Science for Future?

What we can and need to change to keep climate change low

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What is scientist for future?

S4F an association of scientists that joined together after the students ond pupil of „fridays for future“ were questioned

„They should leave this to the professionals“

Well, we were the professionals and can say, they are right!

What is scientist for future?

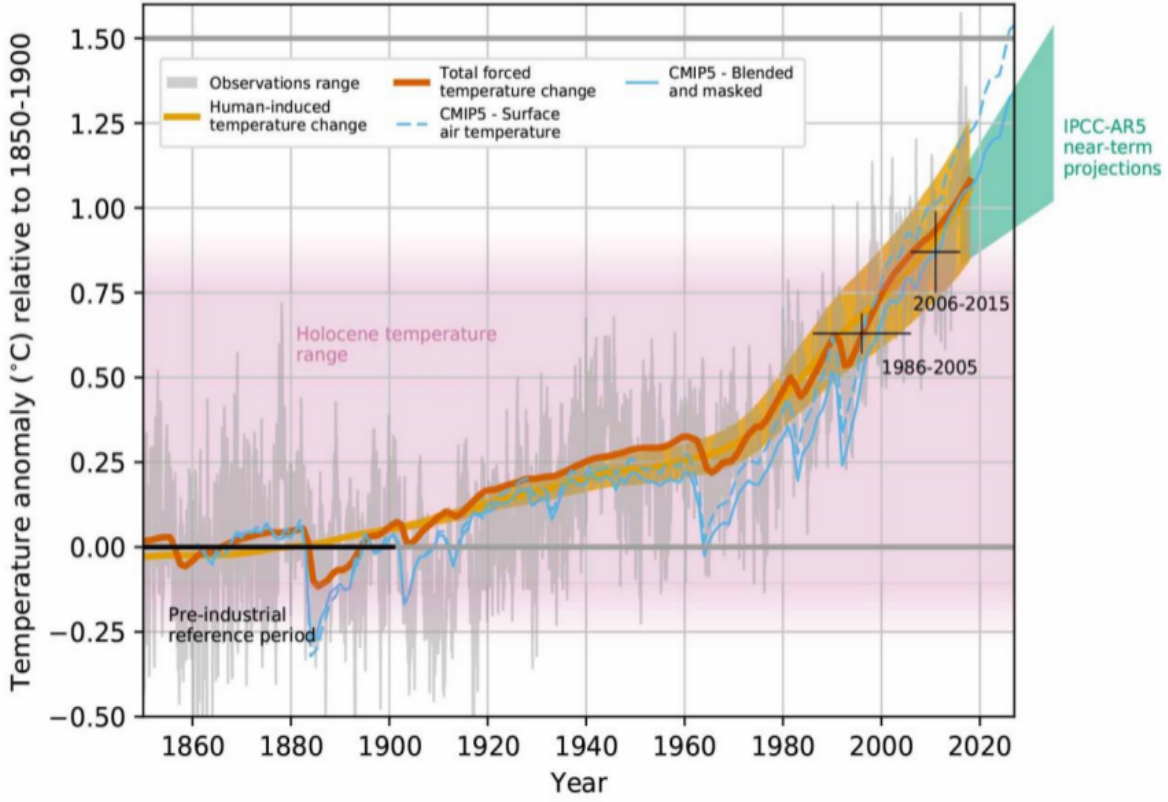
Scientists and scholars involved in Scientists for Future advise groups and individuals from Fridays for Future and other movements committed to a sustainable future. They also engage in proactive science communication. Examples include information events in schools, universities, businesses and public spaces, activities in traditional and digital media, and participation in panel discussions and other events.

Scientists for Future actively translate the current state of science to the social debate on sustainability and a secure future in a scientifically sound and intelligible form. In this way, they support the political process and decision-making for the future. (From charta of S4F, 2019)

Current temperature change

- ca. 1°C increase to pre industrial level in 2017 within the floating averaged curve

(IPCC-2018-Chap1)



Cimalte development today: Where we are

- Increase of CO_2 in atmosphere from approx. 280 ppm in pre-industrial times to about 410 ppm in 2019
- Approx.: In 2017 the global temperature increase reached in average 1°C
- Strong differences in the increase in temperature globaly: Biggest increase in winters in the Arctic
- Current anthropogenic CO_2 surplus is about 40 Gt CO_2 per year

Climate scenarios 1,5°C

- How many Gt CO_2 can we emmit to still remain with a specific certainty below a specified temperature change?

→ 420 Gt CO_2 with 67% probablity for 1,5 °C

Additional Warming since 2006–2015 [°C]*(1)	Approximate Warming since 1850–1900 [°C]*(1)	Remaining Carbon Budget (Excluding Additional Earth System Feedbacks*(5)) [$GtCO_2$ from 1.1.2018]*(2)			Key Uncertainties and Variations*(4)					
		Percentiles of TCRE *(3)			Earth System Feedbacks *(5)	Non-CO_2 scenario variation *(6)	Non-CO_2 forcing and response uncertainty	TCRE distribution uncertainty *(7)	Historical temperature uncertainty *(1)	Recent emissions uncertainty *(8)
		33rd	50th	67th	[$GtCO_2$]	[$GtCO_2$]	[$GtCO_2$]	[$GtCO_2$]	[$GtCO_2$]	[$GtCO_2$]
0.3		290	160	80						
0.4		530	350	230						
0.5		770	530	380						
0.53	**~1.5°C**	**840**	**580**	**420**	Budgets on the left are reduced by about −100 on centennial time scales	±250	−400 to +200	+100 to +200	±250	±20
0.6		1010	710	530						
0.63		1080	770	570						
0.7		1240	900	680						
0.78		1440	1040	800						
0.8		1480	1080	830						
0.9		1720	1260	980						
1		1960	1450	1130						
1.03	**~2°C**	2030	1500	1170						
1.1		2200	1630	1280						
1.13		2270	1690	1320						
1.2		2440	1820	1430						

(IPCC-2018-Chap2)

Climate change scenario for 1,5°C

- To stay below 1,5°C temperature increase with a 2/3 propability, we shall not emit more than 420 Gt surplus CO_2 into the atmosphere in total

However:

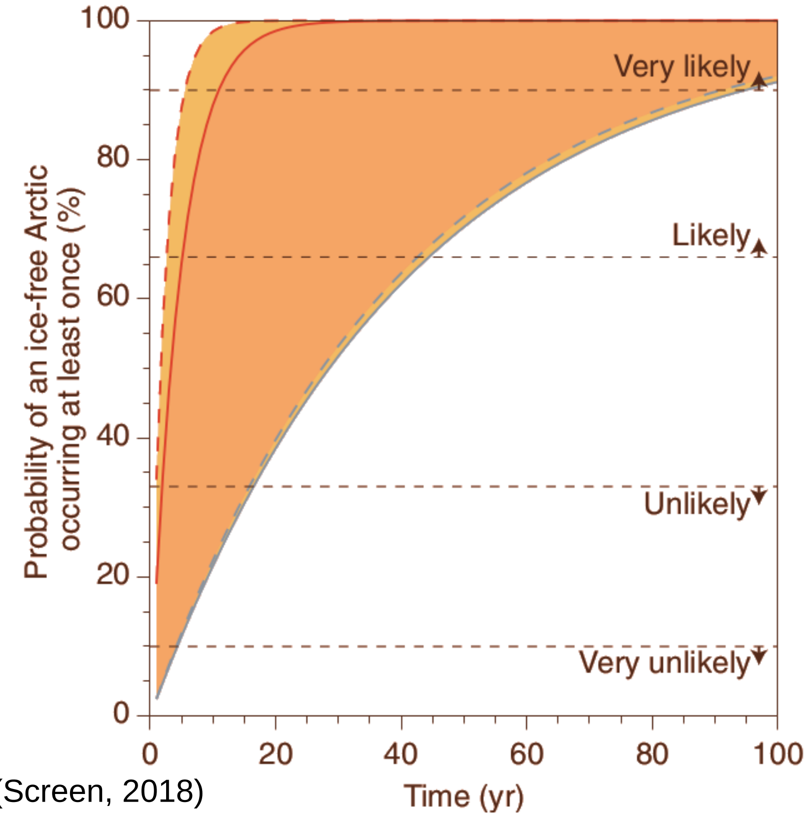
→ 100 Gt CO_2 will additionally emitted my earth-response (long term)

→ Current anthroprogenic emissions are about 40 Gt CO_2eq/y (average between 2011 and 2017)

→ Planned CO_2 emissions by existing coal power plants are about 200 Gt CO_2

→ Further 100-150 Gt CO_2 by planned coal power plants or plants under construction

What does 1.5 to 2°C change mean – example arctic



(Screen, 2018)

Probability of a summer without ice in the arctic according to two models (Sigmand et al. Full and Jahn doted line). Both shown for a 1.5°C (blue) and 2°C (red) increase.

Result:
Ice fre arctia 1x every 45 years likely for 1.5°C
1 x at least every10 years for 2°C according to Sigmand et al.. Acorrding to Jahn more often ...

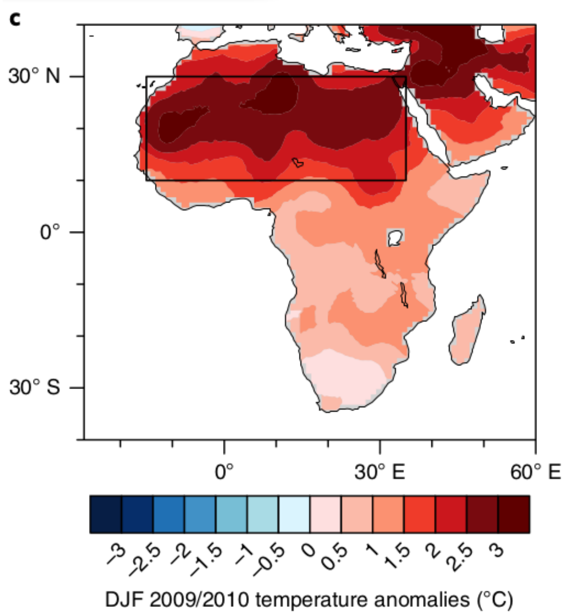
What is 1.5 vs 2°C increase – Extreme conditions in Afrika

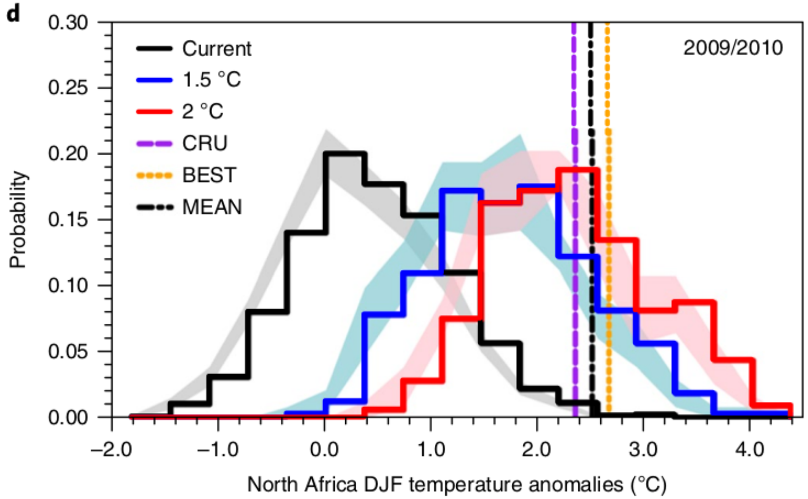
Nangombe et al. (Nangombe, 2018) pulished the effect of climate change for 1.5°C and 2°C on the frequency of extreme weather conditions in Africa of the last 30 years:

- Record average heat in 2015
- December to February extreme heat 2009/2010 in norther Afrika
- Extreme drought in southern Afrika 1991/1992

What is 1.5 vs 2°C increase – Extreme conditions in Afrika

- DJF 2009/2010 record temperatures close to 50°C

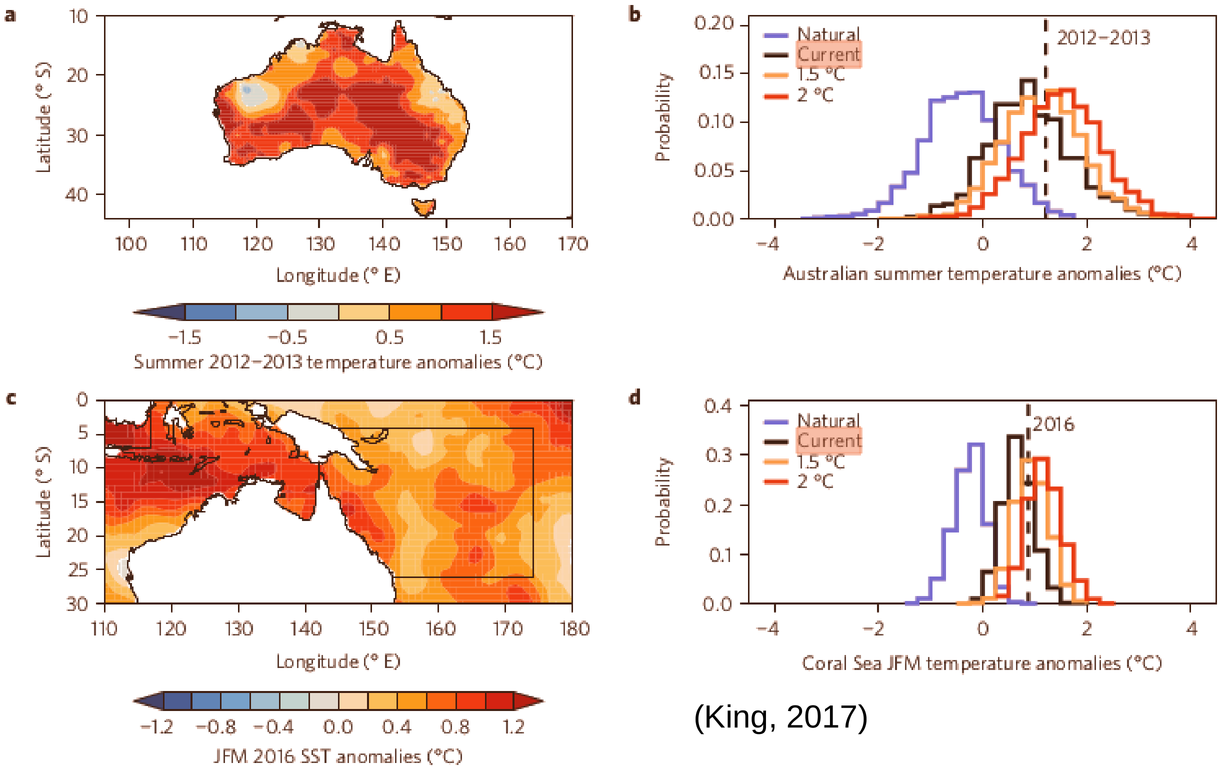




(Nangombe, 2018)

What is 1.5 vs 2°C increase – Extreme conditions in Australia

- Extreme hot summer 2012-2013 and extreme warm water leading to coral bleaching



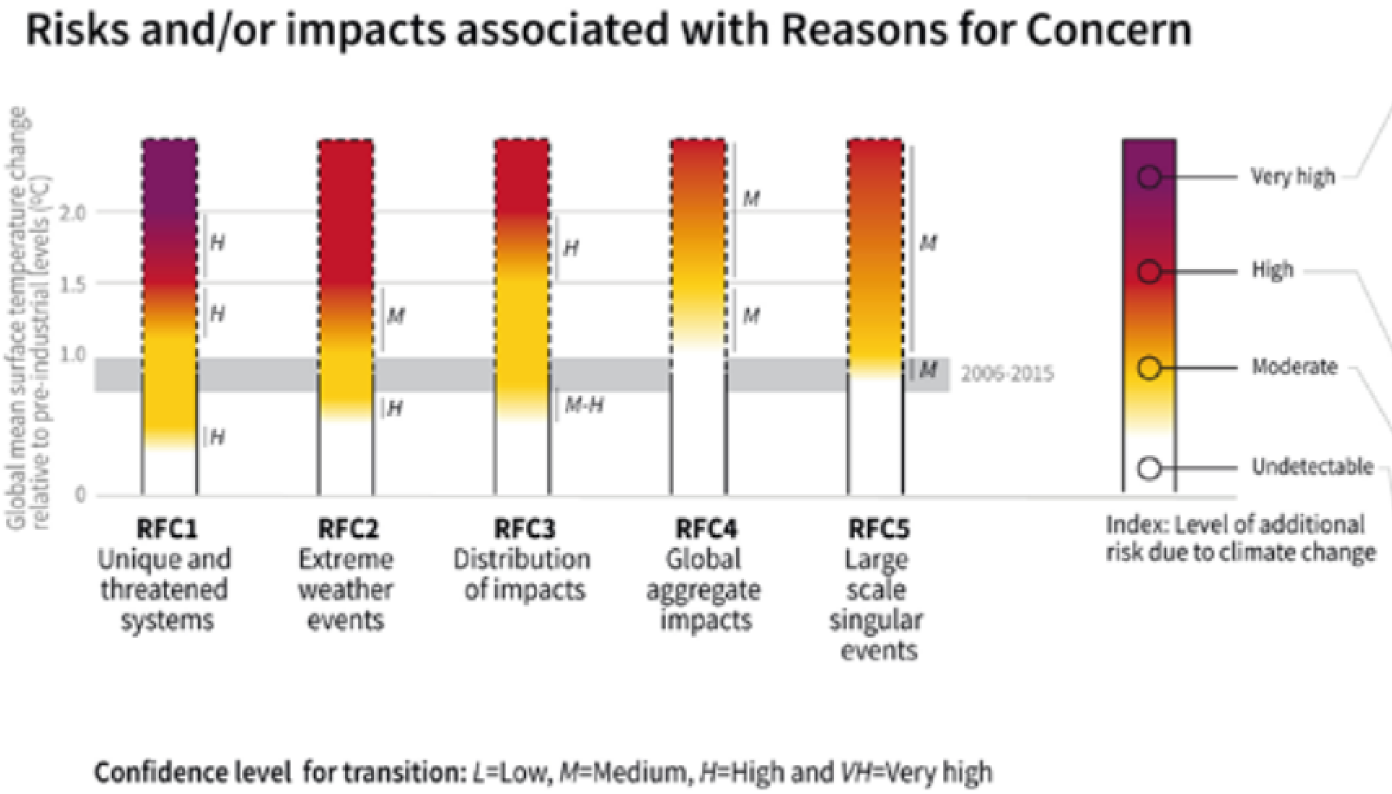
(King, 2017)

What is 1.5 vs 2°C increase – Extreme conditions in Europe

EVENT	CONTEXT, IMPACT	VARIABLE	NATURAL	CURRENT	1.5°C	2°C
			Likelihood of similar event per year			
Europe 2016	Hottest year on record	T	0% (0%)	27% (17-37%)	52% (42-63%)	88% (83-92%)
Central England 2014	Hottest year on record	T	0% (0-1%)	19% (13-25%)	29% (21-37%)	48% (38-59%)
Central Europe JJA 2003	Hottest summer on record, thousands of heat-related deaths	T	1% (1-2%)	25% (17-33%)	42% (32-51%)	59% (50-70%)
		TXx	2% (0-6%)	21% (7-37%)	21% (9-34%)	31% (14-50%)
British Isles Dec 2010	Coldest December on record, excess deaths, airport closures	T	1% (1-2%)	0% (0-1%)	0% (0%)	0% (0%)
		TNn	3% (1-5%)	0% (0%)	0% (0%)	0% (0%)
Southern Europe Mar 2013	Second wettest March on record	R	7% (5-10%)	9% (6-12%)	6% (4-8%)	7% (5-9%)
British Isles MJJ 2007	Wettest May-July on record, widespread floods, 13 deaths	R	0% (0-1%)	1% (0-1%)	0% (0-1%)	0% (0-1%)
		Rx1day	4% (2-6%)	4% (2-6%)	7% (4-9%)	10% (7-12%)

(King, Europe, 2017)

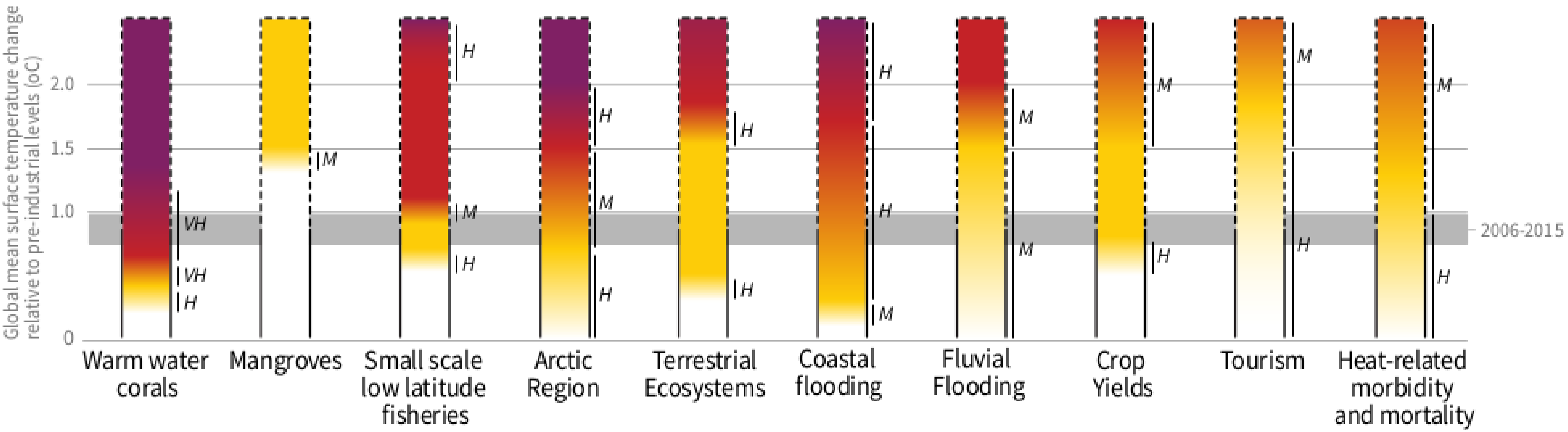
Climate impacts: „Reasons For Concern“



Purple indicates very high risks of severe impacts and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks.
Red indicates severe and widespread impacts/risks.
Yellow indicates that impacts/risks are detectable and attributable to climate change with at least medium confidence.
White indicates that no impacts are detectable and attributable to climate change.

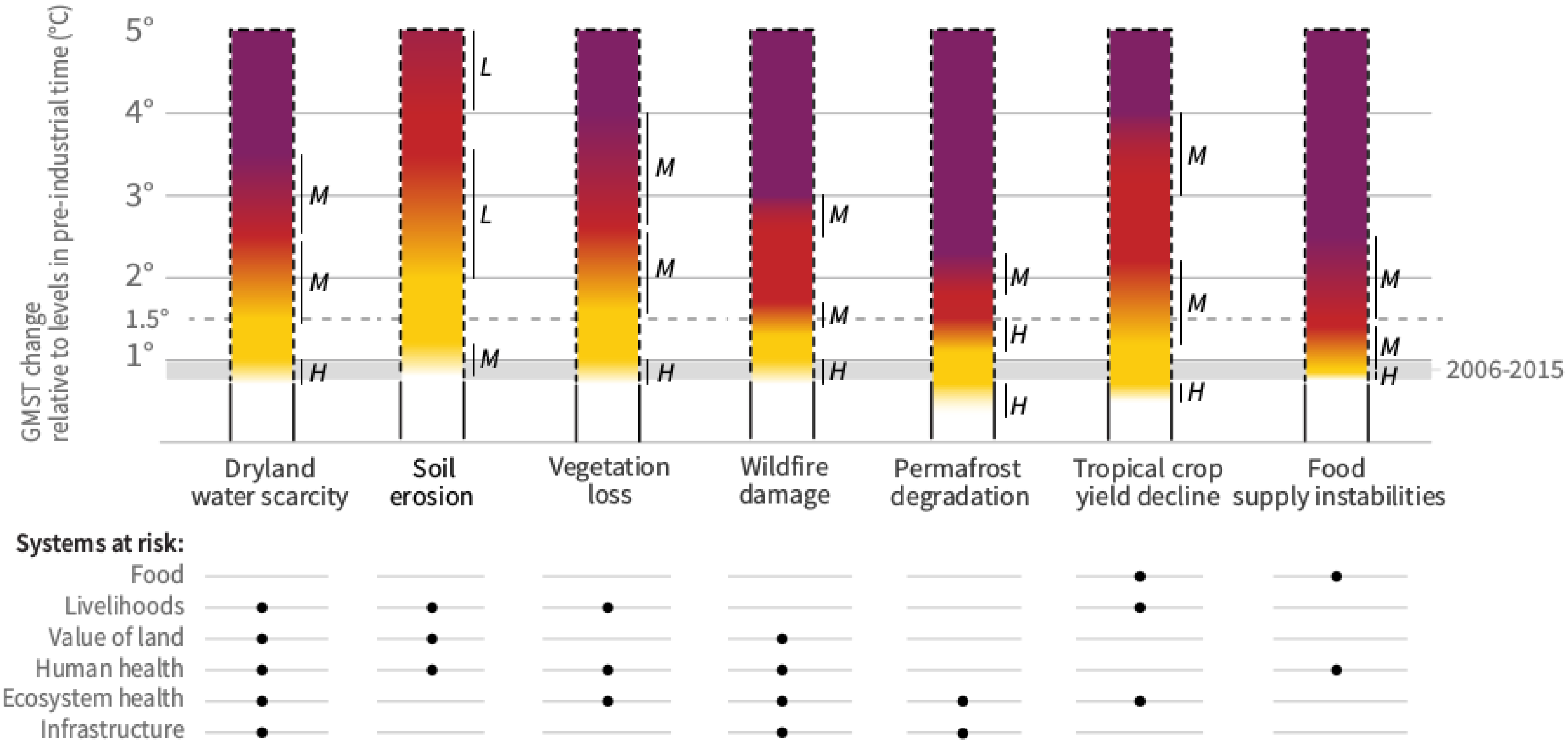
(IPCC-2018-SPM)

Climate impacts on human beings and ecosystems



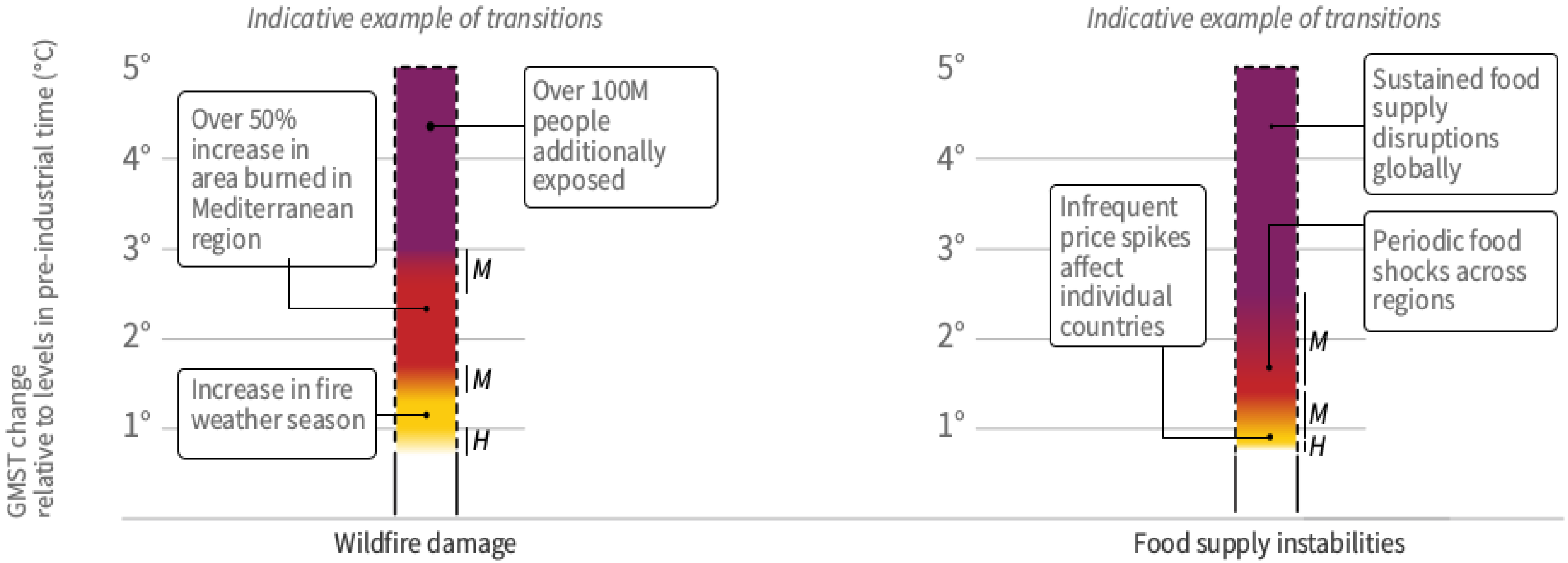
(IPCC-2018-SPM)

Climate change impact on land use



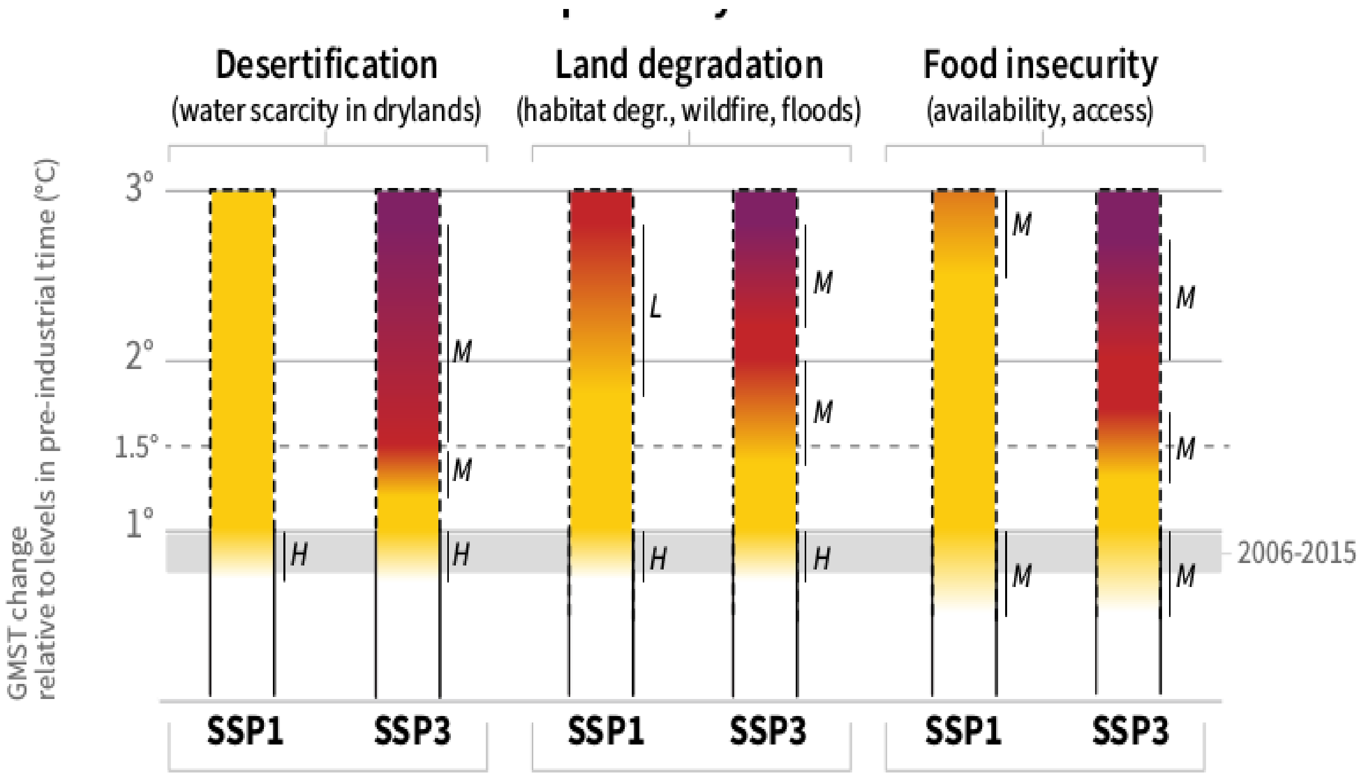
(IPCC-2019-Land-SPM)

Climate change impact on land use



(IPCC-2019-Land-SPM)

Climate change impact on land use



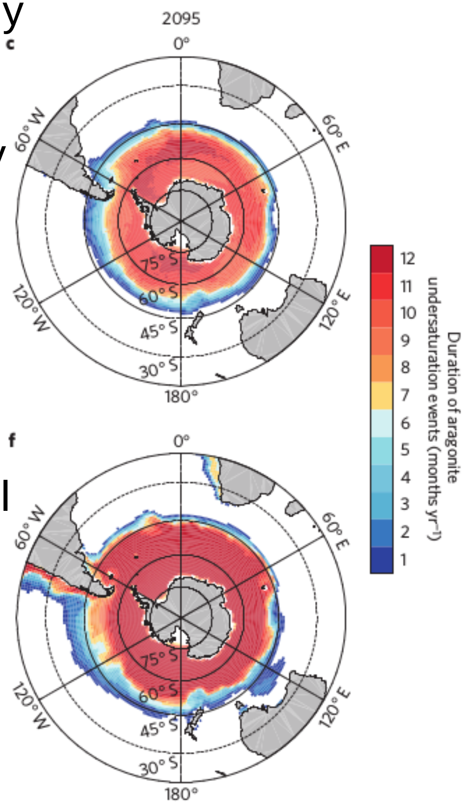
Socio-economic choices can reduce or exacerbate climate related risks as well as influence the rate of temperature increase. The **SSP1** pathway illustrates a world with low population growth, high income and reduced inequalities, food produced in low GHG emission systems, effective land use regulation and high adaptive capacity. The **SSP3** pathway has the opposite trends. Risks are lower in SSP1 compared with SSP3 given the same level of GMST increase.

(IPCC-2019-Land-SPM)

Marine consequences: Change in ocean chemistry

„As ocean waters have increased in sea surface temperature (SST) by approximately 0.9°C they have also decreased by 0.2 pH units since 1870–1899.“

„Organisms with shells and skeletons made out of calcium carbonate are particularly at risk, as are the early life history stages of a large number of organisms and processes such as de-calcification, although there are some taxa that have not shown high-sensitivity to changes in CO_2 , pH and carbonate concentrations (Dove et al., 2013; Fang et al., 2013; Kroeker et al., 2013; Pörtner et al., 2014; Gattuso et al., 2015). Risks of these impacts also vary with latitude and depth, with the greatest changes occurring at high latitudes as well as deeper regions. The aragonite saturation horizon (i.e., where concentrations of calcium and carbonate fall below the saturation point for aragonite, a key crystalline form of calcium carbonate) is decreasing with depth as anthropogenic CO_2 penetrates deeper into the ocean over time. **Under many models and scenarios, the aragonite saturation is projected to reach the surface by 2030 onwards, with a growing list of impacts and consequences for ocean organisms, ecosystems and people (Orr et al., 2005; Hauri et al., 2016).“.**



(IPCC-2018-Chap. 3 p. 223, Figure: Hauri, 2016.)

Climate change consequences: 1.5 vs. 2 vs. 3 °C

Region and/or Phenomenon	Warming of 1.5°C or less	Warming of 1.5°C to 2°C	Warming of 2°C to 3°C
Artic sea-ice	Arctic summer sea-ice is likely to be maintained. Habitat losses for organisms as polar-bears, seals, whales and sea birds Benefits for arctic fishery	The risk of an ice free Arctic in summer is ~ 50% or higher. Habitat losses for organisms as polar-bears, seals, whales and sea birds may be critical when summers are ice free Benefits for arctic fishery	Arctic is very likely to be ice-free in summer. Critical habitat losses for organisms as polar-bears, seals, whales and sea birds Benefits for arctic fishery

(IPCC-2018-Chap3)

Climate change consequences: 1.5 vs. 2 vs. 3 °C

Region and/or Phenomenon	Warming of 1.5°C or less	Warming of 1.5°C to 2°C	Warming of 2°C to 3°C
Arctic land regions	Cold extremes warm by 2-3°C reaching up to 4.5°C (high confidence) Biome shifts in the tundra and permafrost deterioration is likely	Cold extremes warm up to 8°C (high confidence) Larger intrusions of trees and shrubs in the tundra than under 1.5 °C of warming is likely; larger but constrained losses in permafrost are likely	Drastic regional warming very likely A collapse in permafrost may plausibly occur (low confidence); a drastic biome shift from tundra to boreal forest is possible (low confidence).

(IPCC-2018-Chap3)

Climate change consequences: 1.5 vs. 2 vs. 3 °C

Region and/or Phenomenon	Warming of 1.5°C or less	Warming of 1.5°C to 2°C	Warming of 2°C to 3°C
Southeast Asia	Risks for increased flooding related to sea-level rise Increases in heavy precipitation events Significant risks of crop yield reductions are avoided	Higher risks for increased floodingrelated to sea-level rise (medium Confidence - mc) Stronger increases in heavy precipitation events (mc) One third decline in per capita crop production (mc)	Substantial increases in risks related to flooding from sea-level rise Substantial increased in heavy precipitation and high flow events Substantial reductions in crop yield

(IPCC-2018-Chap3)

Climate change consequences: 1.5 vs. 2 vs. 3 °C

Region and/or Phenomenon	Warming of 1.5°C or less	Warming of 1.5°C to 2°C	Warming of 2°C to 3°C
Small Island (SIDS) (IPCC-2018-Chap3)	Land of 60,000 less people exposed by 2150 on SIDS compared to impacts under 2°C of global warming Risks for coastal flooding reduced by 20-80% for SIDS Fresh water stress reduced by 25% Increas in number of warm days in the tropics Persistent heat stress in cattle avoided Loss of 70-90% of coral reefs	Tens of thousands displaced due to inundation of SIDS High risks for coastal flooding Fresh water stress from projected aridity Further increase of about 70 warm days per year Persistent heat stress in cattle in SIDS Loss of most coral reefs – remaining structures weaker due to ocean acidification	Substantial and wide-spread impacts through indundation of SIDS, coastal flooding, fresh water stress, persistent heat stress and loss of most coral reefs very likely

Climate change consequences: 1.5 vs. 2 vs. 3 °C

Region and/or Phenomenon	Warming of 1.5°C or less	Warming of 1.5°C to 2°C	Warming of 2°C to 3°C
Mediterranean	Increase in probability of extreme drought (medium confidence) Reduction in runoff of about 9% (likely Range: 4.5–15.5%) Risk of water deficit (mc)	Robust increase in probability of extreme drought (medium confidence) High confidence of further reductions (about 17%) in runoff (likely range 8– 28%) Higher risks for water deficit	Robust and large increases in extreme drought. Substantial reductions in precipitation and in runoff (medium confidence) Very high risks for water deficit (mc)

(IPCC-2018-Chap3)

Climate change consequences: 1.5 vs. 2 vs. 3 °C

Region and/or Phenomenon	**Warming of 1.5°C or less**	**Warming of 1.5°C to 2°C**	**Warming of 2°C to 3°C**
West African and the Sahel	Reduced maize and sorghum production is likely, with suitable for maize production reduced by as much as 40% Increased risks for under-nutrition	Negative impacts on maize and sorghum production likely larger than at 1.5 °C Higher risks for under-nutrition	Negative impacts on crop yield may result in major regional food insecurities (medium confidence) High risks for undernutrition

(IPCC-2018-Chap3)

Climate change consequences: 1.5 vs. 2 vs. 3 °C

Region and/or Phenomenon	Warming of 1.5°C or less	Warming of 1.5°C to 2°C	Warming of 2°C to 3°C
Southern African savannahs and drought	Reductions in water availability (mc) High risks for increased mortality from heat-waves; High risk for undernutrition in communities dependent on dryland agriculture and livestock	Larger reductions in rainfall and water availability (mc); Higher risks for increased mortality from heat-waves (high confidence); Higher risks for undernutrition in communities dependent on dryland agriculture and livestock	Large reductions in rainfall and water availability (mc) Very high risks for undernutrition in communities dependent on dryland agriculture and livestock

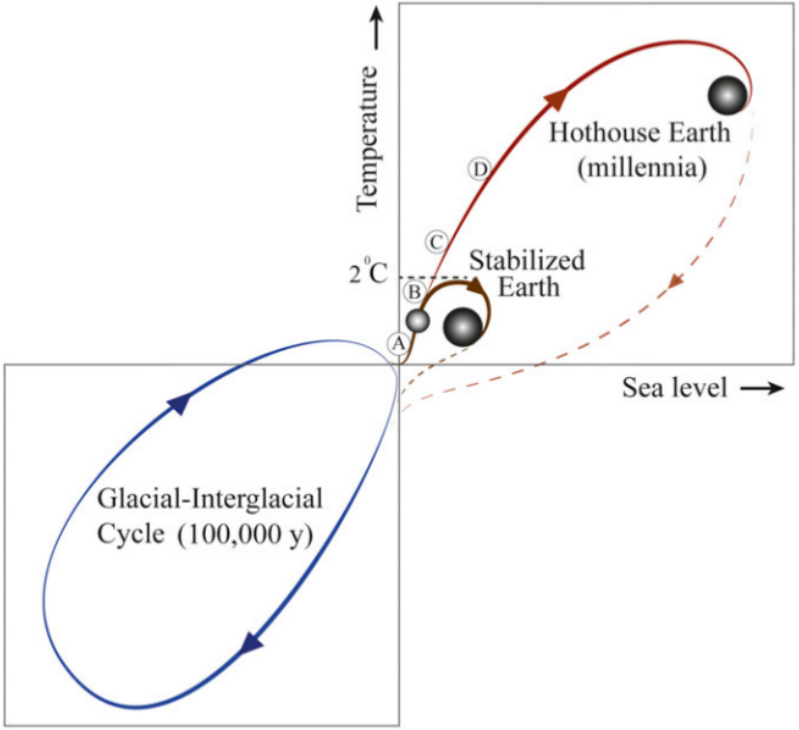
(IPCC-2018-Chap3)

Climate change consequences: 1.5 vs. 2 vs. 3 °C

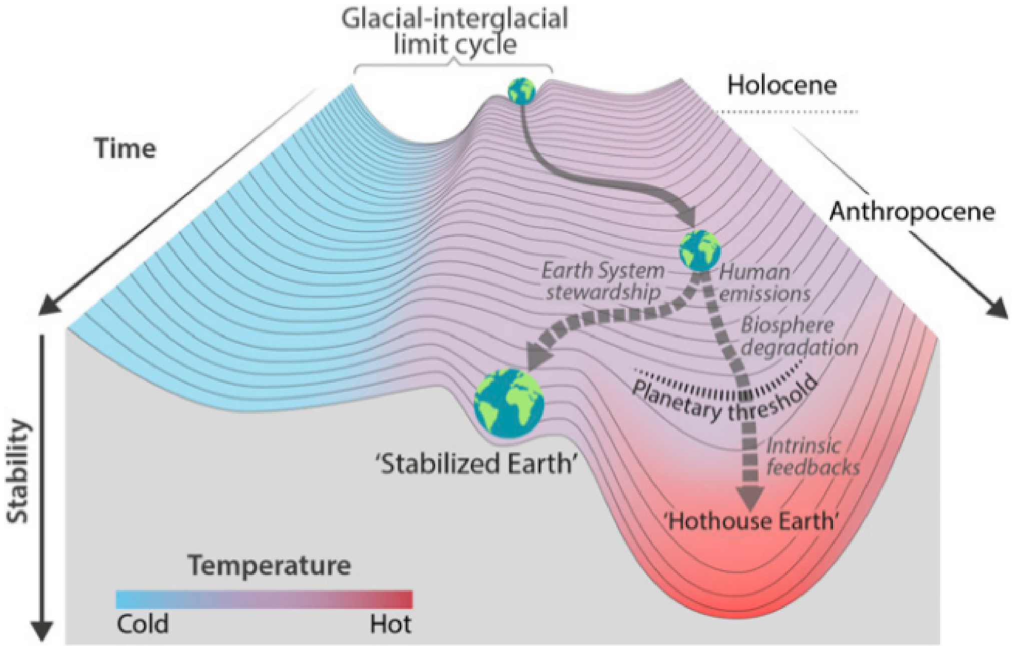
Region and/or Phenomenon	Warming of 1.5°C or less	Warming of 1.5°C to 2°C	Warming of 2°C to 3°C
Tropics	Increases in the number of hot days and hot nights as well as longer and more frequent heatwaves (hc) Risks to tropical crop yields in West Africa, Southeast Asia and Central and South America are significantly less than under 2°C of warming	The largest increase in hot days under 2°C compared to 1.5°C is projected for the tropics. Risks to tropical crop yields in West Africa, Southeast Asia and Central and South America could be extensive	Oppressive temperatures and accumulated heatwave duration very likely to directly impact human health, mortality and productivity Substantial reductions in crop yield very likely

(IPCC-2018-Chap3)

Change of natural climate cycle

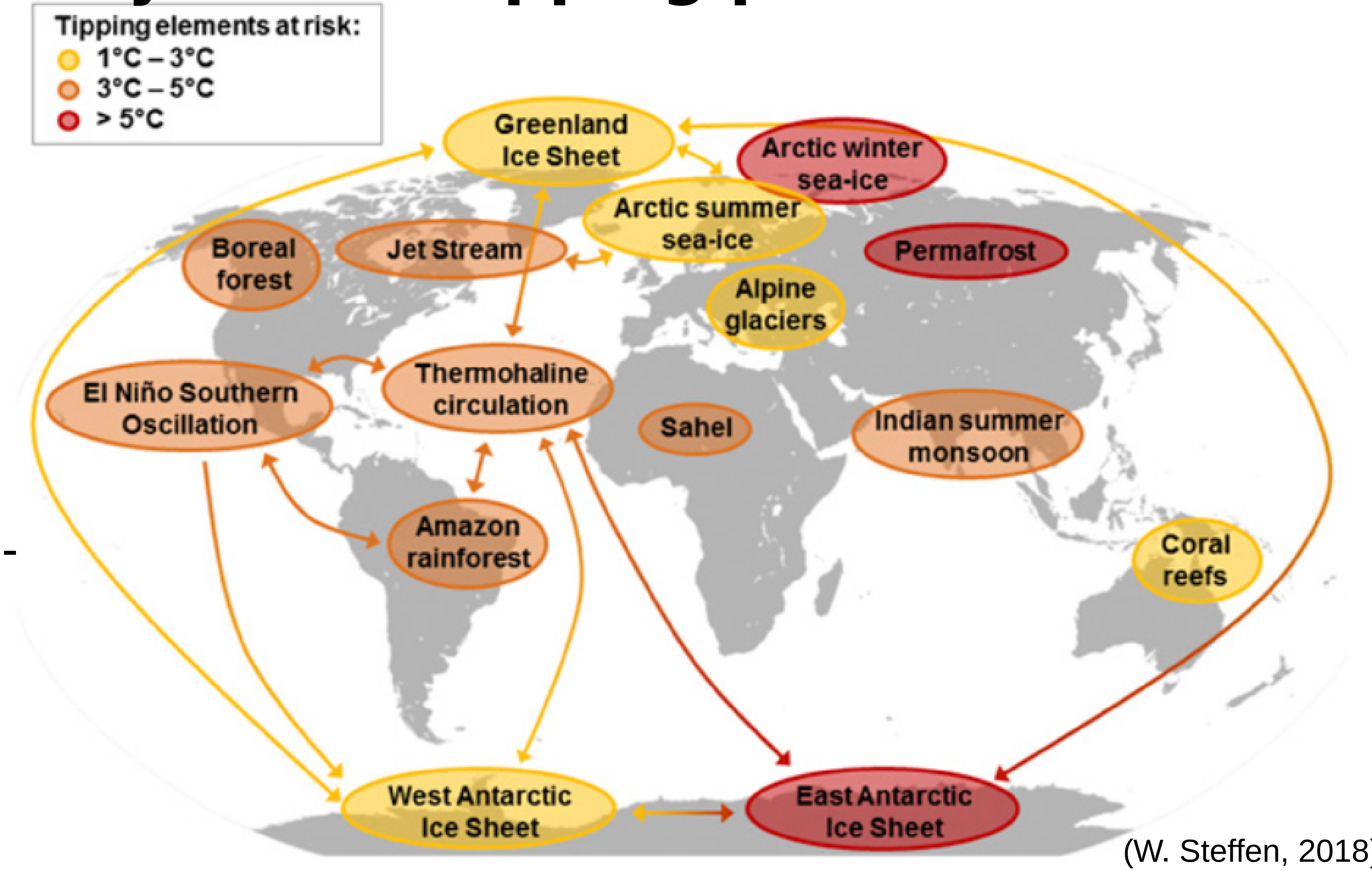


(W. Steffen, 2018)



Climate cylce and tipping points

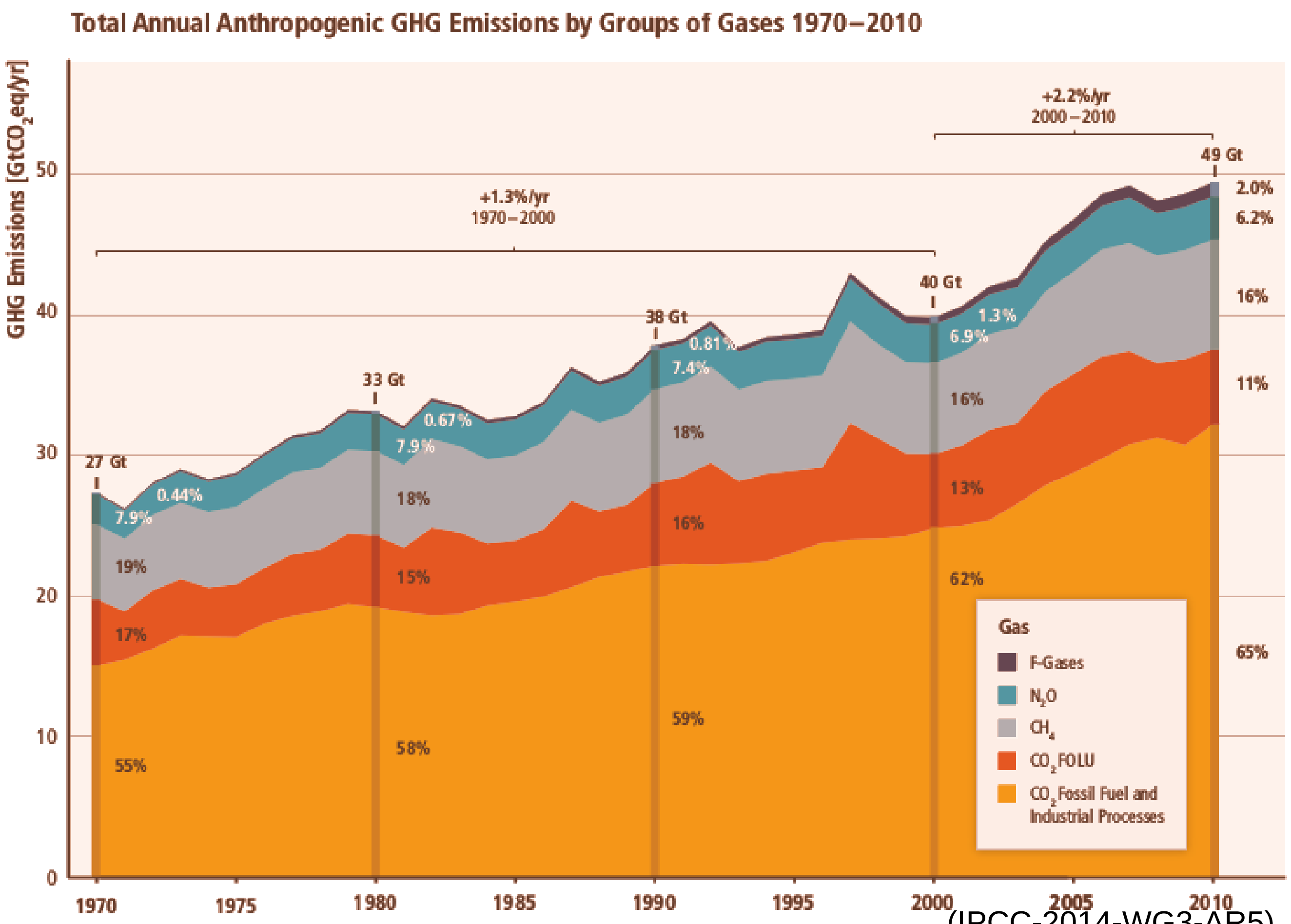
- Thawing of permafrost
- CH_4 from Methanhydrates
- Reduction of CO_2 intake in water and land
- Die off of rain forests
- Die off of boreal forests
- Reduction of ice and snow - reduced albedo
- Reduction of ice volume with increase of sea level



(W. Steffen, 2018)

Green house gas - emissions

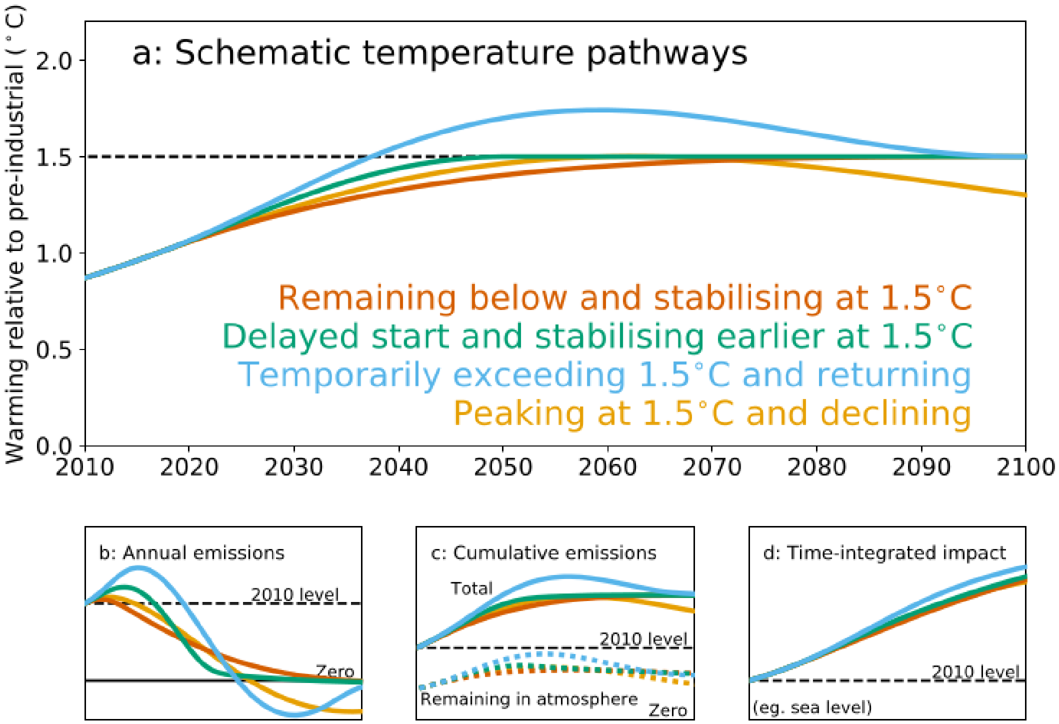
- GHG emissions have show an increasing increase
- Economic crisis showed a slight decrease
- CO_2 is the main driver of the increase



(IPCC-2014-WG3-AR5)

Scenarios for 1.5°C increase

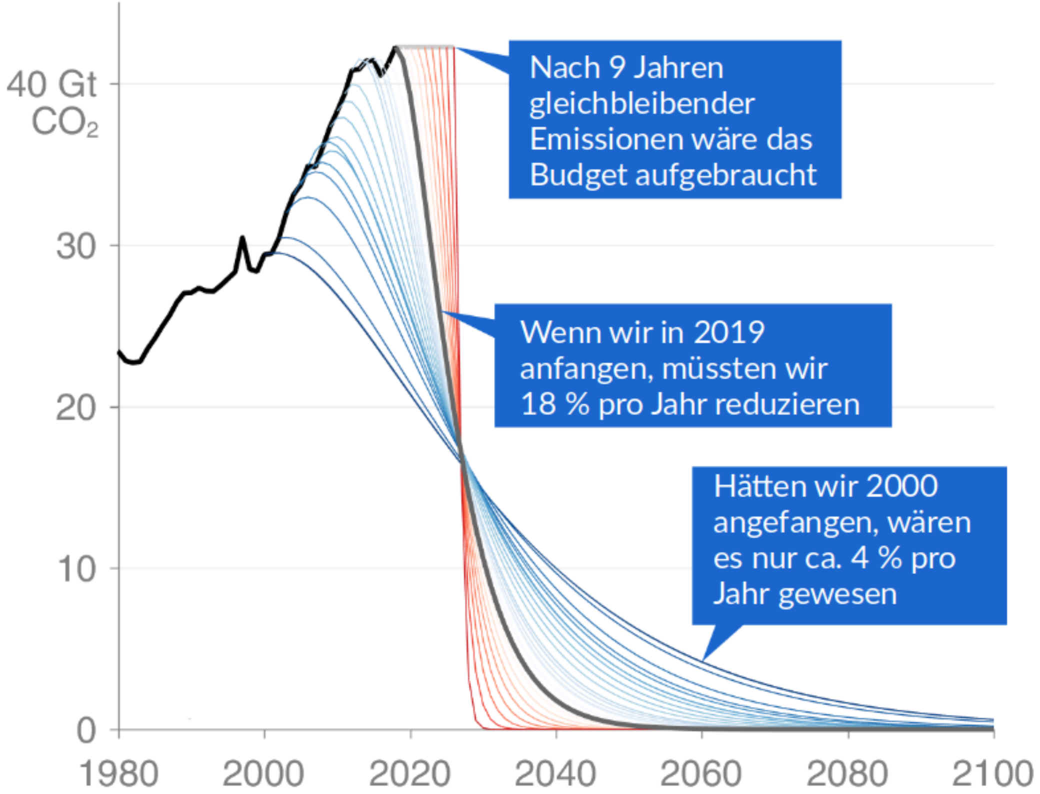
- There are different scenarios
- Some reach the limit
- Some overshoot and then try to reduce CO2 to reach 1.5°C by 2100



(IPCC-2018-Chap1)

CO_2-Pathways: 1.5 °C without CDR

- There are only few years left to reach the target
- With exponential decrease 18% less each year



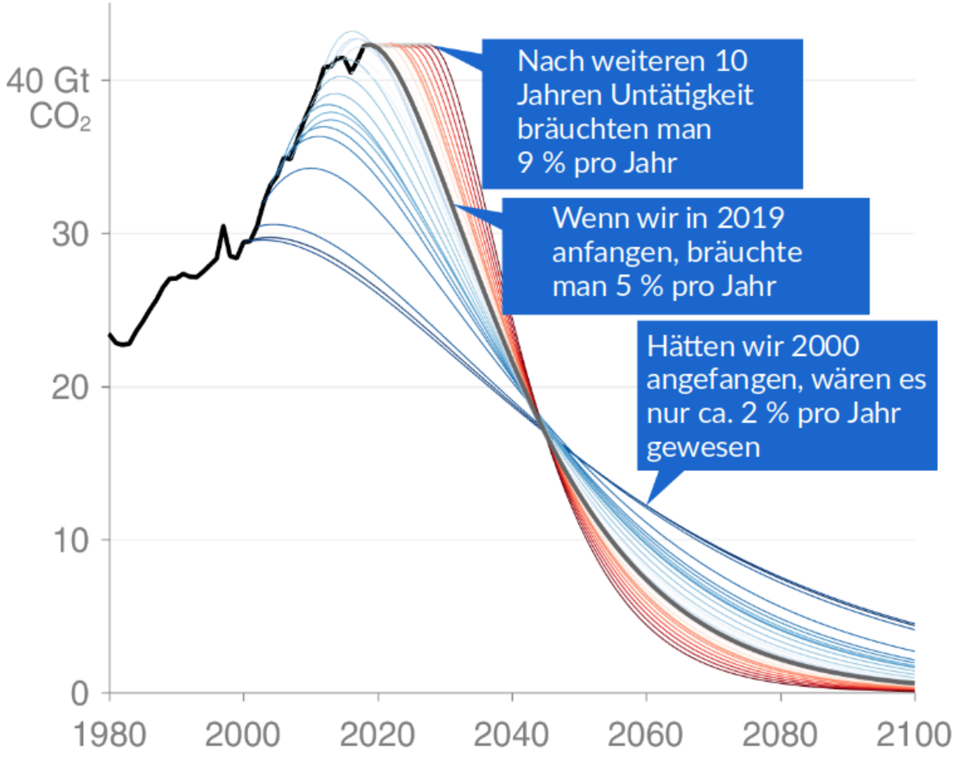
Data: GCP – Emission Budgets from IPCC SR 1.5 (Robbie Andrew/Gregor Hagedorn)

CO_2-Pathways: 2.0 °C without CDR

If we start in 2019, it is still 5% reduction each year

Estimated Budget for Germany (with current share on global emissions) to reach 1.5°C is about 7.3 Gt CO_2

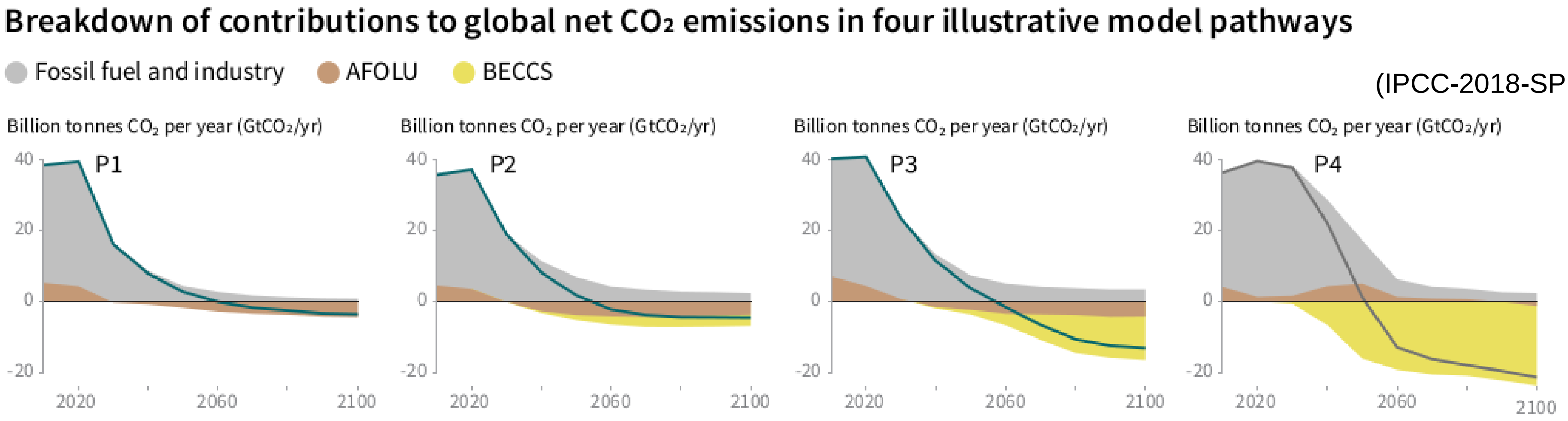
Which leaves for each German 90t to emit



Data: GCP – Emission Budgets from IPCC SR 1.5 (Robbie Andrew/Gregor Hagedorn)

Climate change scenarios for 1.5°C

(IPCC-2018-SPM)



P1: A scenario in which social, business, and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A down-sized energy system enables rapid decarbonisation of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

1.5 Degree scenarios – what is to do?

Rapid and profound near-term decarbonisation of energy supply

Strong upscaling of renewables and sustainable biomass and reduction of unabated (no CCS) fossil fuels, along with the rapid deployment of CCS lead to a zero-emission energy supply system by mid-century.

(IPCC-2018-Chapt2)

1.5 Degree scenarios – what is to do?

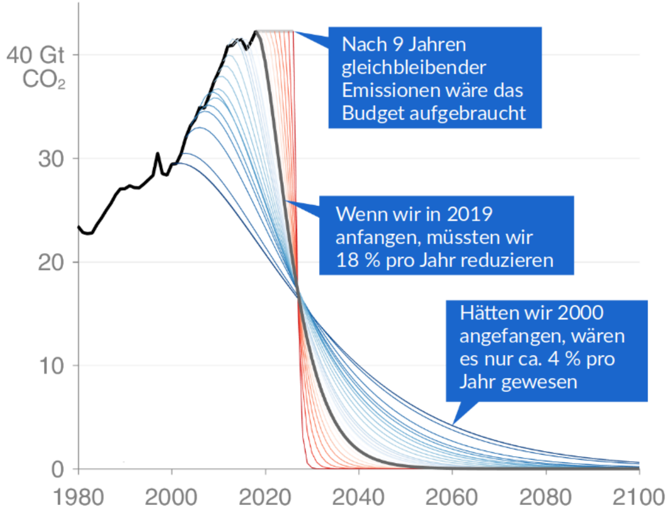
Greater mitigation efforts on the demand side

All end-use sectors show marked demand reductions beyond the reductions projected for 2°C pathways. Demand reductions from IAMs for 2030 and 2050 lie within the potential assessed by detailed sectorial bottom-up assessments.

(IPCC-2018-Chapt2)

1.5 Degree scenarios – what is to do?

Comprehensive emission reductions are implemented in the coming decade



Virtually all 1.5°C-consistent pathways decline net annual CO2 emissions between 2020 and 2030, reaching carbon neutrality around mid-century. Below-1.5°C and 1.5°C-low-OS show maximum net CO2 emissions in 2030 of 18 and 28 GtCO2 yr $^{-1}$, respectively. GHG emissions in these scenarios are not higher than 34 GtCO2 e yr $^{-1}$ in 2030.

(IPCC-2018-Chapt2)

1.5 Degree scenarios – what is to do?

1.5°C pathway characteristic	Supporting information
Additional reductions, on top of reductions from both CO_2 and non-CO_2 required for 2°C, are mainly from CO_2	Both CO_2 and the non-CO_2 GHGs and aerosols are strongly reduced by 2030 and until 2050 in 1.5°C pathways. The greatest difference to 2°C pathways, however, lies in additional reductions of CO_2 , as the non-CO_2 mitigation potential that is currently included in integrated pathways is mostly already fully deployed for reaching a 2°C pathway.
Considerable shifts in investment patterns	Low-carbon investments in the energy supply side (energy production and refineries) are projected to average 1.6-3.8 trillion 2010USD yr^{-1} globally to 2050. Investments in fossil fuels decline, with investments in unabated coal halted by 2030 in most available 1.5°C-consistent projections, while the literature is less conclusive for investments in unabated gas and oil. Energy demand investments are a critical factor for which total estimates are uncertain.

(IPCC-2018-Chapt2)

1.5 Degree scenarios – what is to do?

1.5°C pathway characteristic	Supporting information
Options are available to align 1.5°C pathways withsustainable development	Synergies can be maximized, and risks of trade-offs limited or avoided through an informed choice of mitigation strategies. Particularly pathways that focus on a lowering of demand show many synergies and few trade-offs.
CDR at scale before mid-century	By 2050, 1.5°C pathways project deployment of BECCS at a scale of 3–7 GtCO2 yr^{-1} (range of medians across 1.5°C pathway classes), depending on the level of energy demand reductions and mitigation in other sectors. Some 1.5°C pathways are available that do not use BECCS, but only focus terrestrial CDR in the AFOLU sector.
Switching from fossil fuels to electricity in end-use sectors	Both in the transport and the residential sector, electricity covers markedly larger shares of total demand by mid-century.

(IPCC-2018-Chapt2)

What is CDR?

- CDR – is Carbon Dioxide Removal
- There are different options for CDR
  - AFOLU – Agriculture forestry and land use or even hydro-thermal carbonisation (to use biomass to produce coal and bring it out to the field).
  - BECCS – Use biomass to produce gas, burn it and capture the CO_2 and store it
  - Direct air capturing of CO_2 an storage somewhere (DACCS)

Intermission: What is CDR?

CLIMEWORKS

- Example DACCS
- Energy use by this is ca. 12.9 GJ/tCO_2

  => to extract 15 $GtCO_2/y$ about ¼ of the current globale energy usage is needed.
  (IPCC-2018, Chapter 4.3.7)

(Lackner-2015)

Intermission: What is CDR?

Further issues with CCS:

“The average amount of BECCS in these pathways requires 25–46% of arable and permanent crop area in 2100.”

Die mittlere Menge an BECCS in den Szenarien würden im Jahr 2100 25-46% der landwirtschaftlich nutzbaren Fläche benötigen.
(IPCC2018 Chapter 4.3.7)

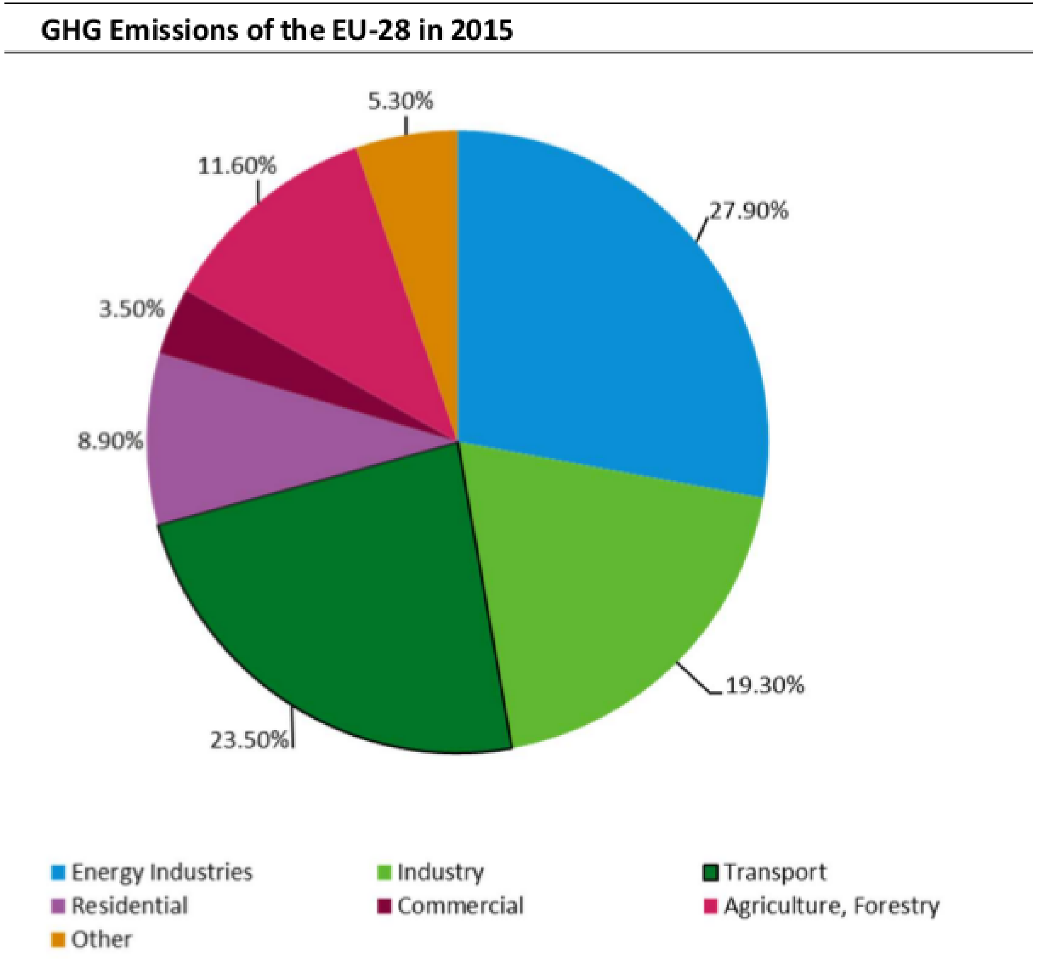
“CO_2 retention in the storage reservoir was recently assessed as 98% over 10,000 years for well-managed reservoirs, and 78% for poorly regulated ones (Alcalde et al., 2018).”

Die CO_2 Zurückhaltung in Speicher über 10000 Jahre wurde kürzlich mit 98% für gut geführte und bei 78% für schlecht geführte Speicher angegeben (Alcalde et al. 2018)
(IPCC2018, Chapter 4.3.1)

GHG – emissions by sector

- Most important sectors:

  - Electricity and heat
  - Agriculture forestry and land use (AFOLU)
  - Other industry
  - Transport

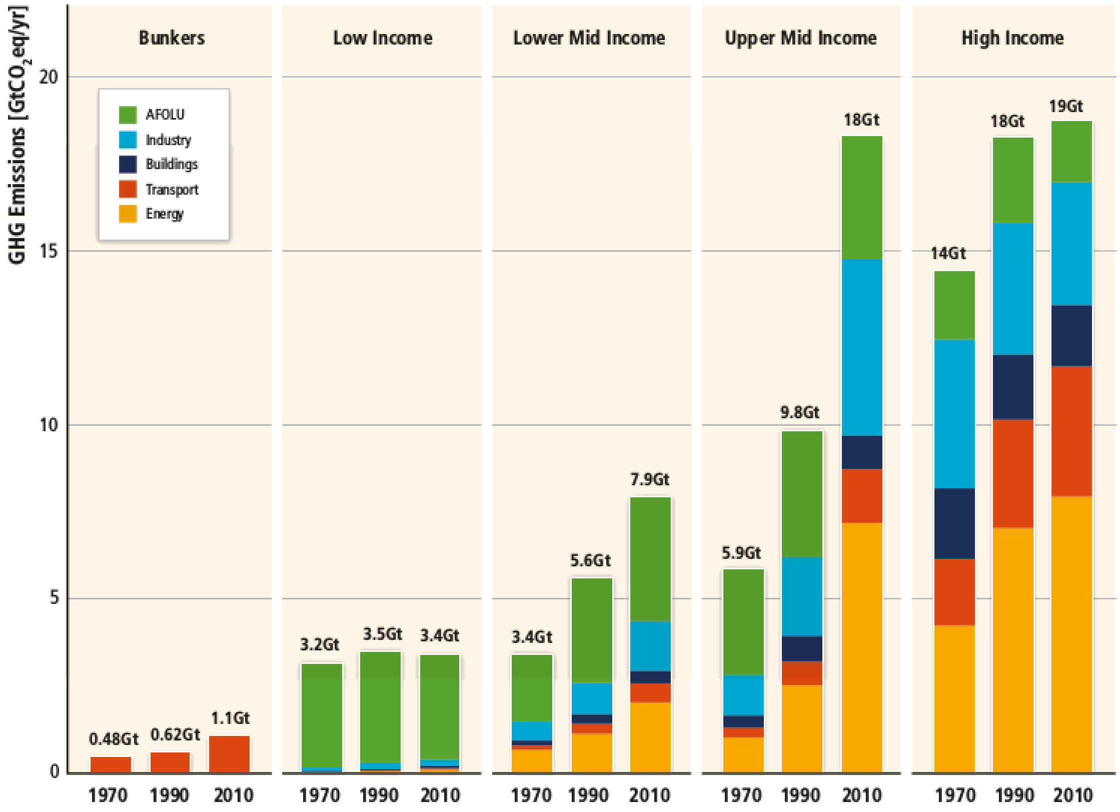


(Duscha et al. 2019)

GHG – Emissions by Countries

- Strong dependency by average income

- Strong increase within countries of mid-high income – however, not worse than high income countries



(IPCC-2014-WG3-AR5)

Can we make it to 1.5°C?

Good question! There are several studies for this for Germany a few for the EU

- Quaschning, 2016: On Energy demand for a 100% Renewable Energy infrastructure
- Robinius et al. 2019: On 95% CO_2 reduction scenario until 2050

- Duscha et al. 2019: GHG neutral EU by 2050

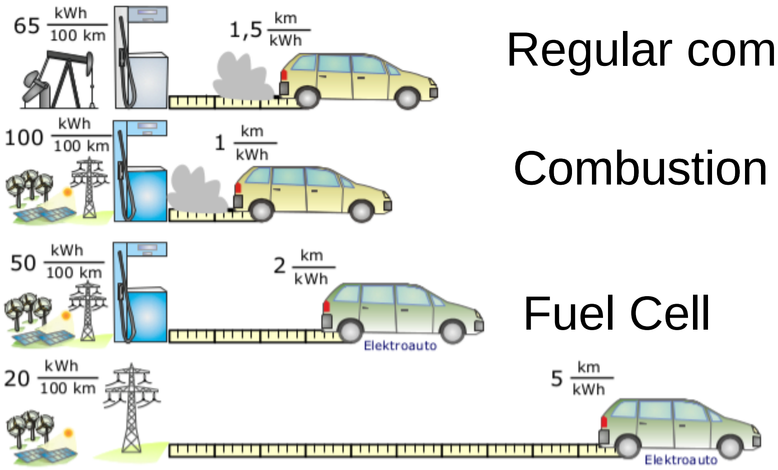
What are the assumptions?

Energy efficiency by use of electricity!

Current prime energy consumption in Germany ~3200 TWh in total

- Quaschning, 2016: In 2050 1320 TWh
- Robinius et al. 2019: In 2050 1008 Twh

Differences due to scenarios



Regular combustion

Combustion from P2L

Fuel Cell

Battery

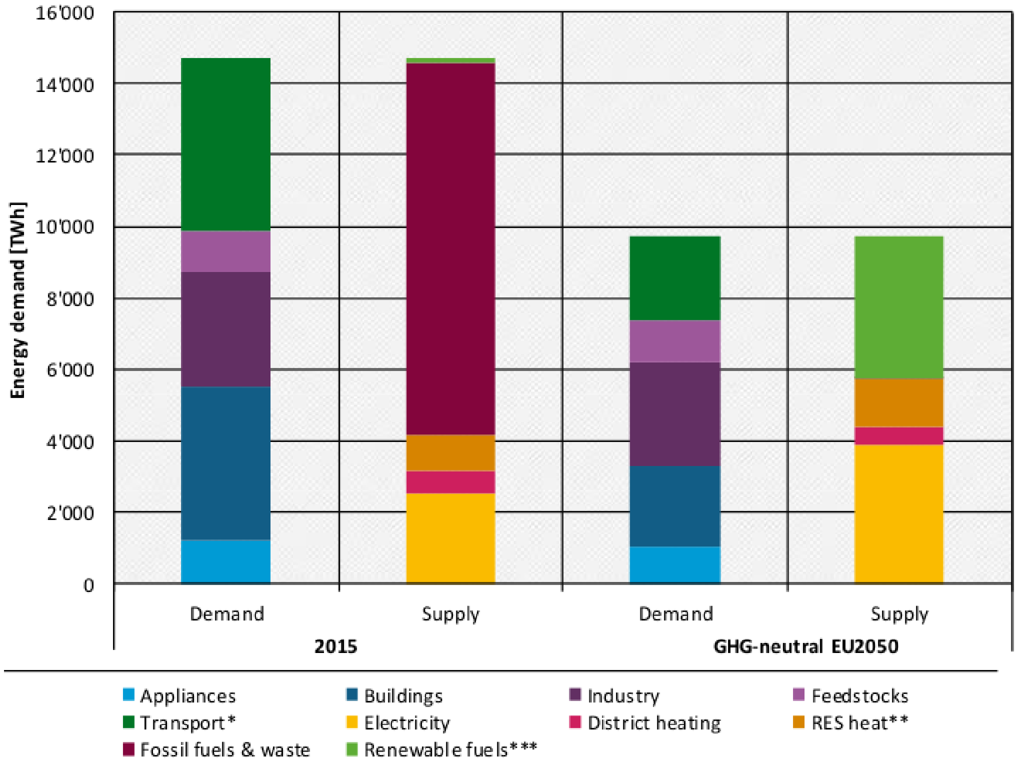
(Quaschning, 2016)

What are the assumptions?

Energy efficiency by use of electricity!

Similar for EU in total

- Duscha, 2019: Energy need reduction by 1/3

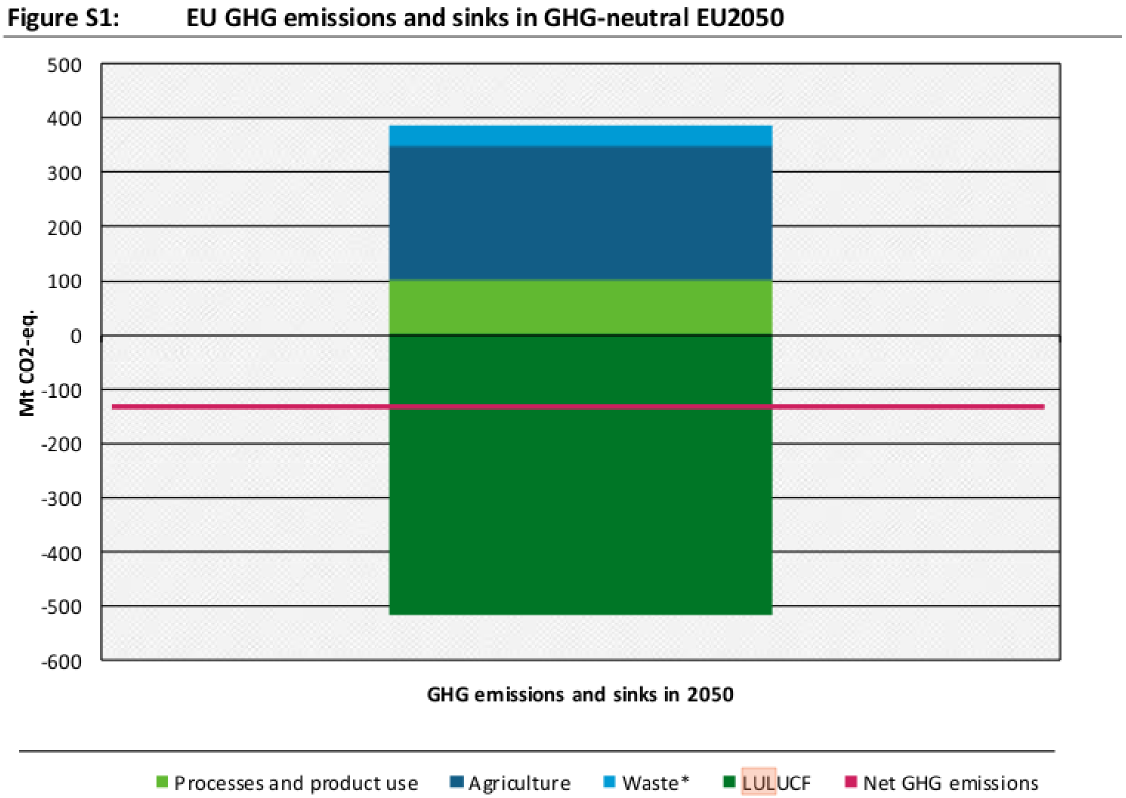


Can we make it to 1.5°C?

Now Robinius and Duscha not 100% CO_2 reduction:

- Problem is some industry
- Remaining old infrastucture also issue

- Therefore: Negative emissions by AFOLU



But if there is no sun and wind?

Robinius et al. also calculated the phenomenon of the „Dunkelflaute“ - no wind in winter: Extensive use of PtX storages (strategic reserve)

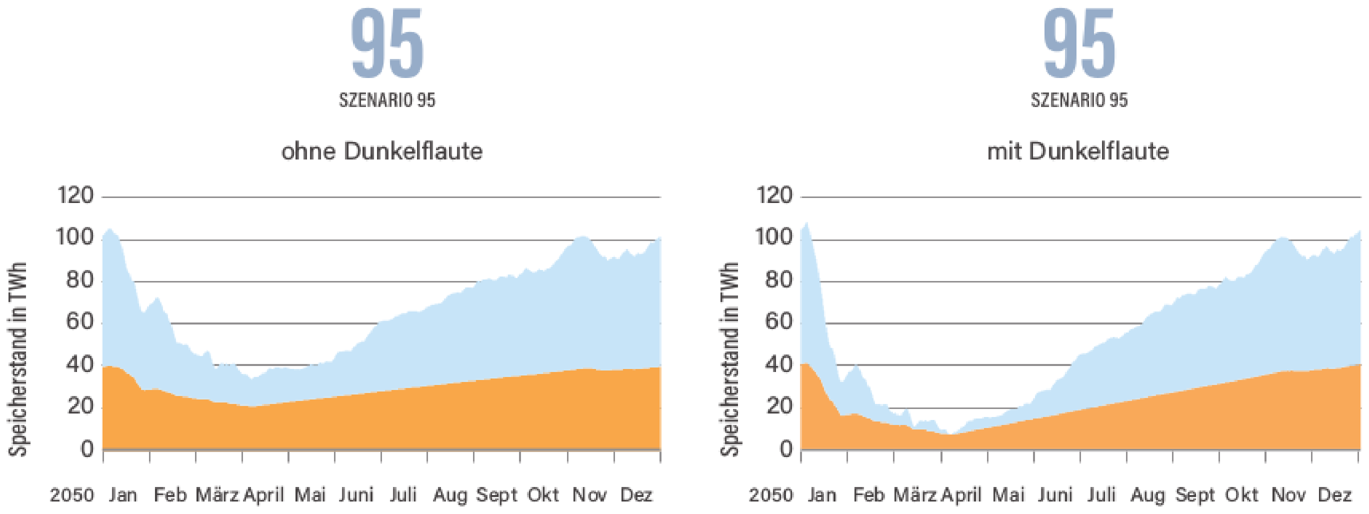


Abbildung 14: Vergleich der Speichernutzung in **SZENARIO 95** mit und ohne die Berücksichtigung einer kalten Dunkelflaute

▸ Erdgas-/Methanspeicher ▸ Wasserstoffspeicher

(Robinius et al. 2019)

Conclusions

- Already the current status of the climate is in some areas critical
- The prospects of a 1.5°C warmer earth are bitter
- The IPCC tries to show that more than 2°C will be extremly harmful
- In several regions of the earth this will be the case already at 2°C
- CDR is presented by IPCC to be hard to avoid. However, CCS has several drawbacks and issues
- We need to act fast. Changes are possible, they need to be implemented quickly!

Conclusions

It is not so much a technical issue – it is a political one!

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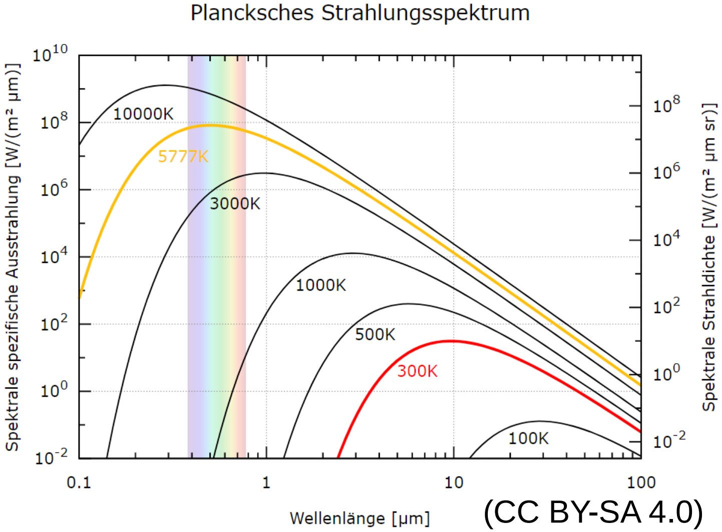
Aufruf an die Politik

https://www.youtube.com/watch?v=WaojkxBuWwk

Treibhauseffekt: Physikalischer Hintergrund



- Die gesamte Strahlung, die auf die Erde einfällt verlässt diese auch wieder

  → Die Strahlungsbilanz ist geschlossen

- Plancksches Strahlungsgesetz

$$\rho(\upsilon,T)\,d\upsilon = \frac{8\pi h\upsilon^3}{c^3}\frac{1}{e^{h\upsilon/(kT)}-1}\,d\upsilon$$

- Stefan Boltzmann-Gesetz

$$R = \frac{4\pi^5}{15}\frac{k^4}{c^2h^3}T^4 = \sigma\cdot T^4$$

- **Solarkonstante:**

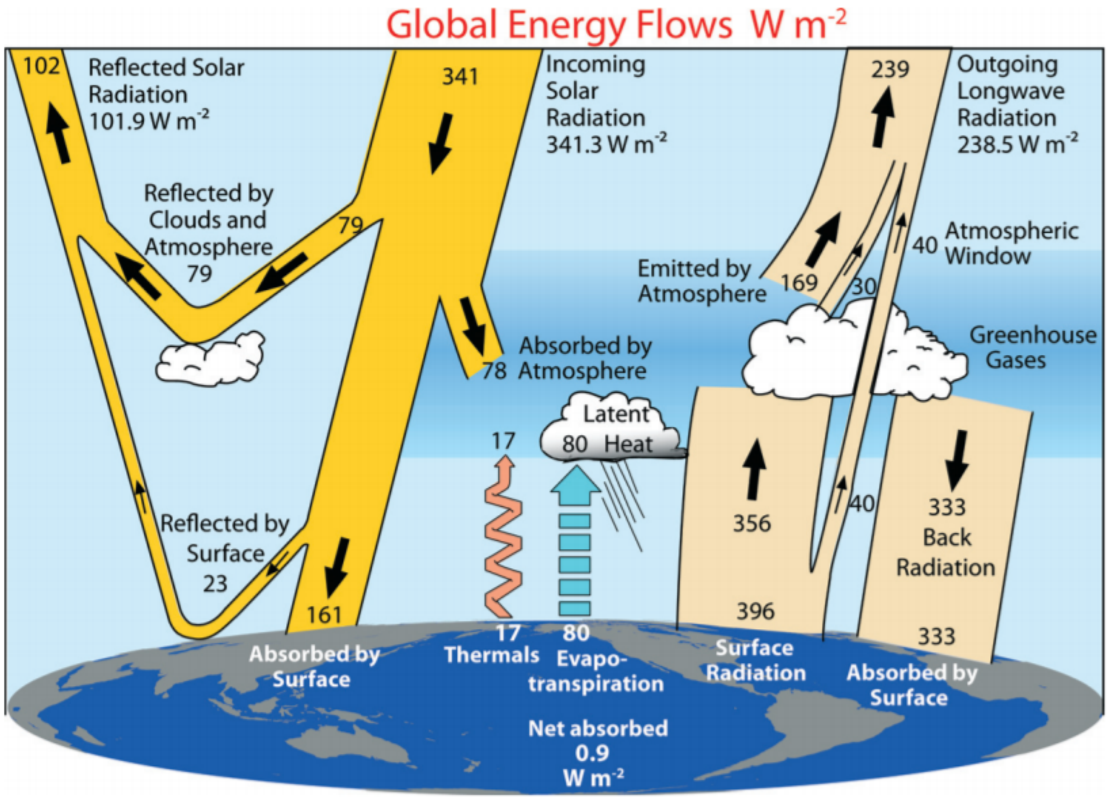
  → mit 95-100% Schwarzkörperstrahler → 271-275 K (~0ºC - globale Mitteltemperatur)

- **Wie hoch ist die mittlere Temperatur der Erde?**

  → 288 K (~15º Celsius) → ohne den natürlichen Treibhauseffekt gäbe es uns nicht!

Die Strahlungsbilanz der Erde

- Die Strahlungsbilanz ist geschlossen, das heißt alle Strahlung (Energie), die einfällt verlässt die Erde wieder
- Sonst würde die Erde immer heißer



(Trenberth et al. 2009)

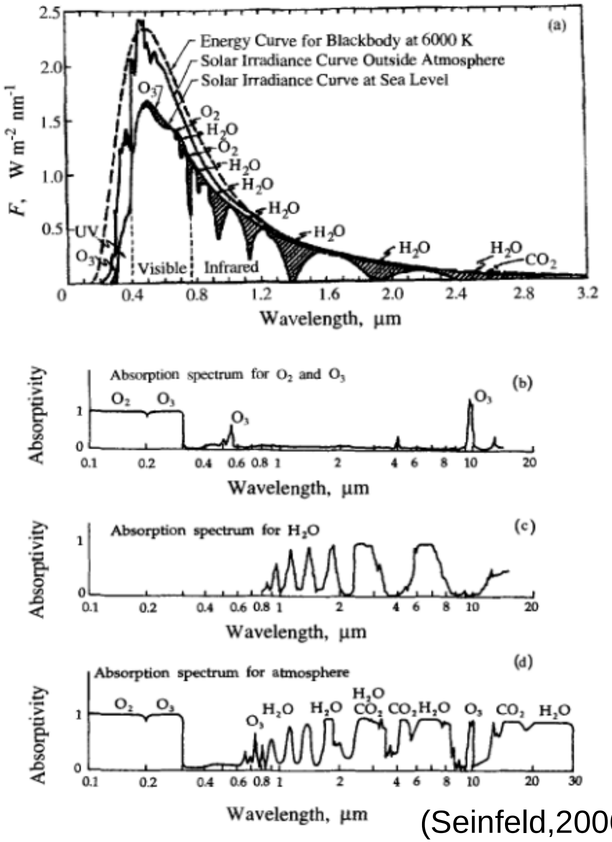
Wie funktioniert der Treibhauseffekt?

- Erde absorbiert kurzwellige Strahlung der Sonne und sendet diese als langwellige (Wärmestrahlung) zurück ins Weltall. Unterschiedliche Gase in der Atmosphäre “verhindern” einen Teil des Ausstrahlung, die Erde erwärmt sich.

- Das sind die sogenannten Treibhausgase (Englisch: Greenhouse Gases – GHG)!

- **Welches ist das wichtigste Treibhausgas?**

  → Wasserdampf!

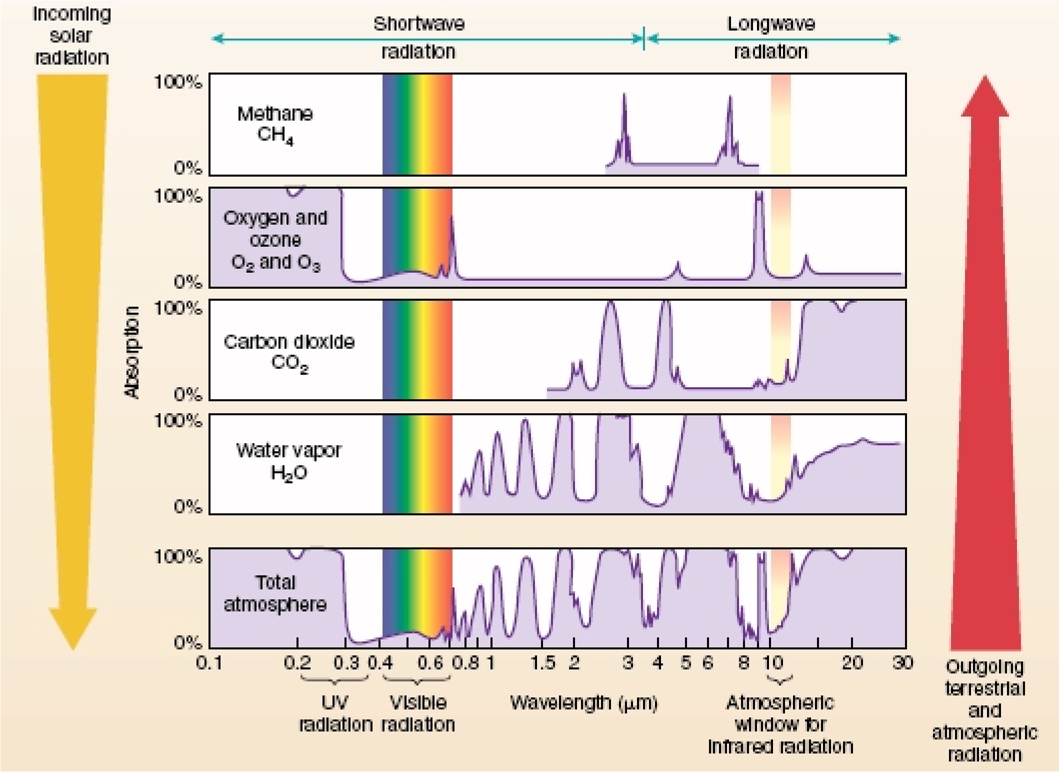


(Seinfeld,2006)

Wie funktioniert der Treibhauseffekt?

- Erde sendet durch das *atmosphärische Fenster* Wärmestrahlung ins Weltall, die durch CO_2 und andere Gase in einem bestimmten Bereich absorbiert wird. Das Fenster *„schließt“* sich.

- Dadurch kommt es zu geringerer Wärmeabstrahlung: Die Wärme bleibt in der Atmosphäre, die sich ungewöhnlich aufheizt.



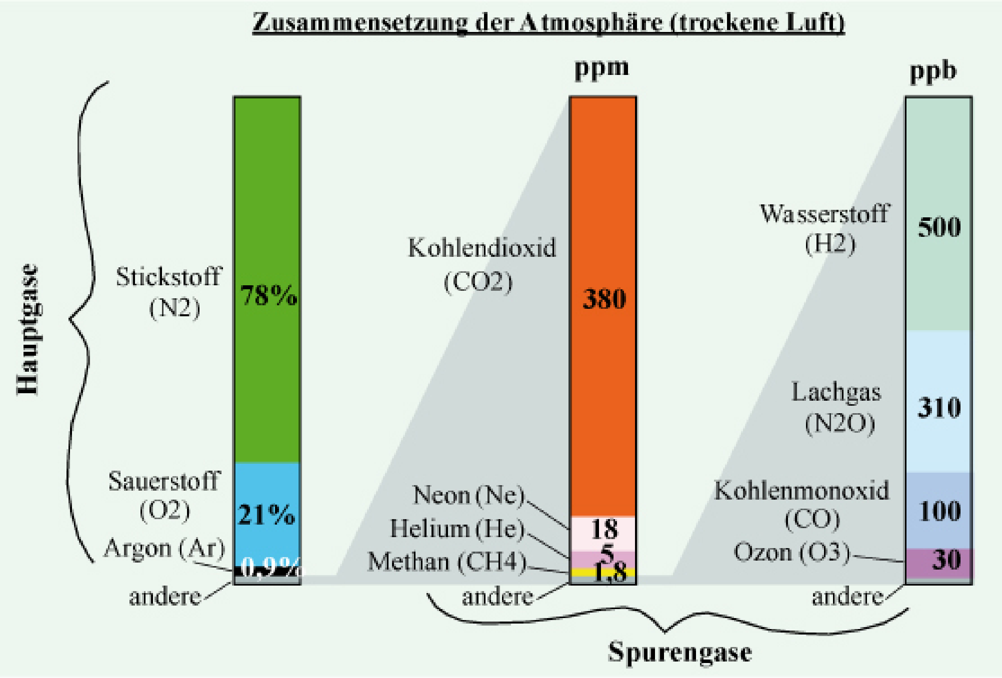
(cimss.ssec.wisc.edu)

Zusammensetzung der Atmosphäre der Ede

- Treibhausgase haben nur einen geringen Anteil an Gesamtkonzentration, Veränderung gegenüber vorindustrieller Konzentration (1800) ist stark.

Wichtige anthropogene Treibhausgase

	Kohlendioxid	Methan	Distickstoffoxid	FCKW-12
Vorindustrielle Konzentration	280 ppm	730 ppb	270 ppb	0
Konzentration 2016	403 ppm	1843 ppb	329 ppb	512,5 ppt
Verweilzeit in Jahren	?	9,1	123	102
Treibhauspotential	1	25	298	5200
Strahlungsantrieb in W/m2	1,82	0,48	0,17	0,17



Datenquellen: Blunden, J., and D. S. Arndt, Eds. (2017); IPCC (2013); IPCC (2007)

Das Klimasystem unserer Erde:

- Warum können wir Klimaveränderungen vorhersagen?

Wettervorhersage vs. Klimaprojektion

- **Warum können wir Klimaprojektionen für die nächsten 100 Jahre und darüber hinaus durchführen, wenn wir noch nicht mal das Wetter für die kommenden 3 Wochen richtig vorhersagen können?**

- **Stellen Sie sich einen Topf mit kochendem Wasser vor:**

- **Klimaprojektion:** Bei welcher Temperatur kocht das Wasser?

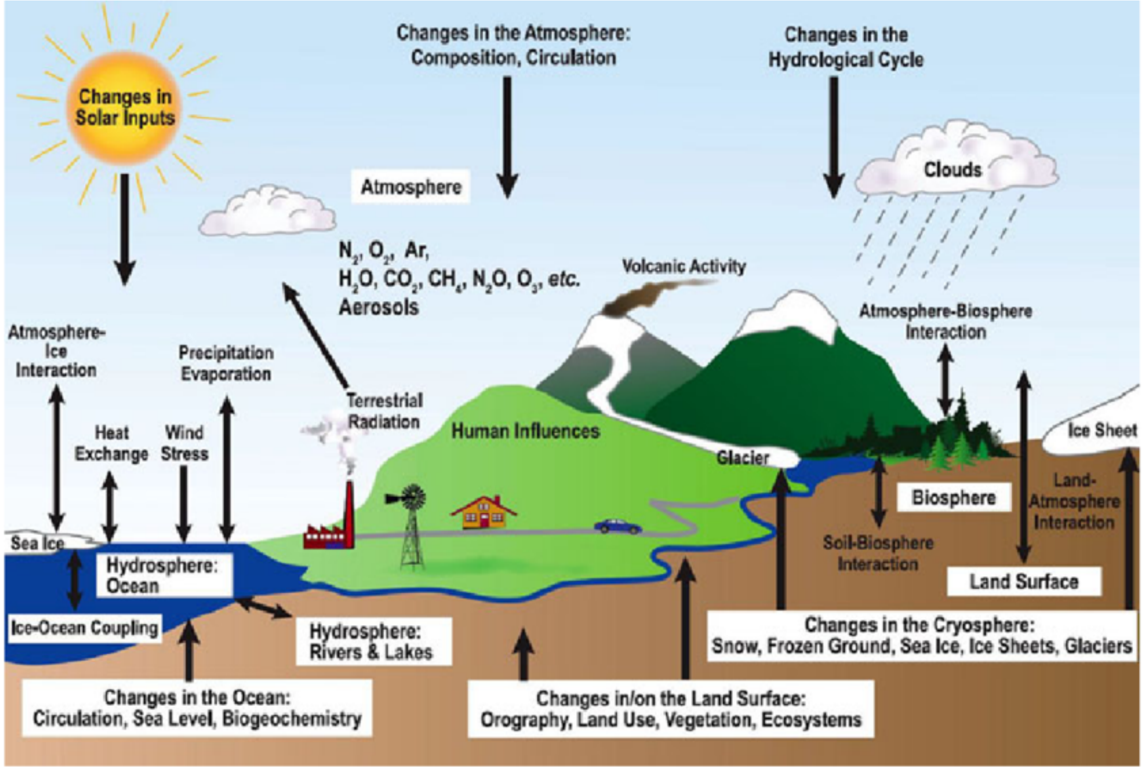
  → **Randbedingungen sind wichtig!**

- **Wettervorhersage:** Wo genau steigen die Wasserdampfblasen im Topf auf?

  → **Anfangswert ist wichtig!**

Das Klimasystem im Klimamodell

- **Klimamodelle:** Physikalische Beschreibung aller relevanten Prozesse und Interaktionen von:
    - Atmosphäre
    - Ozean
    - Landoberflächen
    - Eisflächen
    - Biosphäre
    - Änderung der Sonneneinstrahlung
    - Einfluss des Menschen
    - ....
- **Bevor ein Klimamodell Projektionen für die Zukunft berechnet muss erst die Vergangenheit richtig dargestellt werden können!**



(IPCC – AR 4, 2007)

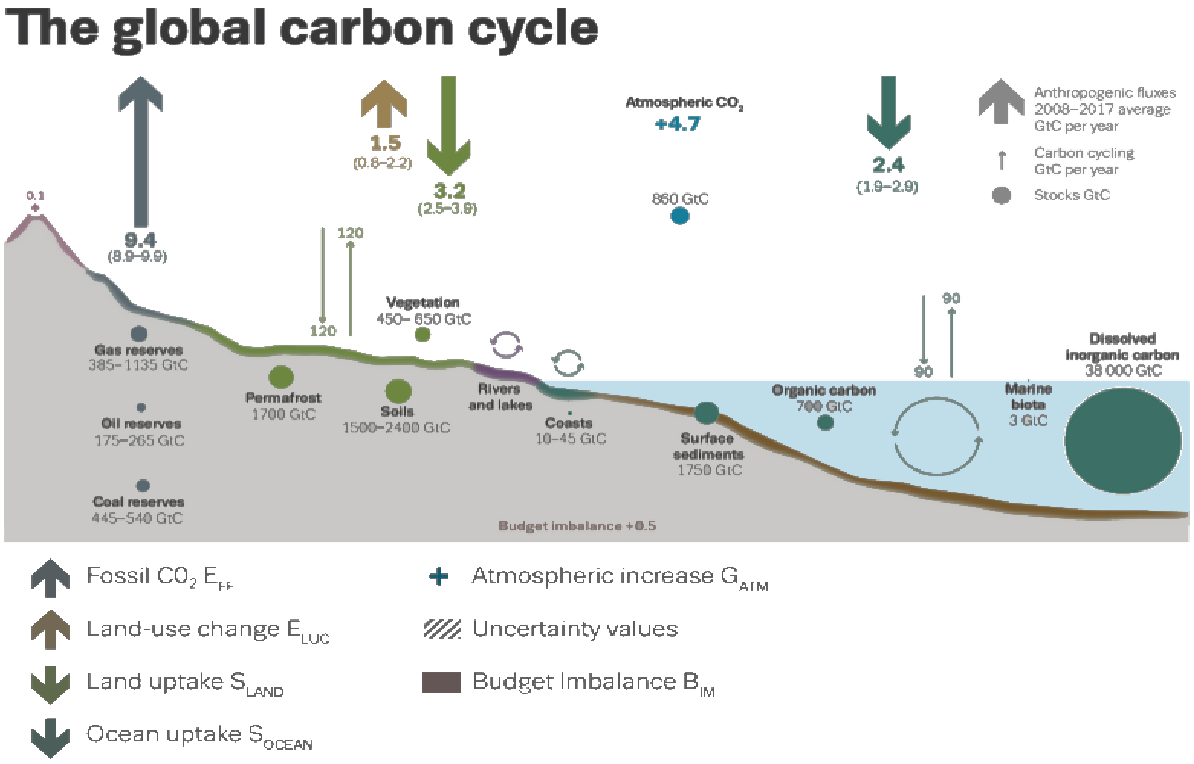
Anthropogener Kohlenstoffkreislauf

C. Le Quéré et al.: Global Carbon Budget 2018

- Der menschliche Einfluss ist klein….

  …. aber **entscheidend** weil er den Kreislauf verändert

- 1 t C → 3.67 t CO_2

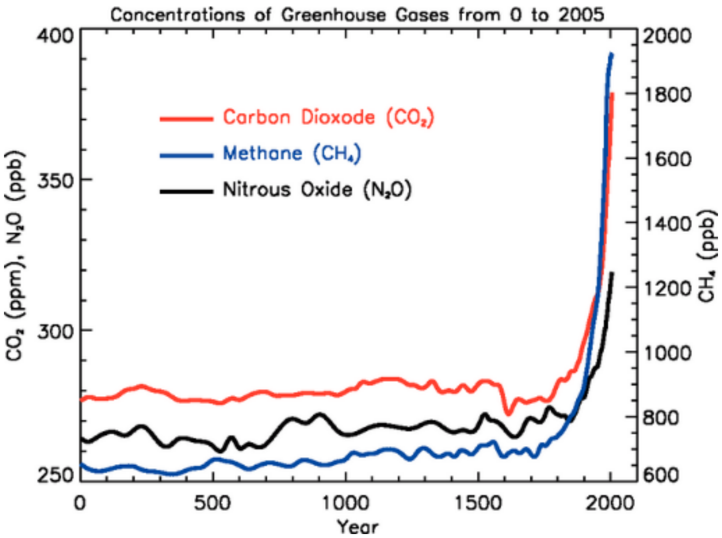


Das Klimasystem unserer Erde:

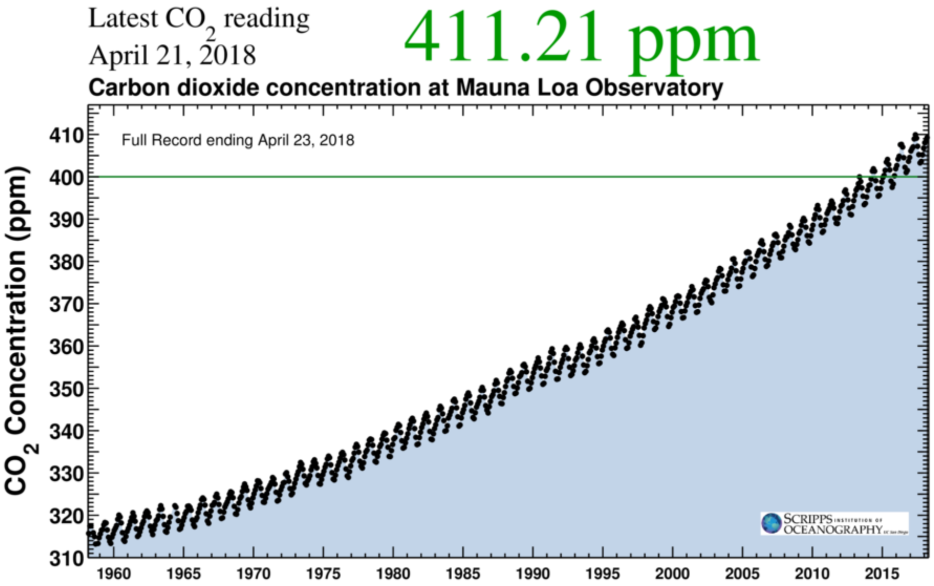
- Wo stehen wir heute?

Treibhausgase – Konzentrationen

- Die Konzentrationen von CO_2, Methan und N_2O waren vor der industriellen Revolution über viele Jahrhunderte nahezu konstant!



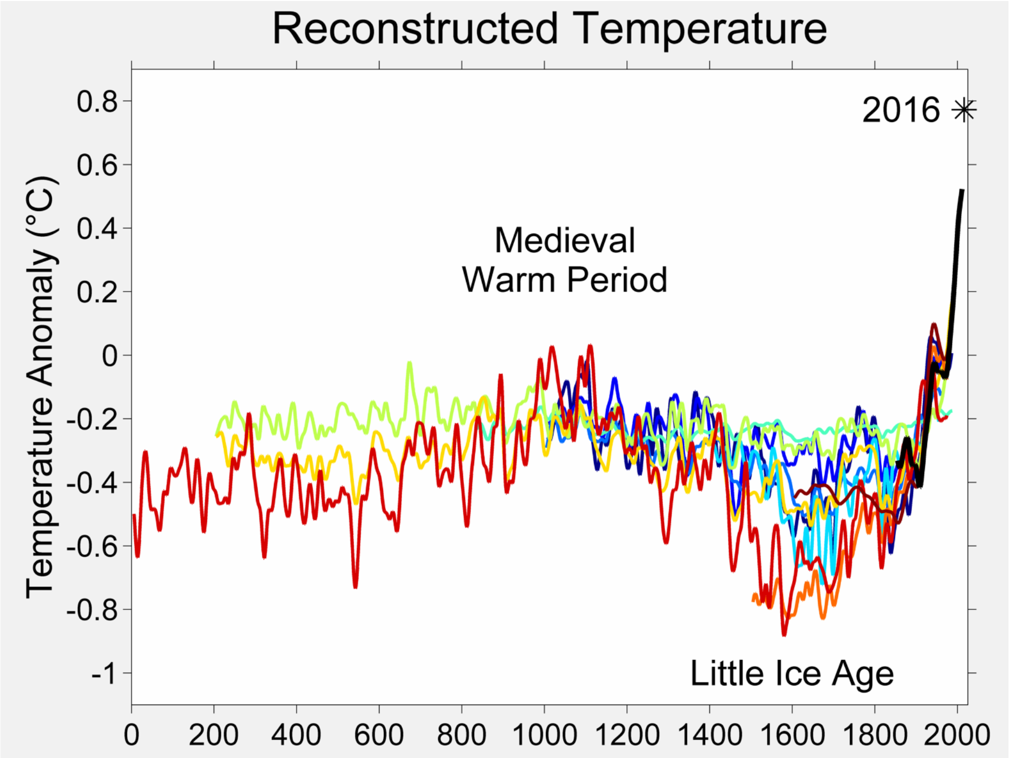
(Forster et al. 2007; Blasing 2008)



(Scripps Institution of Oceanography, 2018)

Derzeitige Temperaturveränderung

- Starker Temperaturanstieg seit Beginn des 20. Jahrhunderts
- Temperaturanstieg viel stärker und schneller als Mittelalter-Wärmeperiode



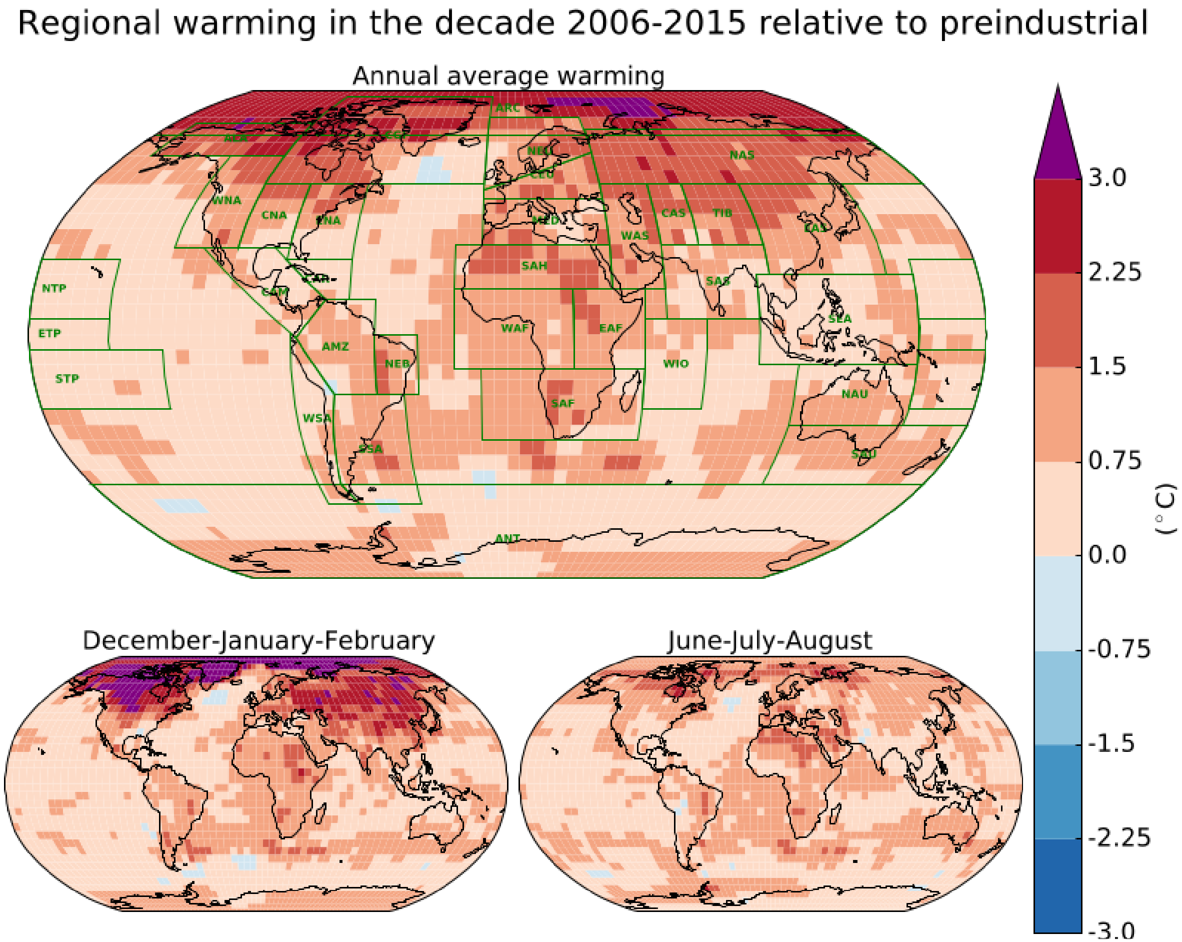
Temperaturrekonstruktion der Nordhemisphäre aus Klimaproxy-Daten
Quellen: Moberg et al. 2005, Jones and Mann 2004, Mann and Jones 2003, Jones at al 1998, Mann et al 1999, Crowley and Lowery 2000, Briffa et al. 2001, Huang 2004, Oerlemanns 2005

Derzeitige Temperatur-veränderung

- Erwärmung besonders stark in der Arktis und besonders im Nordhemisphären-Winter

- Regionen mit mehr als 3 Grad Temperaturanstieg!

- Manche Regionen ohne Anstieg z.B. wegen Abschwächung des Golfstroms



(IPCC-2018-Chap1)