

## SSC 2030: Energy Systems & Sustainability

### **2. Global climate change**

- 2.1: The elephant in the room: What is GCC?
- 2.2: What is the evidence of GCC?
- 2.3: What are the cause(s) of GCC?
- 2.4: Paradigms, change, revolutions and transitions
- 2.5: Decarbonization and the energy trilemma

## 2. Global climate change

### **2.1: *The elephant in the room* What is GCC?**

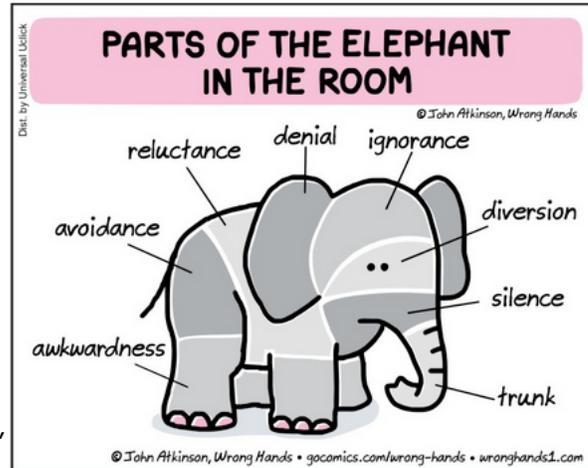
## The elephant in the room (???)



*"Five blind people encounter an elephant. One pats the stubby flank, another feels the hot breath, a third grasps a bony tusk, another the bristly tail, and yet another the soft winding trunk.*

*They find that their individual observations give completely different impressions of the thing they are trying to describe.*

*I recently talked to a scientist and a corporate official about climate change, and it reminded me of the story about the blind people describing an elephant."*



<https://www.northeastipm.org/about-us/publications/ipm-insights/climate-change-is-the-elephant-in-the-room/>  
<http://northsideforum.org.au/forum-71-climate-change-the-election-the-elephant-in-the-room/>

## What's in a name?



**Pre-1975:** the term of art was "inadvertent climate modification"

- Scientists knew that human-caused emissions were likely to cause climate change. But would it be warming or cooling from aerosols?

**1975:** geochemist Wallace Broecker of Columbia University published an article titled, "Climatic change: Are we on the brink of a pronounced **global warming**?"

- Described an increase in average global surface temperatures from greenhouse gases emitted by human activity.

**1979:** National Academy of Sciences report also used the term "**climate change**" to describe other, non-warming effects likely to occur.

**Today:** We know that emissions will cause a host of changes around the globe. Warming and increased precipitation are just two of the effects. So, **global climate change** is the most inclusive and descriptive term.

<https://pmm.nasa.gov/education/articles/whats-name-global-warming-vs-climate-change>

## 2. Global climate change



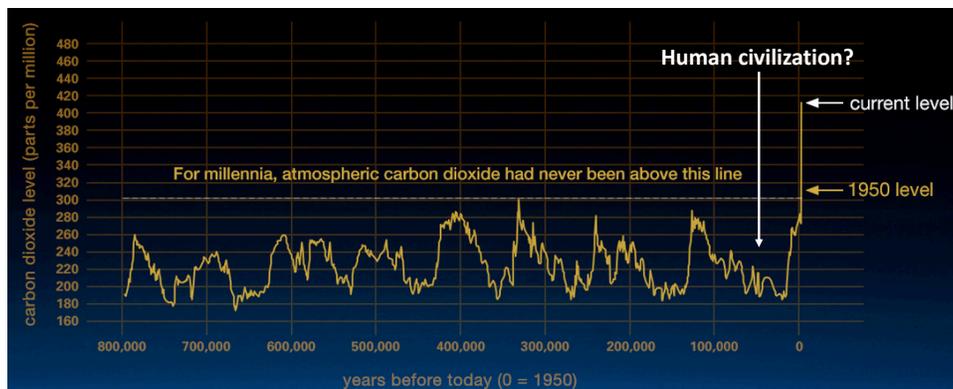
### 2.2: What is the evidence of GCC?

## Atmospheric carbon is way up



Our current spike in atmospheric CO<sub>2</sub> follows both:

- The rise of human civilization; and
- A number of revolutions, driven by extraction and combustion of fossil fuels.



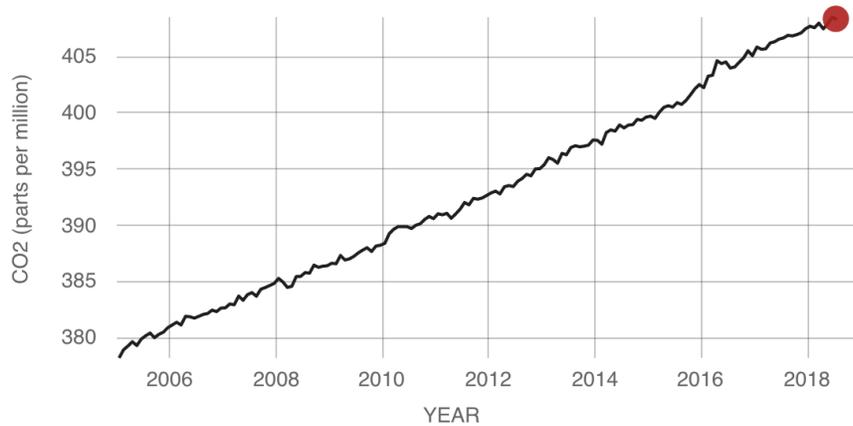
<https://climate.nasa.gov/evidence/>

## Vital signs: CO<sub>2</sub> levels



### DIRECT MEASUREMENTS: 2005-PRESENT

Data source: Monthly measurements (average seasonal cycle removed). Credit: [NOAA](#)



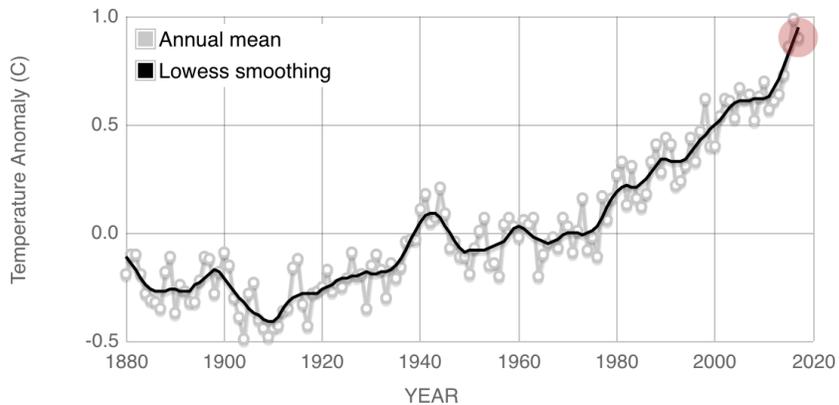
<https://climate.nasa.gov/evidence/>

## Vital signs: global temperature



### GLOBAL LAND-OCEAN TEMPERATURE INDEX

Data source: NASA's Goddard Institute for Space Studies (GISS). Credit: NASA/GISS



<https://climate.nasa.gov/evidence/>

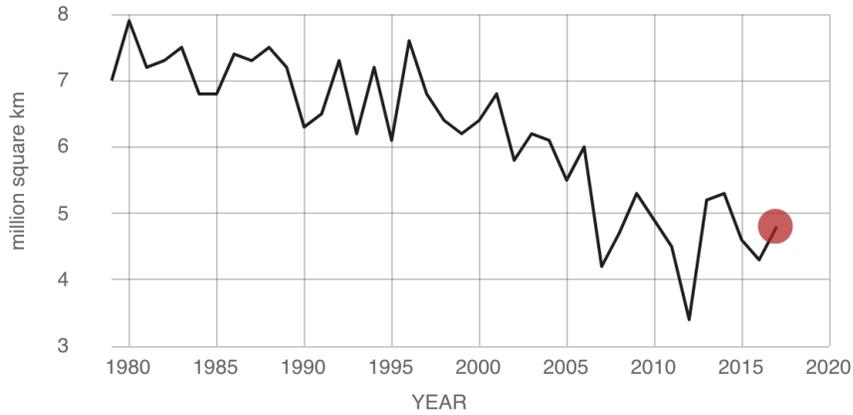
## Vital signs: Artic sea ice

### AVERAGE SEPTEMBER EXTENT

Data source: Satellite observations. Credit: NSIDC/NASA

### RATE OF CHANGE

↓ 13.2  
percent per decade



<https://climate.nasa.gov/evidence/>

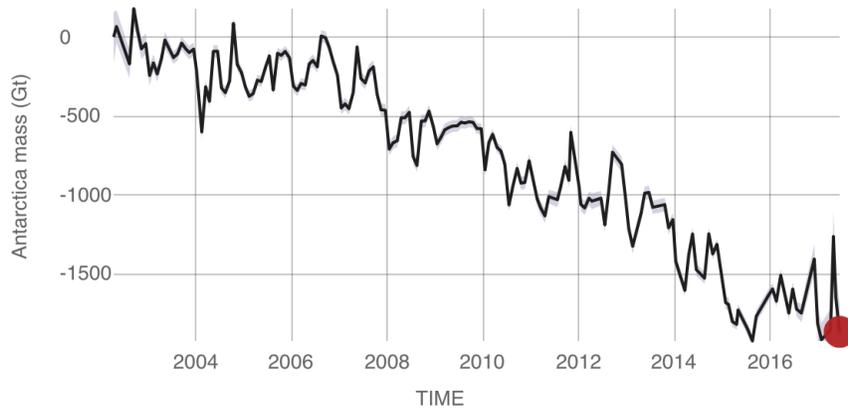
## Vital signs: ice sheets

### ANTARCTICA MASS VARIATION SINCE 2002

Data source: Ice mass measurement by NASA's GRACE satellites.  
Credit: NASA

### RATE OF CHANGE

↓ 127.0  
Gigatonnes per year  
margin: ±39



<https://climate.nasa.gov/evidence/>

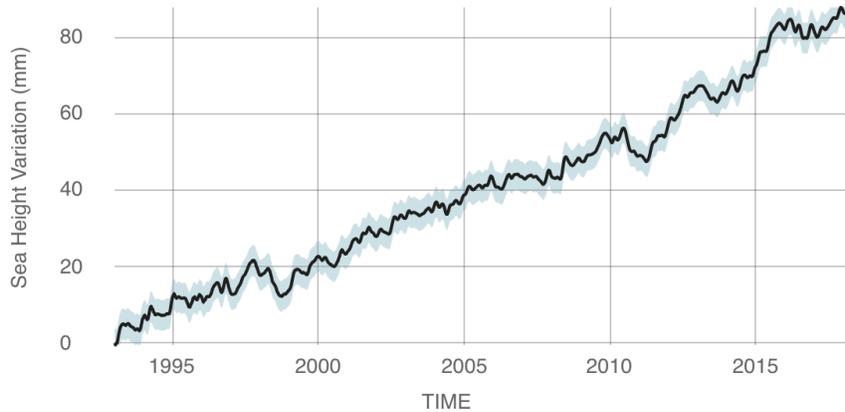
## Vital signs: sea level

### SATELLITE DATA: 1993-PRESENT

Data source: Satellite sea level observations.  
Credit: NASA Goddard Space Flight Center

### RATE OF CHANGE

 **3.2**  
millimeters per year



<https://climate.nasa.gov/evidence/>

## Example: Glacier National Park, MT

Montana's Glacier National Park

1910: **150** glaciers

*Globally, glaciers store 3/4 of the world's freshwater.*

2019: **30** glaciers

National Geographic: Effects of global warming

## Iceland's first glacier has disappeared



And a memorial plaque has been placed at the site.



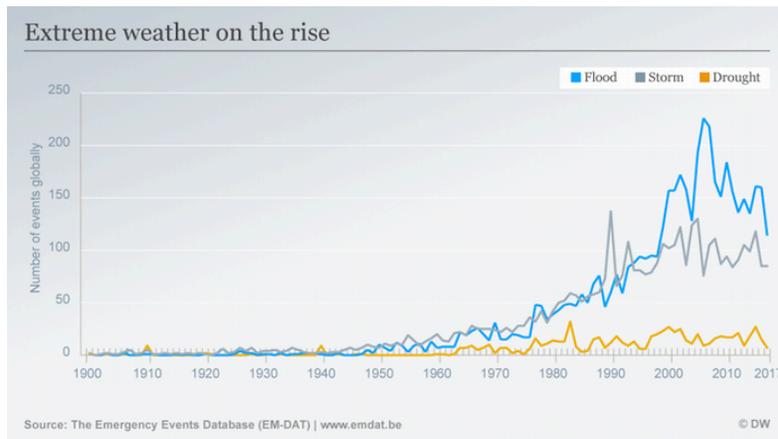
<https://www.theguardian.com/environment/2019/jul/22/memorial-to-mark-icelandic-glacier-lost-to-climate-crisis>

## Extreme weather events



Increasing:

- Record high temperature events (decreasing lows);
- Intense rainfall and storm events.



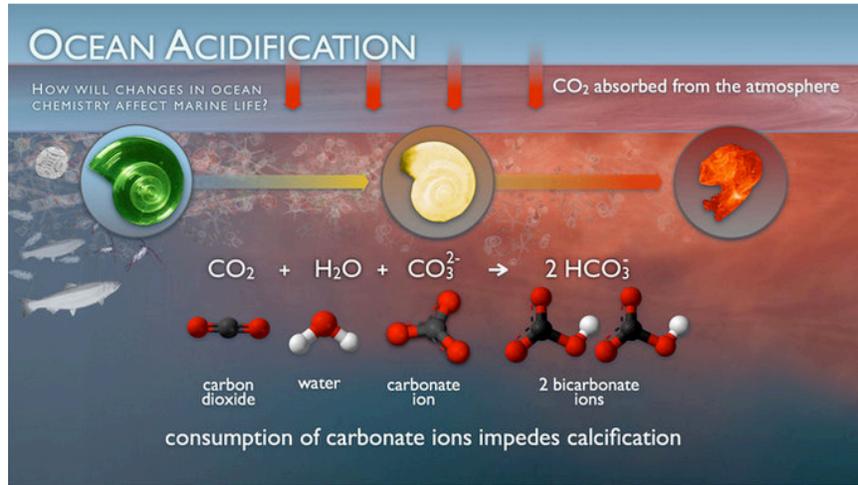
<https://climate.nasa.gov/evidence/>

<https://www.dw.com/en/climate-change-and-extreme-weather-science-is-proving-the-link/a-43323706>

## Ocean acidification

Since the industrial revolution (starting in the 1860's) acidity of surface waters has increased by 30% due to increased carbon emissions.

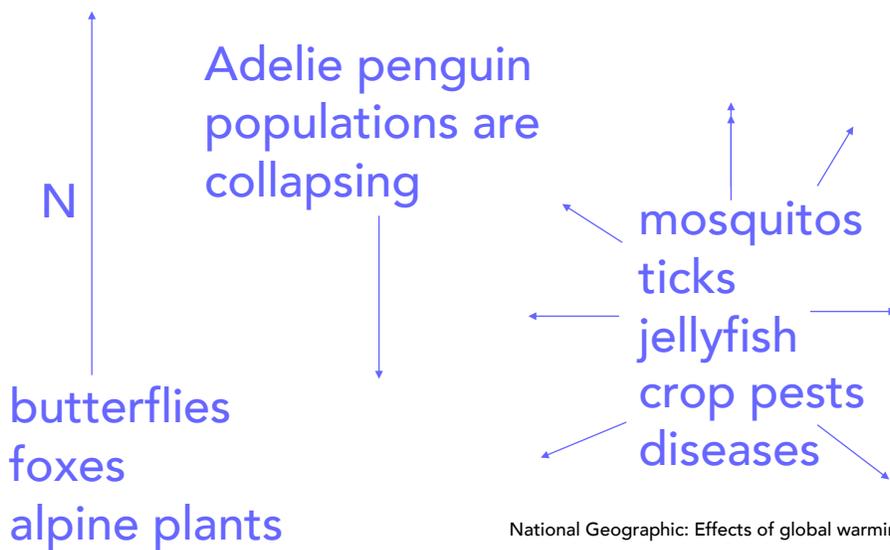
- CO<sub>2</sub> absorbed by the ocean has increased by 2 b tons/year



<https://climate.nasa.gov/evidence/>  
<https://www.pmel.noaa.gov/co2/story/Ocean+Acidification>

## Ecosystems are changing

And species are moving.



National Geographic: Effects of global warming

## Today's planetary vital signs

**CO<sub>2</sub> = 412 ppm**

**Temperature up 0.8°C**

**Arctic Sea ice down 12.8%**

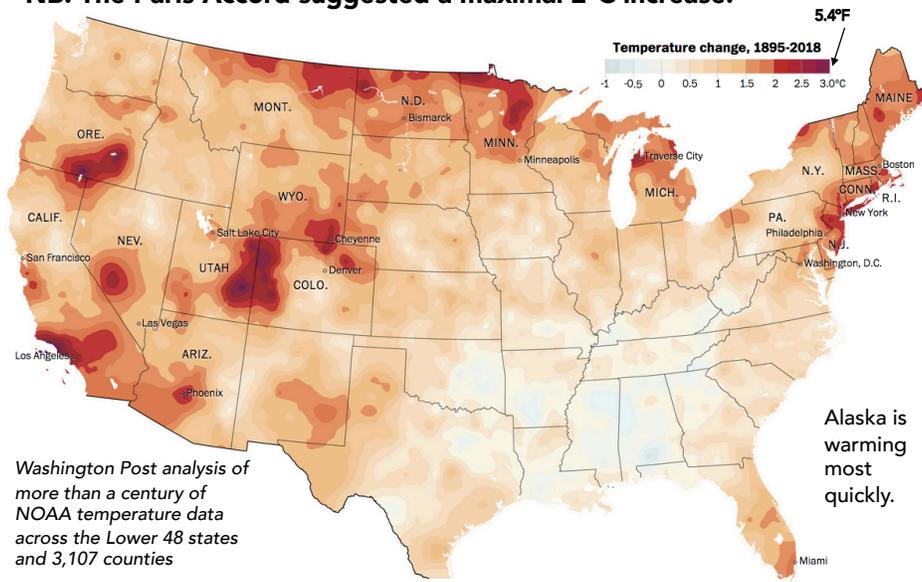
**Ice sheets down 127.0%**

**Sea levels up 3.3%**

<https://climate.nasa.gov/evidence/>

## US: warming more quickly than expected

**NB: The Paris Accord suggested a maximal 2°C increase.**



*Washington Post analysis of more than a century of NOAA temperature data across the Lower 48 states and 3,107 counties*

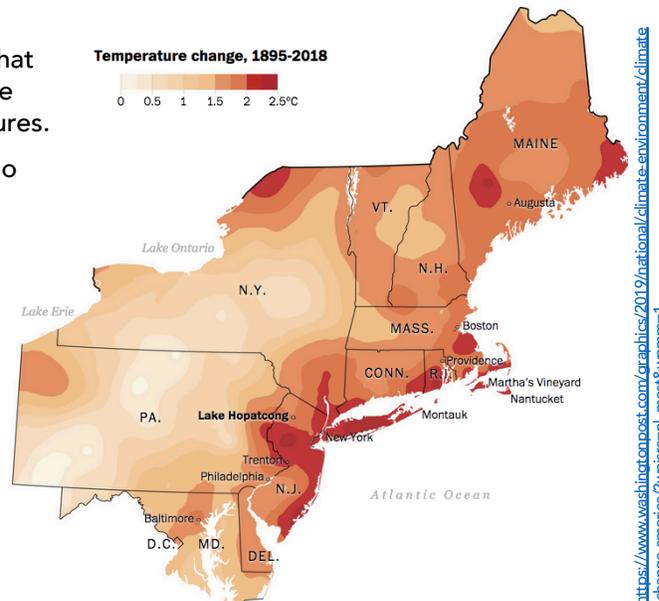
[https://www.washingtonpost.com/graphics/2019/national/climate-environment/climate-change-america/?hpid=hp\\_hp-top-table-main-climate-change-america\\_2wpisrc=nl\\_most&wpmn=1](https://www.washingtonpost.com/graphics/2019/national/climate-environment/climate-change-america/?hpid=hp_hp-top-table-main-climate-change-america_2wpisrc=nl_most&wpmn=1)

## NE is a hotspot



### Why?

- **Losing winters** that lower our average annual temperatures.  
Loss of the albedo effect.
- **Warming waters** along the coast.



## Predictions of future change in the US?



- **Change will continue** through 2100.... And on.
- **Temperatures** will continue to rise.
- **Growing seasons** will lengthen.
- Northern US: **more** winter and spring precipitation  
Southwest US: **less** precipitation
- **Droughts** in the Southwest
- **Heatwaves** will increase across the country.
- **Hurricanes** will become stronger and more intense.
- **Sea level** will rise 1 - 4 feet by 2100.
- Arctic Sea will become **ice-free** in summer by ~2050.

<https://climate.nasa.gov/evidence/>

## Regional predictions

<b>Northeast:</b>	heat waves heavy downpours sea-level rise	ecosystems agriculture fisheries water supplies health Infrastructure  economy
<b>Northwest:</b>	reduced supplies of freshwater sea-level rise erosion and inundation effects from increasing ocean acidity increasing wildfire, insect damage to forests	
<b>Southeast:</b>	sea-level rise extreme heat decreased availability of freshwater	
<b>Midwest:</b>	extreme heat heavy downpours and flooding many changes and risks to Great Lakes	
<b>Southwest:</b>	increased and extreme heat drought wildfires and insect outbreaks	

<https://climate.nasa.gov/evidence/>

## Predictions for Vermont

Roger Hill, longtime Vermont weather forecaster, recently gave a talk about the what Vermont can expect to see from climate change.

- 100 years storms may come every 10 years
- Within 20 years, summers will be like those in Kentucky though we will still have some winter snows
- Weather chaos is the first phase of change, so heavy snowfalls – perhaps 6 – 10 feet on occasion, will still occur
- Significant increases in flooding, particularly in river valleys

You are not alone.  
We are in this together!

▶ 0:14 / 1:19:04
⚙️ 📺 🗑️

Roger Hill, Climate change comes to Vermont  
<https://www.youtube.com/watch?v=5A03kOcTLdA>

## 2. Global climate change



### 2.3: What are the cause(s) of GCC?

#### The earth is a greenhouse



“Life on Earth depends on energy coming from the Sun.

- About half the light reaching Earth's atmosphere passes through the air and clouds to the surface, where it is absorbed and then radiated upward in the form of infrared heat.
- About 90 percent of this heat is then absorbed by the **greenhouse gases** and radiated back toward the surface, which is warmed to a life-supporting average of 59 degrees Fahrenheit (15 degrees Celsius).”

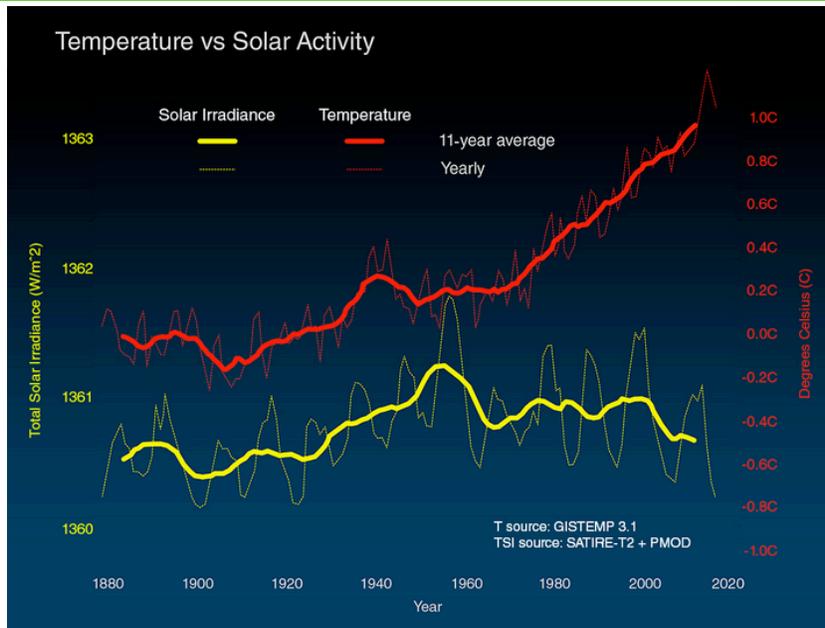
<https://climate.nasa.gov/evidence/>

## A quick overview



<https://www.nationalgeographic.com/environment/global-warming/global-warming-effects/>

## It's not just the sun



<https://climate.nasa.gov/evidence/>

## Is it natural?



Yes!

GCC is a **natural climatic response** to increasing levels of CO<sub>2</sub> and other GHGs (greenhouse gases) in the atmosphere.

gas	formula	GWP*	** % increase	increased forcing***	contribution to GCC %
carbon dioxide	CO <sub>2</sub>	1	41.2	1.88	9 - 26
methane	CH <sub>4</sub>	84	151 - 170	0.49	4 - 9
nitrous oxide	N <sub>2</sub> O	264	20	0.17	
ozone	O <sub>3</sub>		42	0.4	3 - 7
water	H <sub>2</sub> O				36 - 72
Industrial HCs	many	5K - 17.5K		0.36	

GWP\* = 20-year global warming potential  
 \*\*% increase = atmospheric increase since 1750  
 Increased forcing\*\*\* = W/m<sup>2</sup>

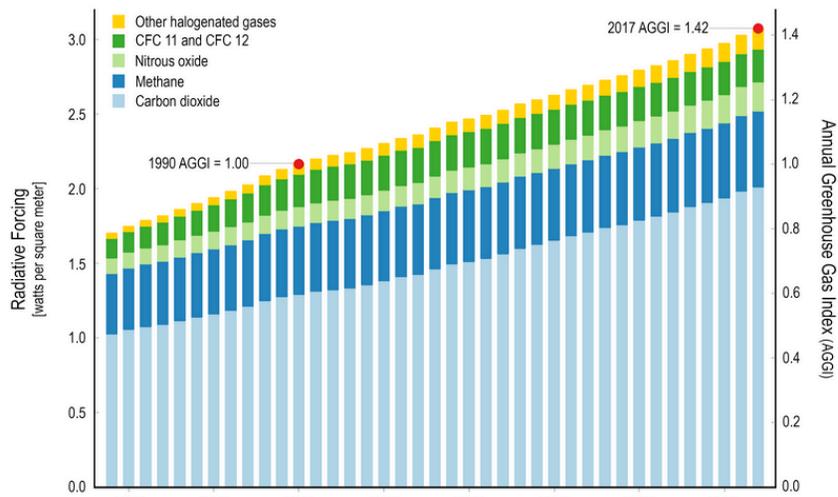
<https://climate.nasa.gov/evidence/>  
[https://en.wikipedia.org/wiki/Greenhouse\\_gas](https://en.wikipedia.org/wiki/Greenhouse_gas)

## GHG concentration are rising...



... as is their 'radiative forcing' effect, aka warming effect.

Annual Greenhouse Gas Index



<https://www.globalchange.gov/browse/indicators/indicator-annual-greenhouse-gas-index>

## Consensus about the cause of GHG



“Multiple studies published in peer-reviewed scientific journals show that **97 percent or more of actively publishing climate scientists agree\***: Climate-warming trends over the past century are extremely likely due to human activities. In addition, most of the leading scientific organizations worldwide have issued public statements endorsing this position. The following is a partial list of these organizations, along with links to their published statements and a selection of related resources.”

*\*Technically, a “consensus” is a general agreement of opinion, but the scientific method steers us away from this to an objective framework. In science, facts or observations are explained by a hypothesis (a statement of a possible explanation for some natural phenomenon), which can then be tested and retested until it is refuted (or disproved).*

<https://climate.nasa.gov/scientific-consensus/>

## We’re living in the Anthropocene age



**Human activity** has increased the concentration of GHGs in the atmosphere since the start of the industrial revolutions.

Thus, GCC is **anthropogenic**.

**Holocene**  
since the end of  
the last glacial  
era

**Anthropocene**  
age of human-  
caused GCC

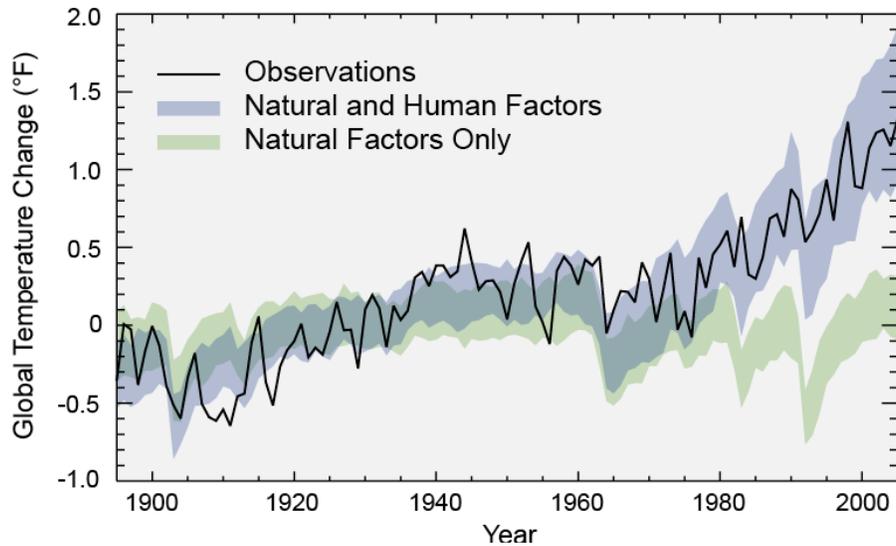


en.wikipedia.org/wiki/Geologic\_time\_scale#/media/File:Geological\_time\_spiral.png

## Modeling: natural vs. anthropogenic



Separating Human and Natural Influences on Climate



## 2. Global climate change



### **2.4: Paradigms, change, revolutions and transitions**

## Change: needed, constant... not popular



Change is **needed**, but it's not easy and it's seldom popular.

Change is **nothing new** and it's one of the few things we can count on.



The only person who likes **change** is a baby with a wet diaper.

Change is said to be constant, but to us (human society) change often appears **episodic**.

- Nothing big happens for a while... then boom! Big change.
- Scientists use the term 'punctuated'.
- Historians and anthropologists use terms like '**revolution**' or '**transition**'.

## Technical revolutions in Western culture



**Technical revolution:** *is a period in which one or more technologies is replaced by another technology in a short amount of time.*

*It is an era of accelerated technological progress characterized by new innovations whose rapid application and diffusion cause an abrupt change in society.*

1600 - 1740	Financial-agricultural revolution
1780 – 1840	Industrial revolution
1870 – 1920	Technical or second industrial revolution
1940 – 1970	Scientific-technical revolution
1975 – on	Information and telecommunications (digital) revolution
<b>Now?</b>	<b>Energy system transition, aka energy decarbonization</b>

[https://en.wikipedia.org/wiki/Technological\\_revolution](https://en.wikipedia.org/wiki/Technological_revolution)

## Resistance to technological change?



When we look back on the the agricultural revolution, or the first industrial revolution, it's hard to believe that the technologies involved didn't catch on right away.

- **Indeed, there is nearly always a lag period before good ideas are widely adopted.**
- We've known this for years::

*"Although the inventor often times drunk with the opinion of his own merit, thinks all the world will invade and incroach upon him, yet I have observed that the generality of men will scarce be hired to make use of new practices, which themselves have not been thoroughly tried... for as when a new invention is first propounded, in the beginning every man objects, and the poor inventor runs the gantloop of all petulent wits...not one [inventor] of a hundred outlives this torture... and moreover, this commonly is so long a doing that the poor inventor is either dead or disabled by the debts contracted to pursue his design."*

- William Petty, 1679

Mokyr (1977) The Political Economy of Technological Change: Resistance and Innovation in Economic History

## Entrenched interests and inertia



Why do societies resist technological change?

- **Incumbents** who fear a threat to their power and economic rents (perceived market advantage)
- Concern about broader **social and political repercussions** ("unintended ripple effects")
- **Risk and loss aversion:** new technologies often have "unanticipated and unknowable consequences"

*"These three motives often merge and create powerful forces that use political power and persuasion to thwart innovations. As a result, technological progress does not follow a linear and neat trajectory. It is, as social constructionists have been trying to tell us for decades, a **profoundly political process.**"*

He also finds that a critical factor in the ability of a society or nation to change, or to be held back by inertia, is the **'suitability of institutions to the successful adoption of new ideas'**.

**How suited to change are today's American institutions?**

Mokyr (1977) The Political Economy of Technological Change: Resistance and Innovation in Economic History  
[https://en.wikipedia.org/wiki/Joel\\_Mokyr](https://en.wikipedia.org/wiki/Joel_Mokyr)  
[http://eh.net/book\\_reviews/innovation-and-its-enemies-why-people-resist-new-technologies/](http://eh.net/book_reviews/innovation-and-its-enemies-why-people-resist-new-technologies/)

## Revolutions are messy



[https://en.wikipedia.org/wiki/Technological\\_revolution](https://en.wikipedia.org/wiki/Technological_revolution)

## And technical revolutions are too



Consider the effects of the **Industrial Revolution** of the mid-1800s:

### Pro:

- Economic growth
- Development of machines
- Mechanization of agriculture
- Faster communication and transportation
- Slow (reactive) improvements in sanitation

### Con:

- Widened class divides (social and economic inequity)
- Systemic child labor
- Increased environmental pollution, particularly urban
- Overcrowding of cities
- Poor sanitary conditions that led to epidemics of infectious disease, particularly in poor areas of cities

[https://en.wikipedia.org/wiki/Technological\\_revolution](https://en.wikipedia.org/wiki/Technological_revolution)

<https://www.cam.ac.uk/research/news/industrial-revolution-damaging-psychological-imprint-persists-in-todays-populations>

## Today, we need a carbon paradigm shift



Technical revolutions sometimes involve full-scale paradigm shifts.

**Paradigm:** *a theory or group of ideas about how something should be done, made or thought about*

**Paradigm shift:** *important change that happens when the usual way of thinking about or doing something is discarded and replaced by a new and different way*

Let's look at a few examples of paradigm shift from history and how well they were received.

[https://en.wikipedia.org/wiki/Technological\\_revolution](https://en.wikipedia.org/wiki/Technological_revolution)

<https://www.cam.ac.uk/research/news/industrial-revolution-damaging-psychological-imprint-persists-in-todays-populations>

## Copernican revolution



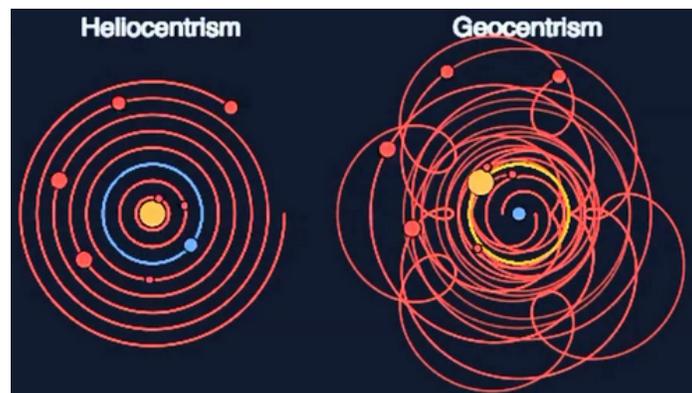
**The sun, not the earth, the center of the solar system.**

**Resistance?**

This new idea was contrary to Church doctrine that held that the Earth, created by God, was the center of the universe.

- Although Copernicus dedicated his book (1543) to the pope, the church later banned it (1616).

<https://www.space.com/15484-nicolaus-copernicus.html>



## Darwin: evolution



**Organisms evolve from gradual modification of ancestors; each organism wasn't specifically created by God.**

### Resistance?

Again, resistance came from organized religion.

*"Man's derived supremacy over the earth; man's power of articulate speech; man's gift of reason; man's free-will and responsibility [...] are all equally and utterly irreconcilable with the degrading notion of the brute origin of him who was created in the image of God."*

- Bishop Samuel Wilberforce,  
Opponent of Evolution

<http://39769227.weebly.com/opposition.html>



## Jenner: vaccination



**Inoculation with dead, weakened or related microbes would protect people from disease caused by that microbe.**

### Resistance?

Jenner adapted a process started by the Chinese and protected people from deadly smallpox by inoculation with the weaker and related cowpox.



[https://en.wikipedia.org/wiki/Smallpox\\_vaccine](https://en.wikipedia.org/wiki/Smallpox_vaccine)

## The Tony Soprano problem?



Tony claimed that he wanted to leave murder and extortion behind and went to therapy. His therapist helped him see that he wanted to change, and gave him suggestions.

**Did he change?**



<https://www.digitaltonto.com/2016/3-paradigm-shifts-that-will-drive-how-we-compete-in-the-21st-century/>

## 2. Global climate change



### **2.5: Decarbonization and the energy trilemma**

## Any solution must lower carbon emissions

Transitioning to low-carbon fuels – or using abundant fuels without emitting carbon - will address the concerns of growthists, peakists and environmentalists.

1. Manage human population levels (speeding the demographic shift).
2. Accept & adapt to lower growth in per capita gross domestic product.

3. Reduce the amount of energy required per unit of GDP.

4. Reduce the amount of carbon emitted per unit of energy produced.

Increase energy efficiency to maximize GDP per unit of energy

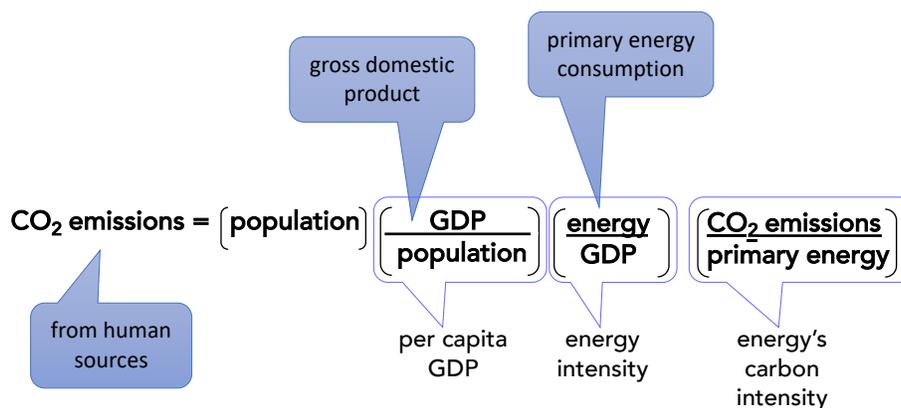
Reduce CO<sub>2</sub> emission from fossil fuels.

Transition to renewable energy &/ nuclear power.

Energy Systems & Sustainability, 2/e, Chapter 1

## Kaya Identity

... a simple formula used to explore the options we have for reducing carbon dioxide emissions from energy production & use.



Energy Systems & Sustainability, 2/e, Chapter 1

## Embodied energy and lifecycle emissions

While no energy source is carbon-free, renewable energy included, a recent study of **life-cycle analysis** of energy technologies used to produce electricity shows that some have significantly lower carbon footprints than others.

**Embodied energy:** energy need to build plants, supply fuel and input.

- Here expressed as a % of lifetime electricity production.

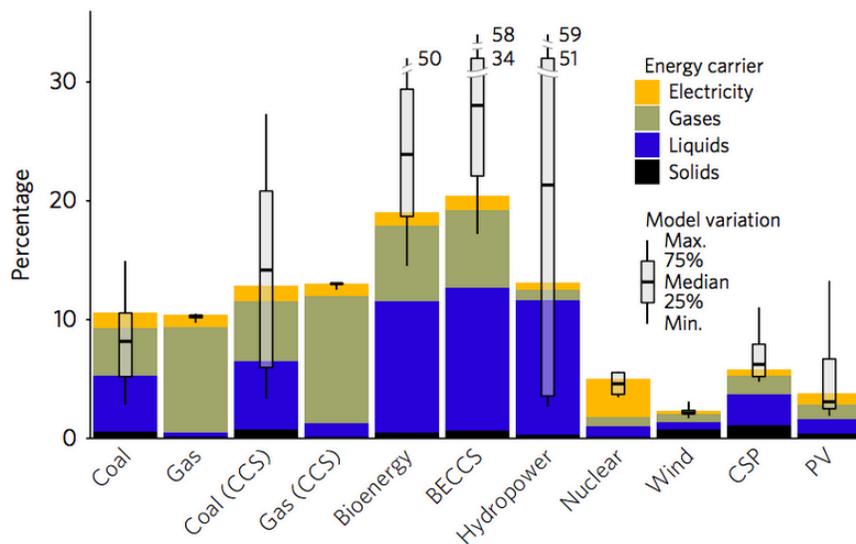
**Lifecycle emissions:** carbon emissions produced by the energy system from building to energy use

- Direct (operational)
- Indirect (non-operational lifecycle)

<https://www.carbonbrief.org/solar-wind-nuclear-amazingly-low-carbon-footprints>

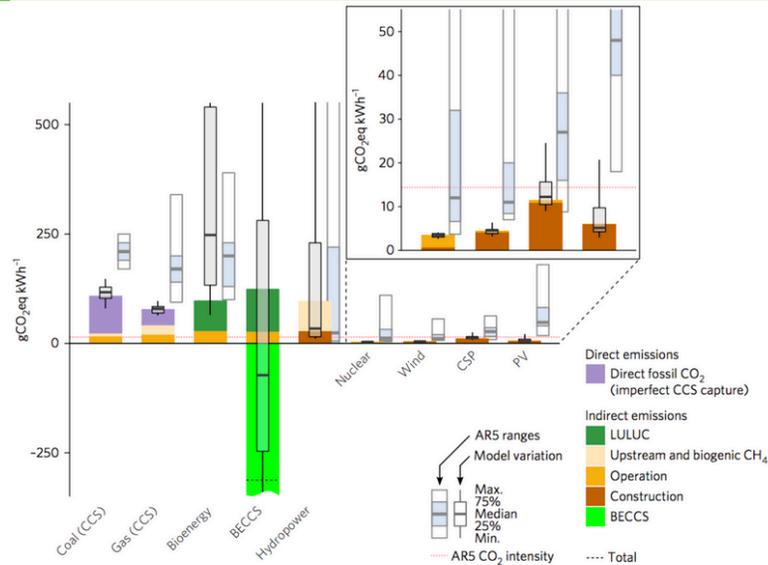
Pehl et al. (2017) Understanding future emissions from low-carbon power systems ...Nature Energy

## Comparing embodied energy



Embodied energy use, as a percentage of lifetime electricity production from different sources. The chart shows embodied energy in 2050. Only solar would show a significant change for 2015, Pehl tells Carbon Brief, rising from around 4 to 10%. Source: Pehl et al.

## Comparing lifetime carbon emissions



Lifecycle direct and indirect greenhouse emissions associated with generating a unit of electricity from different fuels, in a 2C world in 2050 (coloured bars). The colours break down these emissions by source. For comparison, the light blue ranges show the range of results published in the latest Intergovernmental Panel on Climate Change assessment, AR5. Source: Pehl et al.

## Conclusions



This study makes a **strong case for nuclear, wind and solar** at the expense of bioenergy, hydropower and CCS.

### CCS:

- Emissions continue during fuel extraction (mining).
- Capture assumed to be 90% efficient, so 10% emissions continue.

### Hydropower:

- Very variable emissions due to trapped, rotting organics.
- Avoid shallow dams in warm regions with variable flow.

### Bioenergy:

- Very variable footprint; depends on current state of land.
- Avoid transitioning land out of forest.

**“There is no panacea to the energy transition. Coal and gas with CCS will perhaps play a role in certain regions that don’t have ready access wind and solar. But their share in the overall power mix will be much smaller than that of the renewables.”**

<https://www.carbonbrief.org/solar-wind-nuclear-amazingly-low-carbon-footprints>

Pehl et al. (2017) Understanding future emissions from low-carbon power systems ...Nature Energy

## Change: who's in and who's out?



The **Paris Agreement** is an agreement within the United Nations Framework Convention on Climate Change (UNFCCC), dealing with GHG-emissions mitigation, adaptation, and finance, signed in 2016.

### Long-term goal:

- to keep the increase in global average temperature to well below 2 °C above pre-industrial levels; and
- to limit the increase to 1.5 °C, since this would substantially reduce the risks and effects of climate change

While it is widely agreed that climate agreements are vital, the effectiveness of the Paris Agreement is debated.

- Intent matters;
- Compromise and a roadmap are essential.

Following the Trump administration's declaration of intention to withdraw (effective 2020), **only the US has not agreed to or signed onto the accord.**

[https://en.wikipedia.org/wiki/Paris\\_Agreement](https://en.wikipedia.org/wiki/Paris_Agreement)

<https://www.nytimes.com/2017/11/07/climate/syria-joins-paris-agreement.html>

## What do American's think?



Studies by the Yale Program on Climate Communications and the Pew Center for Research show that:

- Americans overwhelmingly believe that global warming is happening;
- That carbon emissions should be scaled back; but
- **Fewer believe that GCC will affect them personally.**

'Beliefs' about GCC are divided along **partisan lines**. [See coming maps]

- Economics of GCC?
  - Failure to address GCC will have greater costs: D 63%; R 35%
  - More concerned GCC regulations will increase costs : R 48%, D 25%.

**Young Republicans** are far more concerned about GCC:

*"It is time for us to get real messaging on environmental and climate issues. And I don't think that we have to sacrifice our values and our roots in, you know, markets and private-sector innovations helping us get across the finish line. And also, like, we are the future of the GOP, and it matters to this growing voting bloc.*

**And it's not going to go away by denial."**

[https://www.nytimes.com/interactive/2017/03/21/climate/how-americans-think-about-climate-change-in-six-maps.html?\\_r=0](https://www.nytimes.com/interactive/2017/03/21/climate/how-americans-think-about-climate-change-in-six-maps.html?_r=0)

<http://climatecommunication.yale.edu/visualizations-data/partisan-maps-2016/?est=happening&group=rep&type=value&geo=cd>

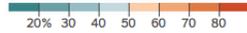
<https://www.forbes.com/sites/boymannmarsico/2019/04/19/democrats-and-republicans-divided-on-climate-change/#78119c233198>

<https://www.npr.org/2019/04/28/717970463/young-republicans-and-climate-change>

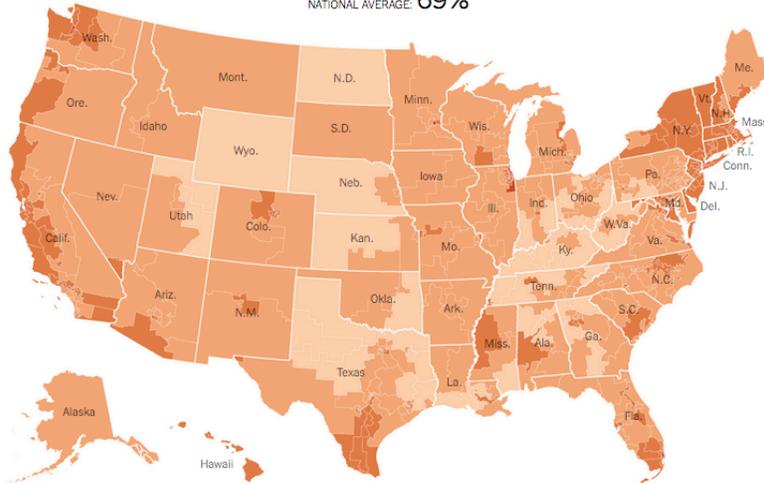
# (1) Americans want to restrict carbon



Percentage of adults per congressional district who support strict CO2 limits on existing coal-fired power plants



NATIONAL AVERAGE: 69%

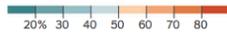


[https://www.nytimes.com/interactive/2017/03/21/climate/how-americans-think-about-climate-change-in-six-maps.html?\\_r=0](https://www.nytimes.com/interactive/2017/03/21/climate/how-americans-think-about-climate-change-in-six-maps.html?_r=0)

# (2) GCC: a problem... but not for me!

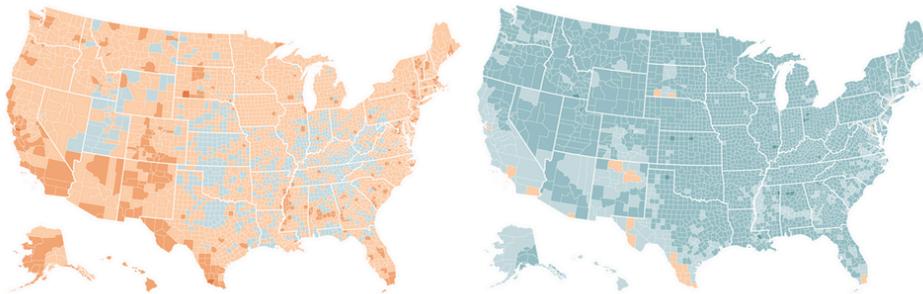


Percentage of adults per county who think ...



Global warming will harm people in the United States

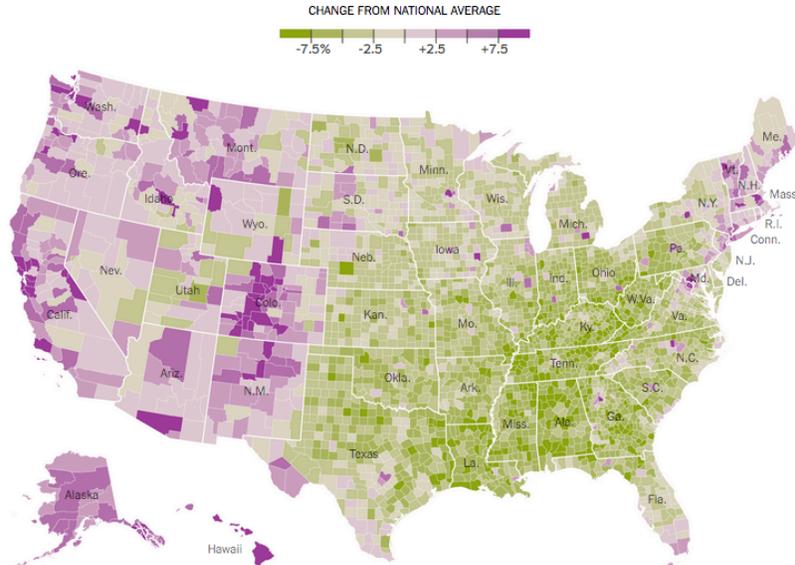
Global warming will harm me, personally



[https://www.nytimes.com/interactive/2017/03/21/climate/how-americans-think-about-climate-change-in-six-maps.html?\\_r=0](https://www.nytimes.com/interactive/2017/03/21/climate/how-americans-think-about-climate-change-in-six-maps.html?_r=0)

### (3) Do we talk about climate and weather?

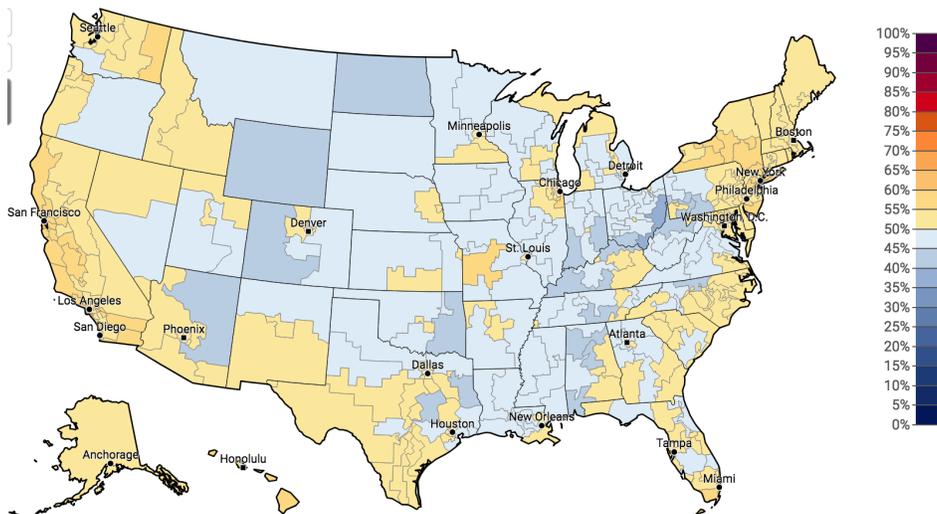
Counties where adults discuss global warming at least occasionally



[https://www.nytimes.com/interactive/2017/03/21/climate/how-americans-think-about-climate-change-in-six-maps.html?\\_r=0](https://www.nytimes.com/interactive/2017/03/21/climate/how-americans-think-about-climate-change-in-six-maps.html?_r=0)

### Partisan divide on GCC

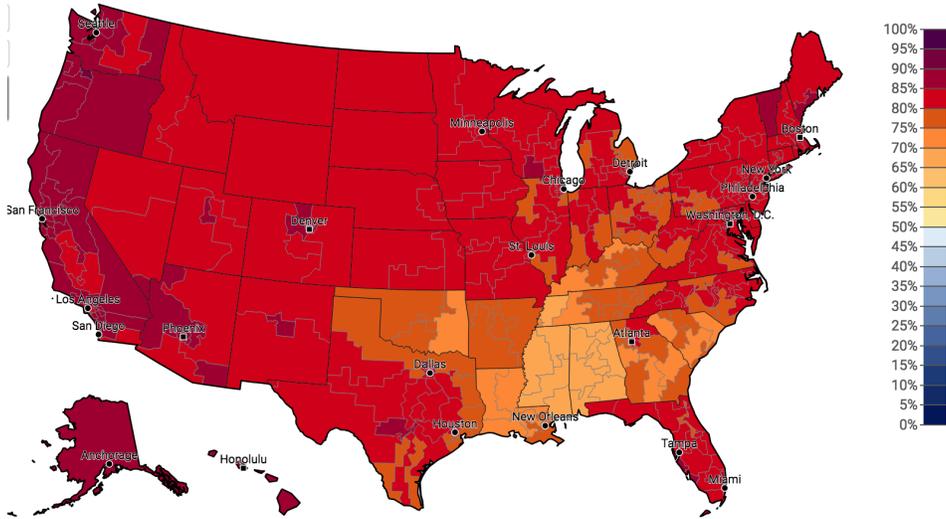
Republicans who think GCC is happening, 2016



<http://climatecommunication.yale.edu/visualizations-data/partisan-maps-2016/?est=happening&group=rep&type=value&geo=cd>

## Partisan divide on GCC

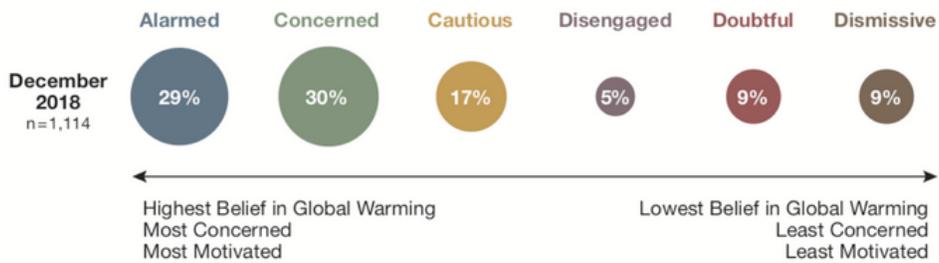
Democrats who think GCC is happening, 2016



<http://climatecommunication.yale.edu/visualizations-data/partisan-maps-2016/?est=happening&group=rep&type=value&geo=cd>

## Global warming's 'six Americans'

Research by the Yale Program on Climate Communications identifies six 'audiences' or attitudes toward GCC in America.



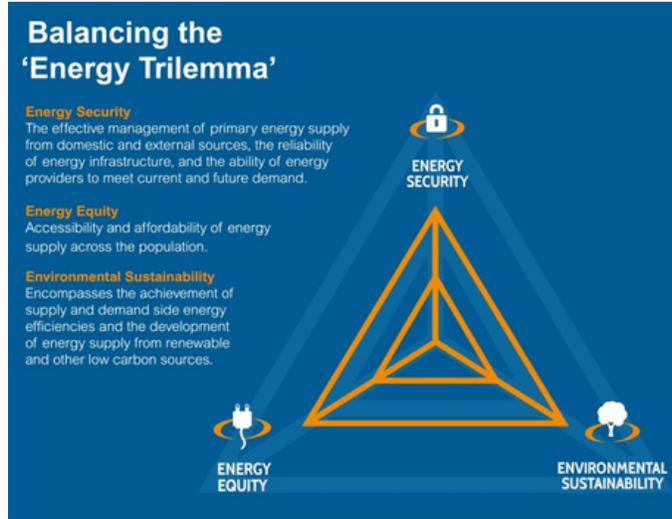
<https://climatecommunication.yale.edu/about/projects/global-warmings-six-americas/>

# The energy trilemma

**Dilemma:** tough choice between two difficult options

**Trilemma:** tough choice between three unfavorable options

- 'Impossible trinity' where two goals are pursued at the expense of the third



<https://www.carbonbrief.org/climate-rhetoric-whats-an-energy-trilemma>  
<https://www.worldenergy.org/work-programme/strategic-insight/assessment-of-energy-climate-change-policy/>

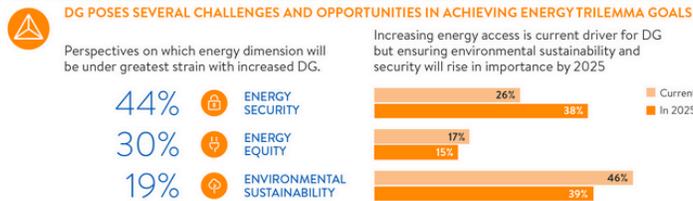
# Example: DG trilemma

**DG EXPECTED TO INCREASE RAPIDLY**  
Energy leaders are predicting a major increase in the amount of DG in their countries' installed electricity supply by 2025.

2017 5% or less → 2025 25%-plus

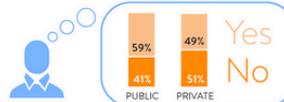
**CHANGES IN ELECTRICAL SUPPLY STRUCTURE 2017-2025**  
Countries' electricity supply structure is expected to shift from a model to a hybrid model by 2017-2025.

- Central large scale electricity generation
- Consumers
- Prosumers (households, communities, industries)
- ★ Distributed energy resources (DERs)



**UNCERTAINTY WHETHER REGULATIONS CAN KEEP PACE WITH CHANGE**  
Increasing DG will require fundamental changes to regulations and who can participate in the energy market. Energy leaders worldwide are sceptical as to whether current regulatory frameworks can accommodate the shifting energy supply structure.

Can the current energy regulatory regime accommodate the shifting energy supply structure?

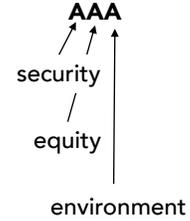


<https://trilemma.worldenergy.org/>

## Energy trilemma index

Country rankings 

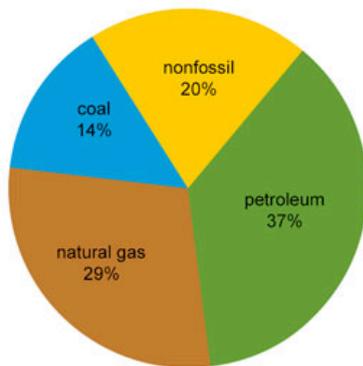
2018	Index rank	Country	Balance score	Energy security	Energy equity	Enviromental sustainability
	1	Denmark	AAA	1	11	17
	2	Switzerland	AAA	17	6	4
	3	Sweden	AAA	4	27	16
	4	Netherlands	AAB	10	4	54
	5	United Kingdom	AAA	18	19	14
	6	Slovenia	AAB	2	33	58
	7	Germany	AAB	12	29	40
	8	New Zealand	AAB	13	30	50
	9	Norway	BAA	45	15	8
	10	France	AAA	26	16	15
	11	Austria	AAB	15	13	37
	12	Finland	AAC	5	26	88
	13	Canada	AAD	3	7	107
	14	United States	AAC	7	14	93
	15	Israel	AAA	25	34	19
	16	Spain	AAA	21	32	22
	17	Ireland	BAA	66	18	10



<https://trilemma.worldenergy.org/>

## Current energy sources and emissions

U.S. energy consumption by major fuel type, 2017



Totals may not equal 100 because of independent rounding.  
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3, June 2018, preliminary data

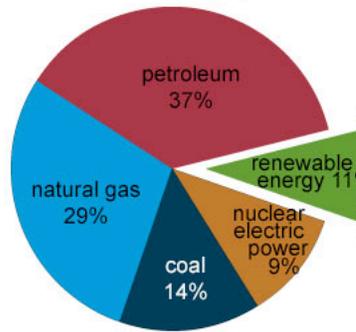
[https://www.eia.gov/energyexplained/index.php?page=environment\\_where\\_ghg\\_come\\_from](https://www.eia.gov/energyexplained/index.php?page=environment_where_ghg_come_from)

## Low-carbon ~ 20% of energy

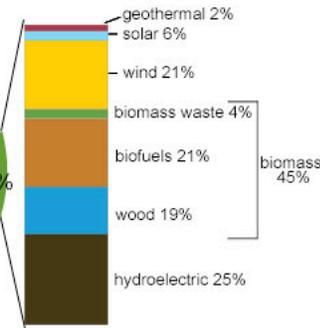
And about half of renewable energy is **biomass**.

### U.S. energy consumption by energy source, 2017

Total = 97.7 quadrillion British thermal units (Btu)



Total = 11.0 quadrillion Btu



Note: Sum of components may not equal 100% because of independent rounding.  
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2018, preliminary data

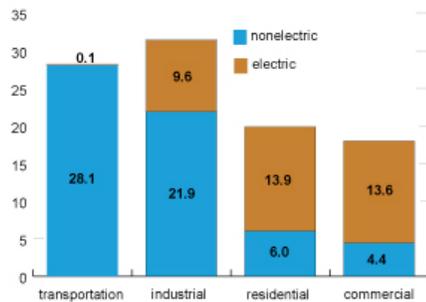


[https://www.eia.gov/energyexplained/?page=us\\_energy\\_home](https://www.eia.gov/energyexplained/?page=us_energy_home)

## Use: transportation is critical

### U.S. energy consumption by end-use sector, 2017

quadrillion British thermal units

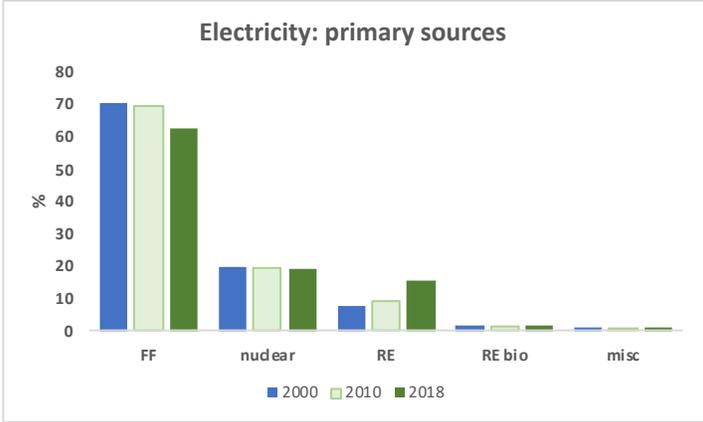


Note: Electric is retail electricity purchased from electric power sector; nonelectric is primary energy.  
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 2.1, June 2018, preliminary data



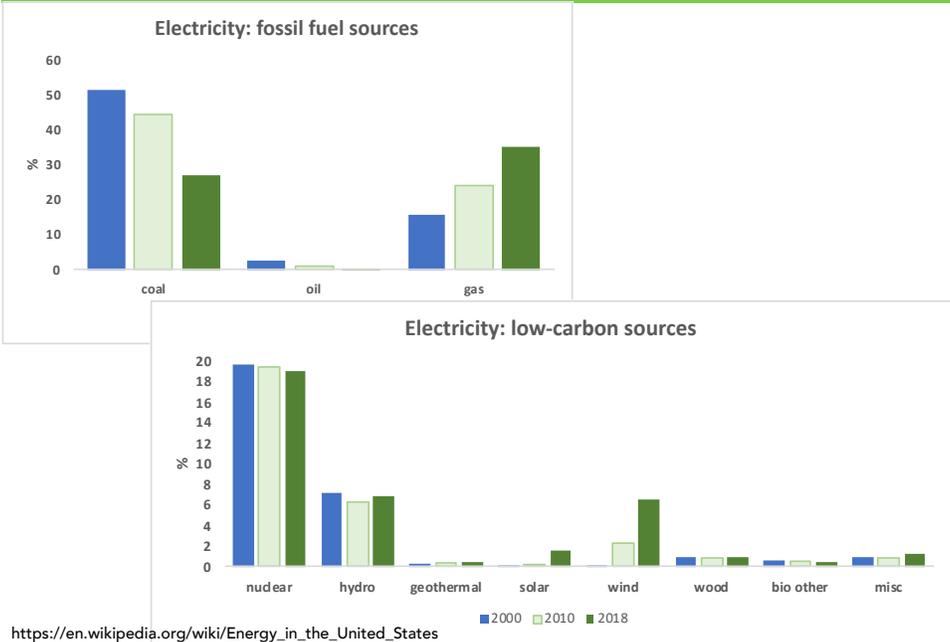
[https://www.eia.gov/energyexplained/index.php?page=environment\\_where\\_ghg\\_come\\_from](https://www.eia.gov/energyexplained/index.php?page=environment_where_ghg_come_from)

To date: tiny change – electricity sources 



[https://en.wikipedia.org/wiki/Energy\\_in\\_the\\_United\\_States](https://en.wikipedia.org/wiki/Energy_in_the_United_States)

To date: tiny change – electricity sources 



[https://en.wikipedia.org/wiki/Energy\\_in\\_the\\_United\\_States](https://en.wikipedia.org/wiki/Energy_in_the_United_States)

## Where do the true challenges lie?



In a 2008 book about what is preventing the US from transitioning to clean power, Sovacool argues that we face “The big four energy challenges”:

1. Rising fossil fuel costs
2. Increasing pollution / carbon emissions
3. Inefficient transmission networks
4. Increasing systems vulnerability to natural disasters, sabotage, financial manipulation

He also identifies “The big four clean solutions”:

1. RE
2. EE
3. DG
4. CHP

His overall conclusion:

**the biggest barriers are institutional**, not technological.

Sovacool (2008) The dirty energy dilemma: what's blocking clean power in the United States

## Adapt or..... adapt



“Most writing about technology and climate change still concentrates on mitigation – ie. Reducing emission by means of clean energy sources, electric vehicles and so on ... While we should never give up on mitigation, **it's time to start talking more about adaptation and suffering** – about the technologies the human race will need in a catastrophically altered world, and about the economic, political and social realities of living in it.”

If we stopped emitting GHGs today, we'd still have **30 years of climate disruption** to deal with.

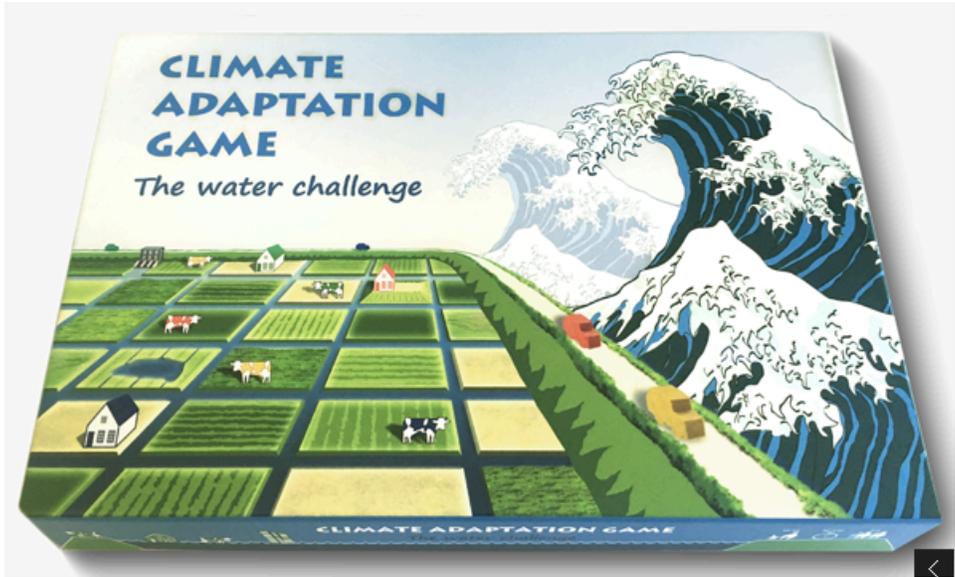
- Change is inevitable, and so must be our adaptation.

**Adaptive capacity:** *the ability of a system (human, natural or managed) to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with consequences.*

- As a property, adaptive capacity is distinct from adaptation itself.

<https://www.technologyreview.com/s/613350/welcome-to-climate-change/>

## Everybody play the game



<http://d.efac.to/en/urbanism/climate-adaptation-game>

## US institutions: GCC is just a game

Since 2017, the current US administration has acted to **weaken, rollback or overturn regulations** in a number of environmental areas.

- Many will slow or reverse action that might mitigate GCC or encourage transition of our energy system.

	49	34	83
	ROLLBACKS COMPLETED	ROLLBACKS IN PROCESS	TOTAL ROLLBACKS
Air pollution and emissions	10	12	22
Drilling and extraction	9	9	18
Infrastructure and planning	12	1	13
Animals	8	2	10
Toxic substances and safety	3	2	5
Water pollution	4	3	7
Other	3	5	8

- Withdrew from Paris Accord
- Repealed Clean Power Plan
- Limiting methane emissions
- Reporting of methane emissions
- Weaker pollution permitting for power plants
- New coal-fired plants won't have to capture carbon
- Weakened calculation of social cost of carbon
- Removed GHG emissions from environmental reviews
- Rolled back auto fuel efficiency
- Opened more public lands to fossil fuel extraction
  - Arctic National Wildlife Ref.
  - US coastal waters

<https://www.nytimes.com/interactive/2019/climate/trump-environment-rollbacks.html>

## Generational change?



Younger generations are more motivated to insist on changes that can mitigate climate change, like changing our energy systems.



On 15 March 2019, roughly **1.4 m students in 123 countries** skipped school to demand changes to address GCC.

- Fridays for the future are expected to continue.

<https://www.vox.com/energy-and-environment/2019/3/15/18267156/youth-climate-strike-march-15-photos>  
<https://www.fridaysforfuture.org/>