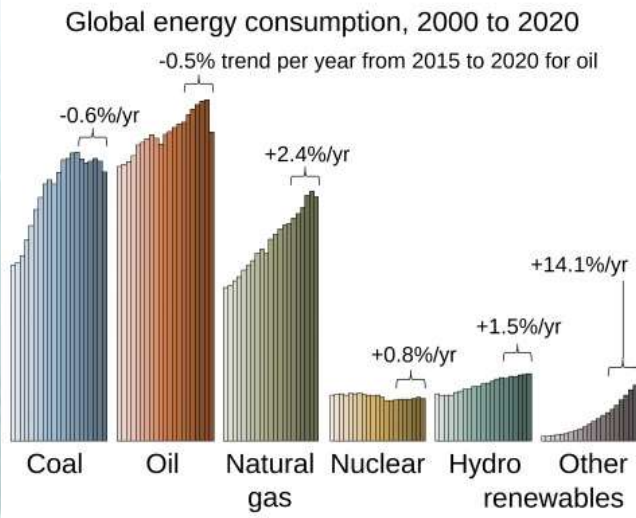
Source: Centre for Research into Energy Demand Solutions **BBC**

Energy & Climate – Current Energy

Burning fossil fuels is sacrilege – we need it as supply stock for future chemicals, fertilisers, polymers etc., etc.
 If we waste it all now, it will take a lot of extra energy in the future to regenerate the equivalent chemical resources
 But we really should stop subsidising fossil fuels such as oil & gas – to keep everyday goods low in price!

Global energy consumption, 2000 to 2020

-0.5% trend per year from 2015 to 2020 for oil



Energy Source	Growth Rate (per year)
Coal	-0.6%/yr
Oil	-0.5% trend per year from 2015 to 2020
Natural gas	+2.4%/yr
Nuclear	+0.8%/yr
Hydro	+1.5%/yr
Other renewables	+14.1%/yr

Energy & Climate – Current Energy

Alternatives to fossil fuels

- Reduce demand & increased efficiency
- Nuclear fission – in large installations & in new small modular reactors – not popular, but do not generate CO₂
- Nuclear fusion – a possible future energy generation that is renewable – but could be 5 years away, 20 is more likely
- Bioenergy – biomass fuels for burning & bioenergy, such as ethanol, as an alternative to oil based fuels
- Hydro-electricity
- Geothermal energy & heat
- Solar – photovoltaic & solar concentrators
- Wind – onshore & offshore
- Marine – tidal & wave energy

Solar & wind energy dominated renewable capacity expansion, accounting for 91% of all net renewable additions in 2020

Insights on Renewables

Installed Capacity Trends

Navigate through the filters to explore trends in renewable energy

©IRENA Visit www.irena.org/Statistics for more information

At the end of 2020, global renewable generation capacity amounted to 2 799 GW. Renewable generation capacity increased by 260 GW (+10.3%) in 2020. Solar energy continued to lead capacity expansion, with an increase of 127 GW (+22%), followed closely by wind energy with 111 GW (+18%). Hydropower capacity increased by 20 GW (+2%) and bioenergy by 2 GW (+2%). Geothermal energy increased by 164 MW. Solar and wind energy continued to dominate renewable capacity expansion, jointly accounting for 91% of all net renewable additions in 2020.

Energy & Climate – Future Energy

Installing renewables such as solar & wind energy is now cheaper per kWh than building fossil fuel power stations

162 gigawatts (GW) or 62 per cent of total renewable energy generation added in 2020 had lower costs than the cheapest new fossil fuel option

Solar and wind power technologies became the economic backbone of the energy transition

©IRENA

Energy & Climate – Future Energy

Using electricity from renewables, such as solar & wind, in new more efficient ways

Mini & micro-grids - a set of small-scale electricity generators (e.g., solar) & possibly energy storage systems interconnected to a distribution network that supplies electricity to a small, localised group of customers & operates independently from the national transmission grid

Have the potential to provide electricity to as many as 500 million people by 2030, with the right policies & about \$220 billion of investment to build around 210,000 mini grids

Over the past decade, mini grid costs have declined significantly, while the quality of service has increased

The per kWh cost of mini grid electricity is expected to decrease by two thirds by 2030.

Significantly more mini grids will need to be deployed in the top 20 electricity access deficit countries – from 10 - 50 mini grids currently deployed each year per country to over 1,600

Home batteries– e.g., Tesla Power Wall

Electric vehicles as local domestic electrical storage

Home energy stores– e.g., heating insulated hot water storage units via excess solar– I have this at my home!

Energy & Climate – Future Energy

The crucial issues with renewables such as solar & wind are:

Capacity – we need very much more than we need at anyone time

Constancy – when the Sun is not shining, & the wind is still, we have no energy!

Storage of energy, & loads of it, solves both problems

Turning night into day is easy, we need enough storage capacity to turn winter into summer – not hours or days, but months or years!

Energy storage options:

Mechanical, spring, compressed air energy storage (CAES), fireless locomotive, flywheels, solid mass gravitational, hydraulic accumulator, pumped -storage hydroelectric

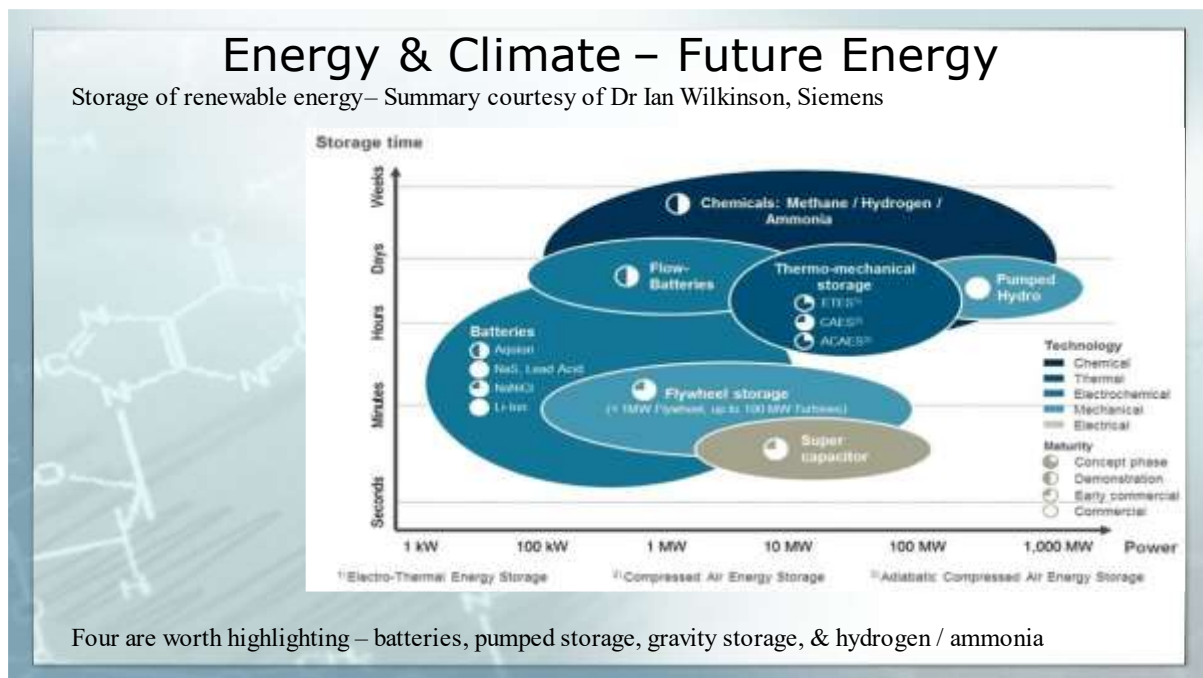
Electrical, electromagnetic, supercapacitor, superconducting magnetic storage

Electrochemical, flow battery, rechargeable battery, ultra -battery

Thermal, brick storage heater, cryogenic energy storage, liquid air energy storage (LAES), liquid nitrogen engine, ice storage for air conditioning, molten salt storage, seasonal thermal energy storage, steam accumulator, thermal energy storage (general)

Chemical, biofuels, hydrogen storage (ammonia), hydrogen peroxide, power to gas (e.g., methane)

The Chinese State Grid Corporation opened another five pumped hydro stations last year (2021) and plans to increase its pumped storage capacity from the current 26.3GW to 100GW by 2030. All over the world, grid operators are desperately searching for long-duration energy storage solutions to leverage renewable energy as baseload power and address the variable nature of clean resources.



Energy & Climate – Future Energy

Storage of renewable energy – batteries

Capacity – 10s to 100s MW

Duration - hours only

e.g., Tehachapi, California

Fixed in place

Mornington project in Victoria Australia 2021 for a 480 MWh battery energy storage system (BESS)

Battery energy storage at grid scale is not cheap, but it is probably the most cost-effective proven technology to date. Announcements of projects for battery energy storage systems rarely include total project values. However, an October 2021 article on the Mornington project in Victoria Australia for a 480 MWh battery energy storage system (BESS) states this is to be installed on Victoria’s Mornington Peninsula at a cost of “upwards of \$190 million”. AUD 190 million is about GBP 100 million. The 2021 UK energy storage requirement is 19 million MWh, which equals about 40,000 Mornington BESSs. Or close to £4,000 billion, roughly ten times what the UK spent on Covid-19 emergency measures.

Energy & Climate – Future Energy

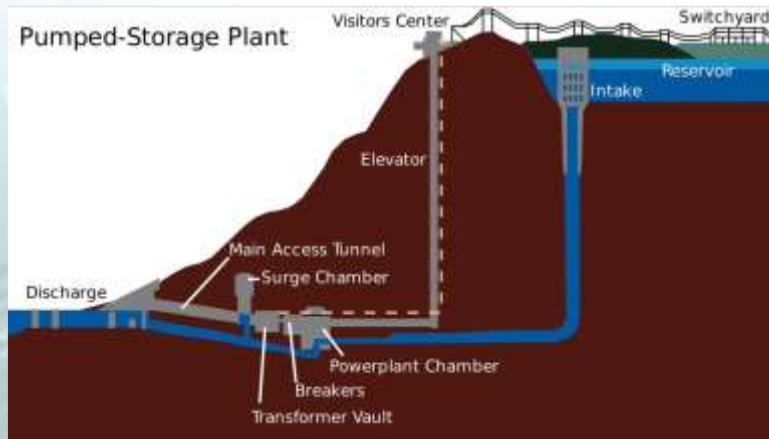
Storage of renewable energy – pumped storage

E.g., The Bath County Pumped Storage Station, in Virginia USA, is a pumped storage hydroelectric power plant, one of the largest in the world with a total storage capacity of 24,000MWh

Duration 11 hours at full capacity

There are five systems in the UK

Fixed in place



Dinorwig Pumped Power Plant in North Wales has a rare combination of features: two bodies of water separated by a large difference in elevation but only ~3 km from each other (no other equivalent site exists in the UK). The upper reservoir, Marchlyn Mawr, is about 500 m above the lower reservoir, Llyn Peris. The two reservoirs are connected by man-made tunnels. At full power, water flows down and through the generator turbines at 400 cubic metres per second.


The Dinorwig station's six reversible turbine generator/pump units are hidden within Europe's largest man-made cavern. They can reach maximum power output in less than 16 seconds. The units act as pumps to move water from the lower reservoir back up to Marchlyn Mawr using off-peak electricity.

Overall energy storage efficiency is around 75%.

Dinorwig was commissioned in 1984 and is the largest scheme of its kind in Europe.

Energy & Climate – Future Energy

Storage of renewable energy – gravity storage
Between 1 & 10 GWh
Fixed in place



ENERGY VAULT

Energy & Climate – Future Energy

Storage of renewable energy – hydrogen / ammonia

Advantages are mobility & transportability – you can move it round with you & ship it to where it's needed

Hydrogen comes in many colours (too many!), but the ideal label is green!

- Green hydrogen is made from renewable energy sources
- Blue from fossil fuels (methane) where the CO₂ is captured & stored
- Grey is created from natural gas (methane) by steam reforming & the water gas shift reaction releasing CO₂
- Orange is made from biogas or biogenic waste (mainly methane)
- Brown or black is made from the gasification of coal & where the CO₂ is released
- Gold is recovered naturally from deep drilling into the Earth
- Turquoise hydrogen is made using a process called methane pyrolysis to produce hydrogen & solid carbon

Worldwide 95% of all hydrogen is grey – but that is about to change dramatically towards green

Hydrogen (or ammonia) from green sources could replace fossil fuels derived from oil in shipping & aircraft

- Hydrogen for transport, via electric fuel cells, or internal combustion engines (JCB & Hyundai & Renault)
- Hydrogen is proposed for domestic use also, e.g., in heating, & as local storage for electricity via fuel cells

Maersk has made the decision to order 12 ocean-going ships which run on methanol. Each costs \$175m (£130m) and is capable of carrying 16,000 containers. "We think this will unlock the scaling that needs to happen," says Jacob Sterling, Maersk's head of decarbonisation innovation and business development.

Global shipping would take 500 million tonnes of green ammonia per annum.

Energy & Climate – Future Energy

Renewable energy – as hydrogen / ammonia, storage & transportation

To maximise the energy density, hydrogen must be highly compressed as a gas (700 bar), it can only be liquified at cryogenic temperatures i.e., <math><253\text{ deg C}</math>, it can also be stored as a solid e.g., a hydride

Hydrogen can be transformed into ammonia (NH_3) which is easily liquified & is very energy dense

But at a very high energy cost, & CO_2 output, so not yet clear if this will ever scale up & be efficient enough

Electrolysers, to efficiently split water into hydrogen & oxygen, are now being scaled up, & reduced in cost, & improved massively

Green hydrogen (or ammonia) can be stored in bulk for later transformation into electricity, via fuel cells or in a combustion engine (piston or turbine) to drive a generator

The potential generating capacity is in 10's of GW

So, at 700 bar, which is 700 times normal atmospheric pressure, hydrogen has a density of 42 kg/m³, compared with 0.090 kg/m³ under normal pressure and temperature conditions. At this pressure, 5 kg of hydrogen can be stored in a 125-liter tank.

Today, most car manufacturers have opted for the solution that consists in storing hydrogen in the gaseous form, at high pressure.

This technology enables us to store enough hydrogen to allow a car that runs on a fuel cell battery to cover between 500 and 600 km between fill-ups.

Hydrogen turns into a liquid when it is cooled to a temperature below -252,87 °C and 1.013 bar, liquid hydrogen has a density of close to 71 kg/m³.

At this pressure, 5 kg of hydrogen can be stored in a 75-liter tank.

In order to maintain liquid hydrogen at this temperature, tanks must be perfectly isolated.

Hydrogen Production

Alkaline electrolysis is a mature technology for large systems, whereas PEM (Proton Exchange Membrane) electrolysers are more flexible and can be used for small decentralized solutions. The conversion efficiency for both technologies is about 65%~70% (lower heating value). High temperature electrolysers are currently under development and could represent a very efficient alternative to PEM and alkaline systems, with efficiencies up to 90%.

Energy & Climate – Summary

It took around 260 million years for fossil fuels to form

Humans harvested & burned most of them in around 260 years; a million times faster than they were laid down

We are now very confident that the extra carbon has changed our environment & climate, & we are still burning them in large amounts

The wealthiest nations & people have caused the issue so they should pay up, so the poorest can cope

It is far from clear that we haven't pushed things too far already– IPCC Feb 2022!

We need to decarbonise our economies, in terms of fuels & electrical energy, & do it quickly

Nuclear fission is helping somewhat, but it has severe issues of its own, i.e., waste disposal & safety!

Nuclear fusion, when it finally works, is sure to be an environmental saviour, but is unlikely to save us in time!

Renewable energy – from solar & wind are the cheapest now, & are having a rapidly growing impact

But we need storage urgently, & lots of it, to balance the supply & demand equation

Green hydrogen & maybe ammonia, batteries, & other forms of storage are likely to be key players & as alternate fuels

Population reduction would make a huge difference, but we are heading from ~8 to 10 billion by 2050

If we reduced our CO₂ to zero it would stop further warming but would not reduce it.

If wanted to reduce temperatures down, to say those of the 1970's, then we would need to reduce CO₂ in the atmosphere to the levels then, and that would take all the energy we produced globally since then and more to do that!

The good news is global emissions have been flattening out for the last few years um so now emissions are only increasing by one percent a year instead of three percent a year

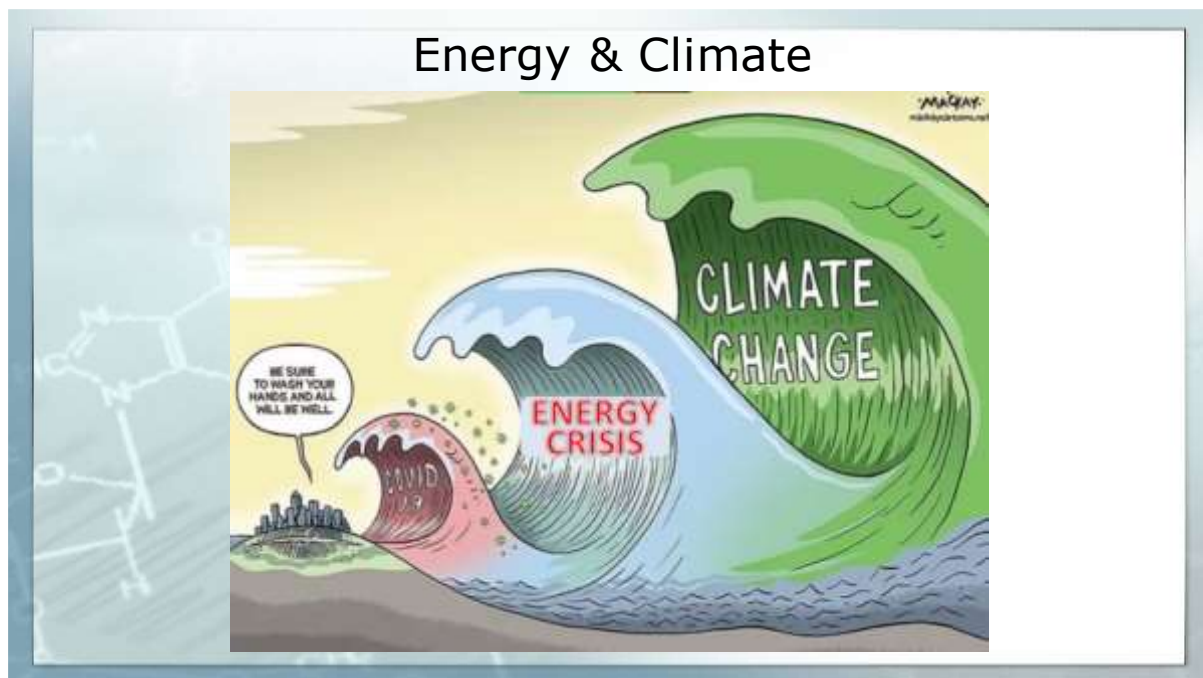
Our emissions from fossil fuels that is uh global coal use peaked back in 2013 and has been modestly declining and a lot of that is due to the fact that we've been pretty successful in making clean energy technologies a lot cheaper

The price of solar panels has fallen by a factor of 10 in the last decade, the price of batteries has fallen by a factor of 10 in the last decade, electric vehicles were 14 of global vehicle sales in the last two quarters, so we're reaching an inflection point. A lot of these clean energy technologies where they're becoming cheaper than fossil fuel alternatives and the reason that's important is it means that they can help drive emission reductions even in the absence of stringent policies taken by countries so that's the good news and that seems to be putting us more on track for a warming of around three degrees by the end of the century the bad news is that you know even a flattening of global emissions means the world is going to keep warming. We're still going to end up at three degrees by 2100, and you know four degrees by 2150 and five degrees by 2200 if emissions stay flat, and so it's in some ways the easiest part to stop emissions from increasing it becomes much harder particularly in a world of growing economies of billions of people in poorer countries you know aspiring to the things we take for granted uh to have emissions decrease and so technology alone is not going to save us.

We need a combination of technology and a lot more ambitious policy commitments than we've seen so far um and so countries have started making long-term pledges that are consistent with solving the problem. In the last two years we've seen countries that represent uh about three-quarters of global emissions commit to get their emissions to zero or net zero uh by mid to late century but there's a big question of how seriously we should take those commitments.

It's one thing for countries to say we're going to do this thing next year or even five years from now it's another thing to say we're going to do this thing 50 years from now when none of us are going to be in power or even alive

Slide 65



Slide 66

