universität freiburg

Sustainability in HEP

Valerie Lang

Belle II Academy

Bad Kissingen, 24.05.2023

Origin of climate change

On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground
by Prof. Svante Arrhenius

- Philosophical Magazine and Journal of Science Series 5, Volume 41, April 1896, pages 237-276.

Europe

TABLE VII.—*Variation of Temperature caused by a given Variation of Carbonic Acid.*

Carbonic Acid=0·67.

Latitude.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.
70–60	–2·9	–3·0	–3·4	–3·1	–3·1
60–50	–3·0	–3·2	–3·4	–3·3	–3·22
50–40	–3·2	–3·3	–3·3	–3·4	–3·3
40–30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30–20	–3·3	–3·2	–3·1	–3·1	–3·17
20–10	–3·1	–3·1	–3·0	–3·1	–3·07
10–0	–3·1	–3·0	–3·0	–3·0	–3·02
0––10	–3·0	–3·0	–3·1	–3·0	–3·02
–10––20	–3·1	–3·1	–3·2	–3·1	–3·12
–20––30	–3·1	–3·2	–3·3	–3·2	–3·2
–30––40	–3·3	–3·3	–3·4	–3·4	–3·35
–40––50	–3·4	–3·4	–3·3	–3·4	–3·37
–50––60	–3·2	–3·3	—	—	—

Carbonic Acid=1·5.

Latitude.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.
70–60	3·3	3·4	3·8	3·6	[illegible]
60–50	3·4	3·7	3·6	3·8	[illegible]
50–40	3·7	3·8	3·4	3·7	[illegible]
40–30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30–20	3·5	3·3	3·2	3·5	[illegible]
20–10	3·5	3·2	3·1	3·2	[illegible]
10–0	3·2	3·2	3·1	3·1	[illegible]
0––10	3·1	3·1	3·2	3·2	[illegible]
–10––20	3·2	3·2	3·2	3·2	[illegible]
–20––30	3·2	3·2	3·4	3·3	[illegible]
–30––40	3·4	3·5	3·7	3·5	[illegible]
–40––50	3·6	3·7	3·8	3·7	[illegible]
–50––60	3·8	3·7	—	—	—

Carbonic Acid=2·0.

Latitude.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.
70–60	6·0	6·1	6·0	6·1	6·05
60–50	6·1	6·1	5·8	6·1	6·02
50–40	6·1	6·1	5·5	6·0	5·92
40–30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30–20	5·6	5·4	5·0	5·2	5·3
20–10	5·2	5·0	4·9	5·0	5·02
10–0	5·0	5·0	4·9	4·9	4·95
0––10	4·9	4·9	5·0	5·0	4·95
–10––20	5·0	5·0	5·2	5·1	5·07
–20––30	5·2	5·3	5·5	5·4	5·35
–30––40	5·5	5·6	5·8	5·6	5·62
–40––50	5·8	6·0	6·0	6·0	5·95
–50––60	6·0	6·1	—	—	—

Carbonic Acid=2·5.

Latitude.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.
70–60	7·9	8·0	7·9	8·0	7·95
60–50	8·0	8·0	7·6	7·9	7·87
50–40	8·0	7·9	7·0	7·9	7·7
40–30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30–20	7·2	7·0	6·6	6·7	6·87
20–10	6·7	6·6	6·3	6·6	6·52
10–0	6·6	6·4	6·3	6·4	6·42
0––10	6·4	6·4	6·6	6·6	6·5
–10––20	6·6	6·6	6·7	6·7	6·65
–20––30	6·7	6·8	7·0	7·0	6·87
–30––40	7·0	7·2	7·7	7·4	7·32
–40––50	7·7	7·9	7·9	7·9	7·85
–50––60	7·9	8·0	—	—	—

Carbonic Acid=3·0.

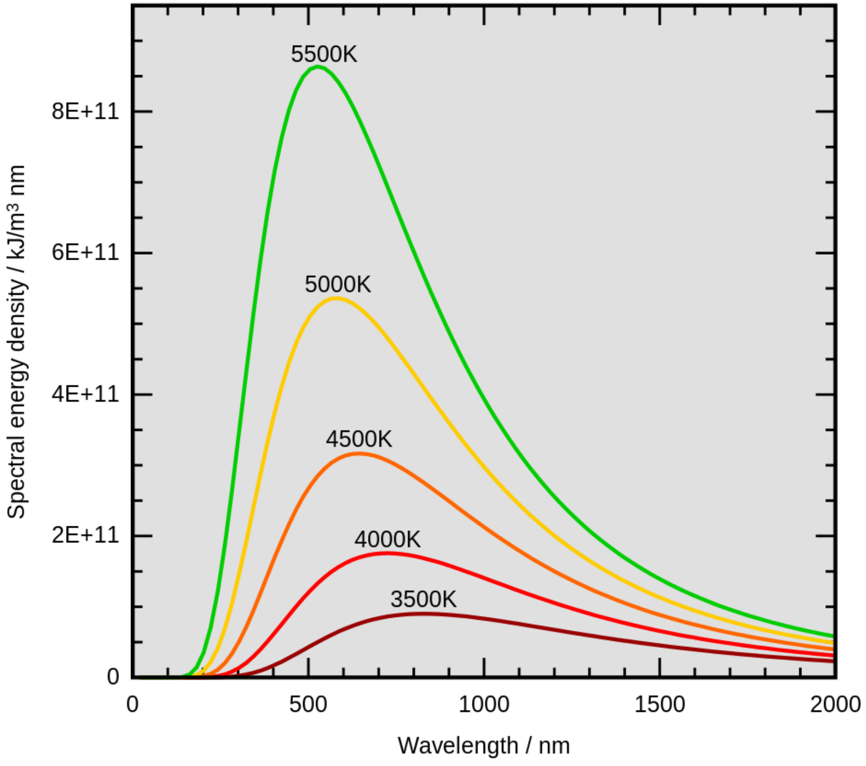
Latitude.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.
70–60	9·1	9·3	9·4	9·4	9·3
60–50	9·3	9·5	8·9	9·5	9·3
50–40	9·5	9·4	8·6	9·2	9·17
40–30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30–20	8·7	8·3	7·5	7·9	8·1
20–10	7·9	7·5	7·2	7·5	7·52
10–0	7·4	7·3	7·2	7·3	7·3
0––10	7·3	7·3	7·4	7·4	7·35
–10––20	7·4	7·5	8·0	7·6	7·62
–20––30	7·9	8·1	8·6	8·3	8·22
–30––40	8·6	8·7	9·1	8·8	8·8
–40––50	9·1	9·2	9·4	9·3	9·25
–50––60	9·4	9·5	—	—	—

266 Prof. S. Arrhenius on the Influence of Carbonic Acid

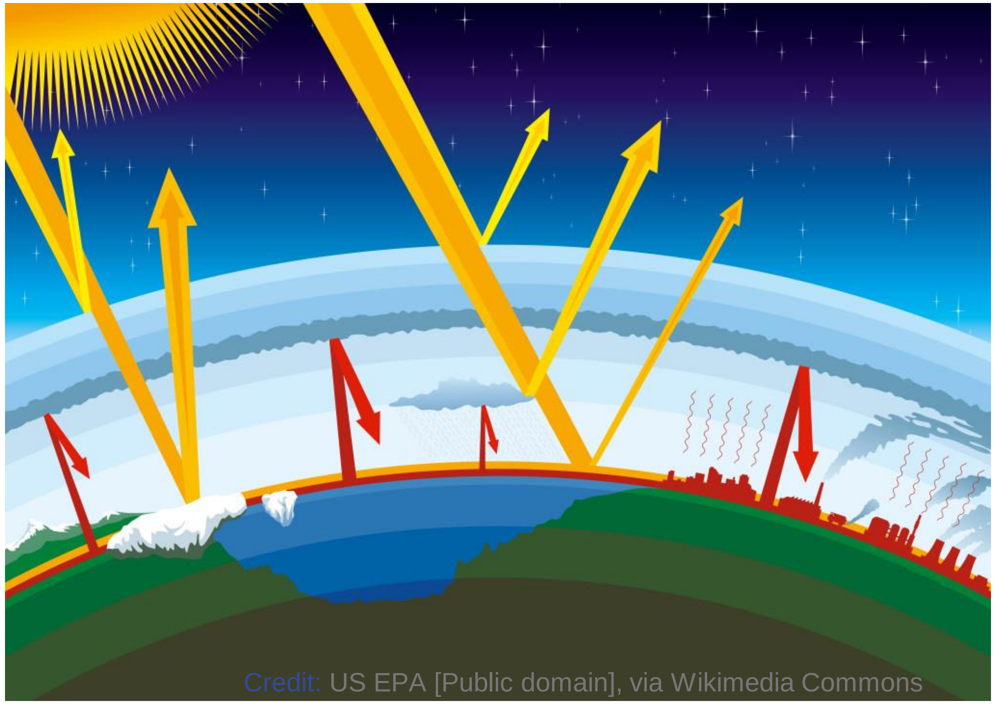
Green house effect

Black body radiation of the sun and Earth

- Sun at 6000°C, Earth at 15°C → Sun radiates in the visible, Earth radiates in the infra-red



Credit: By 4C - Own work based on JPG version Curva Planck TT.jpg, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=1017820

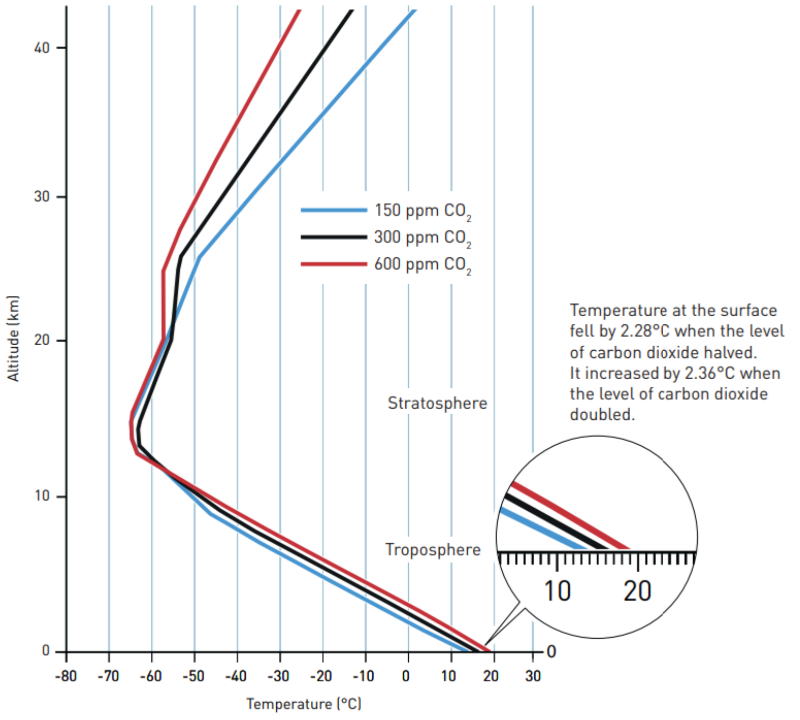


→ If atmosphere did not re-absorb Earth‘s emissions, surface temperature on Earth around -18° C!

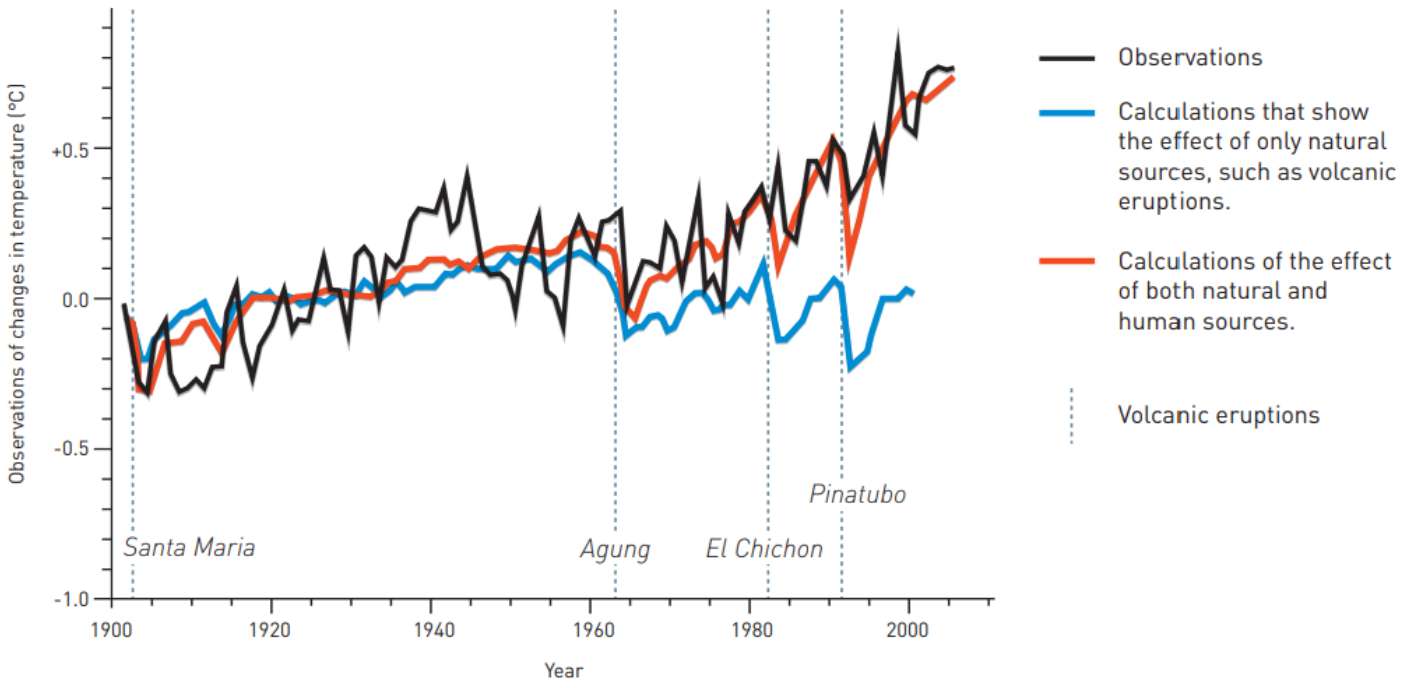
Improving the predictions

Nobel prize 2021 - *”for groundbreaking contributions to our understanding of complex physical systems”*

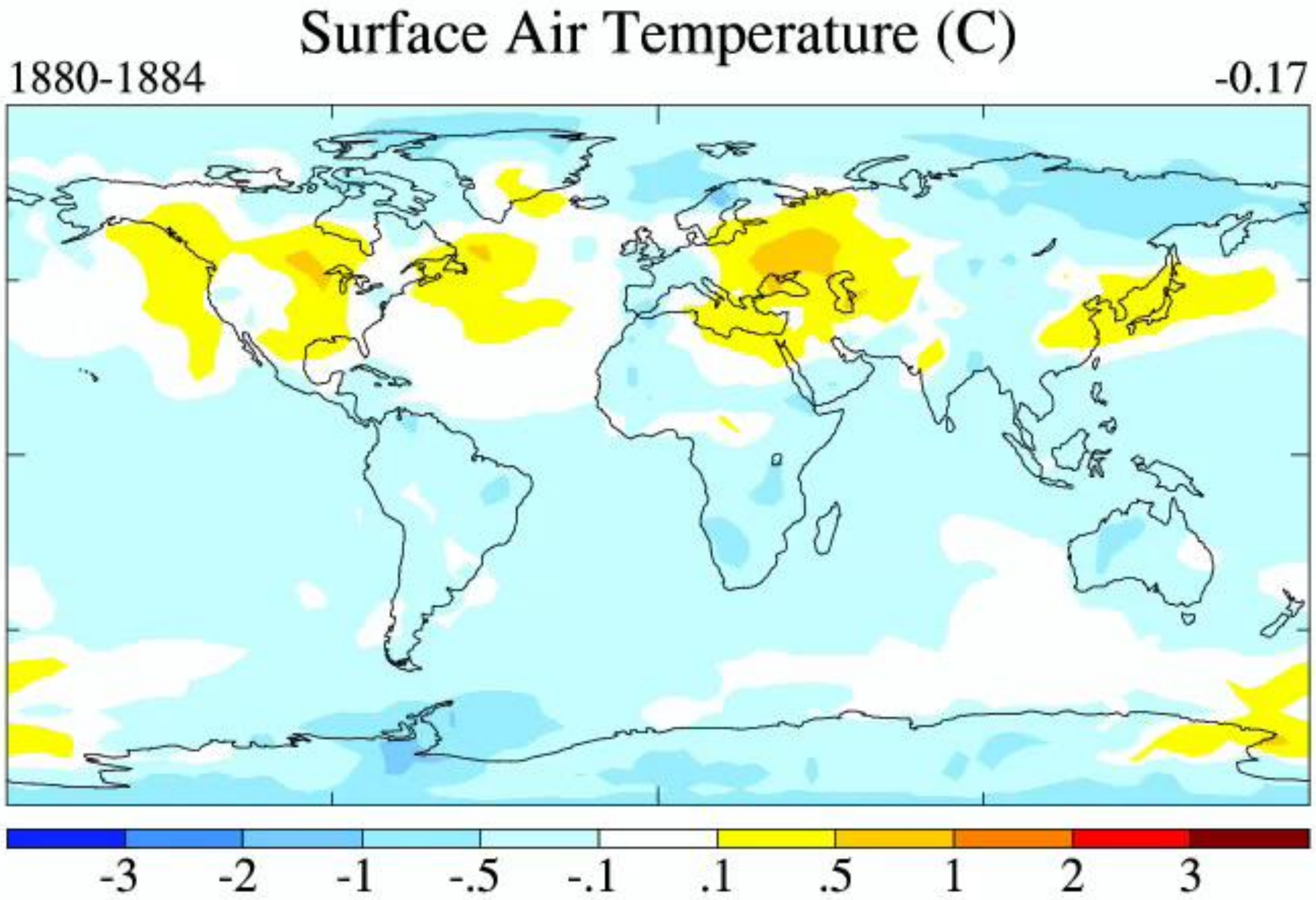
- 1967: Adding convection to the system



Around 1980: Building a stochastic climate model



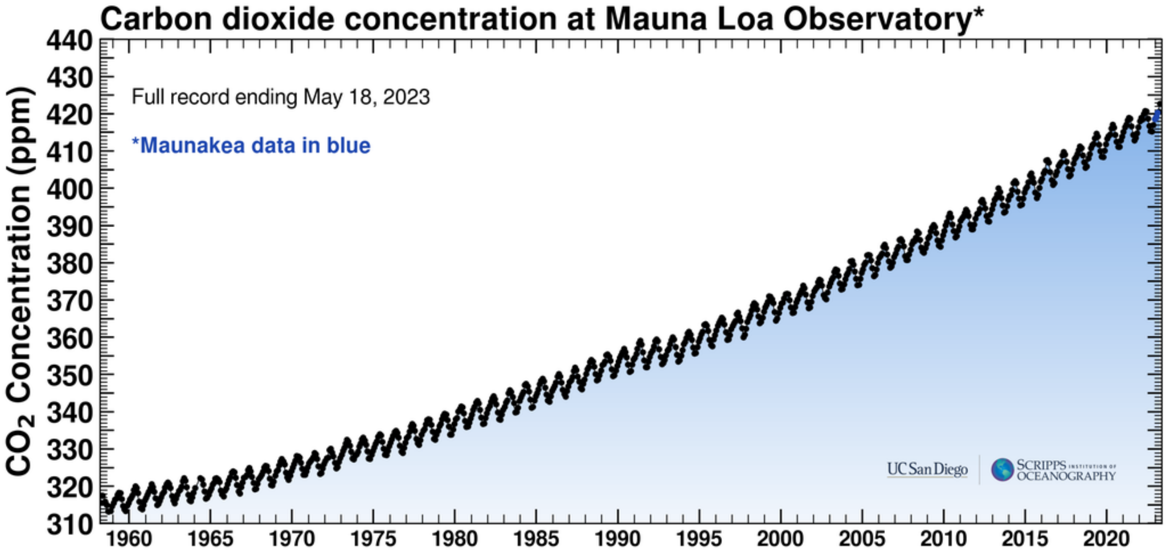
Climate simulation in 2007



Measurements of CO_2 concentrations

Keeling curve

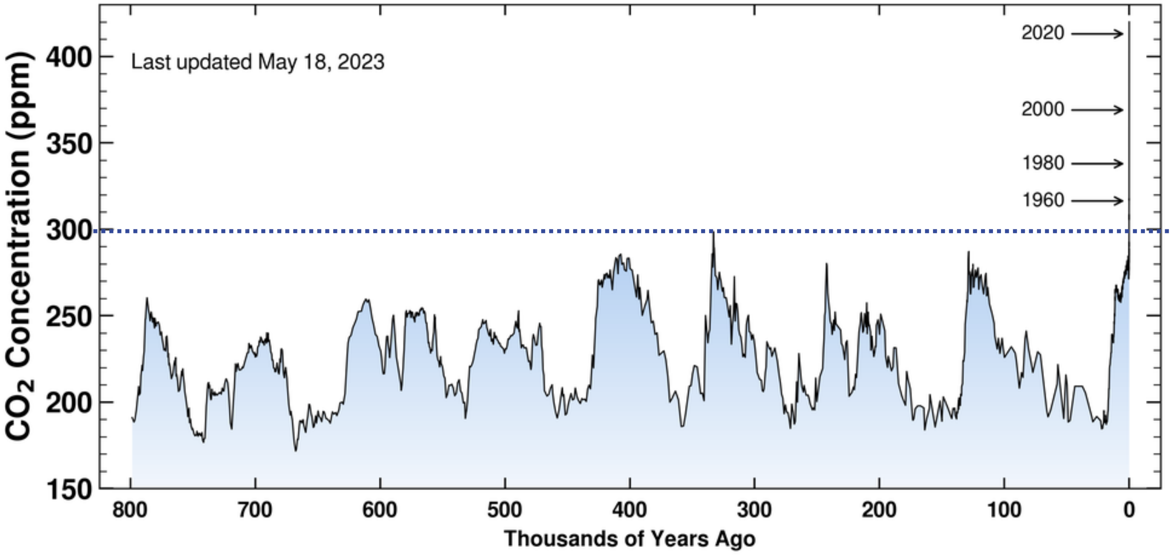
- After Charles Keeling → Started monitoring



→ Variations from annual vegetation cycle
→ No significant impact from pandemic in 2020-2022

Over 800k years

- Latest reading: 422.50 ppm



→ Reaching ~50% more than highest point in past 800k years
→ Far outside of variations during last 800k years

Intergovernmental Panel on Climate Change (IPCC)

Comprehensive reports on the state of climate change, its impacts and risks, as well as mitigation strategies → Latest: Sixth Assment report (AR6)

- Working Group I – The Physical Science Basis → Released Aug 2021
- Working Group II – Impacts, Adaption and Vulnerability → Released Feb 2022
- Working Group III – Mitigation of Climate Change → Released April 2022
- Synthesis Report → Released March 2023

WMO UNEP

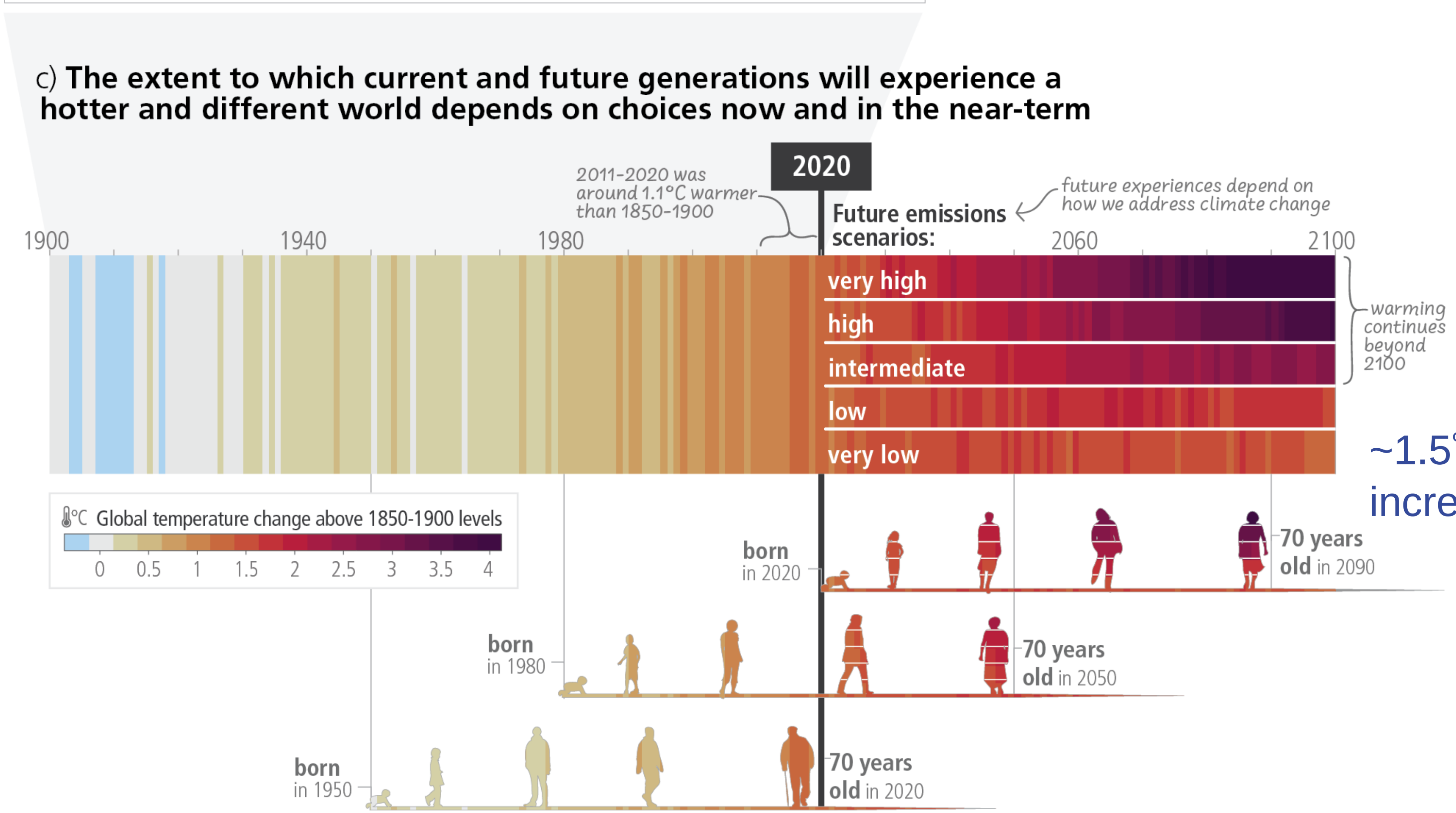
Nobel
2007 PEACE PRIZE
©® THE NOBEL FOUNDATION

From the Summary for Policy Makers of the Synthesis Report:

A.1 Human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850–1900 in 2011–2020. Global greenhouse gas emissions have continued to increase, with unequal historical and ongoing contributions arising from unsustainable energy use, land use and land-use change, lifestyles and patterns of consumption and production across regions, between and within countries, and among individuals (*high confidence*). {2.1, Figure 2.1, Figure 2.2}

Generations affected by climate change

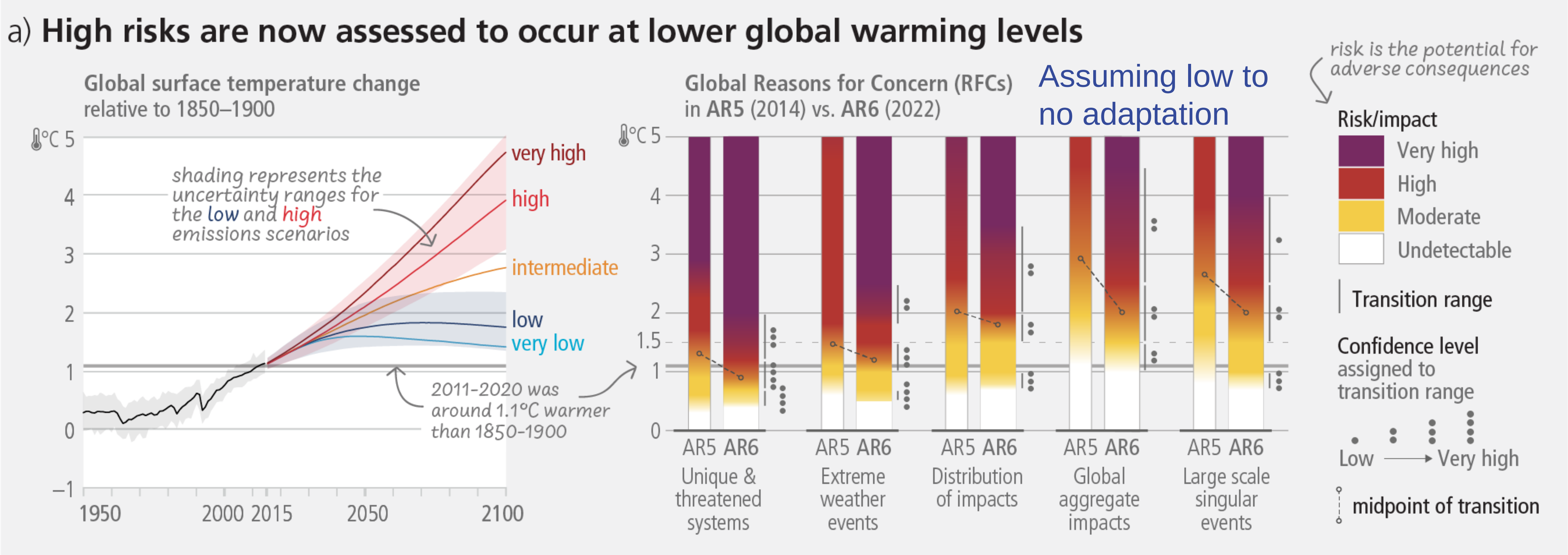
Majority of today‘s audience will live to see the consequences of our actions



~1.5° C increase only

Expected temperature increases

Comparing scenarios and risks

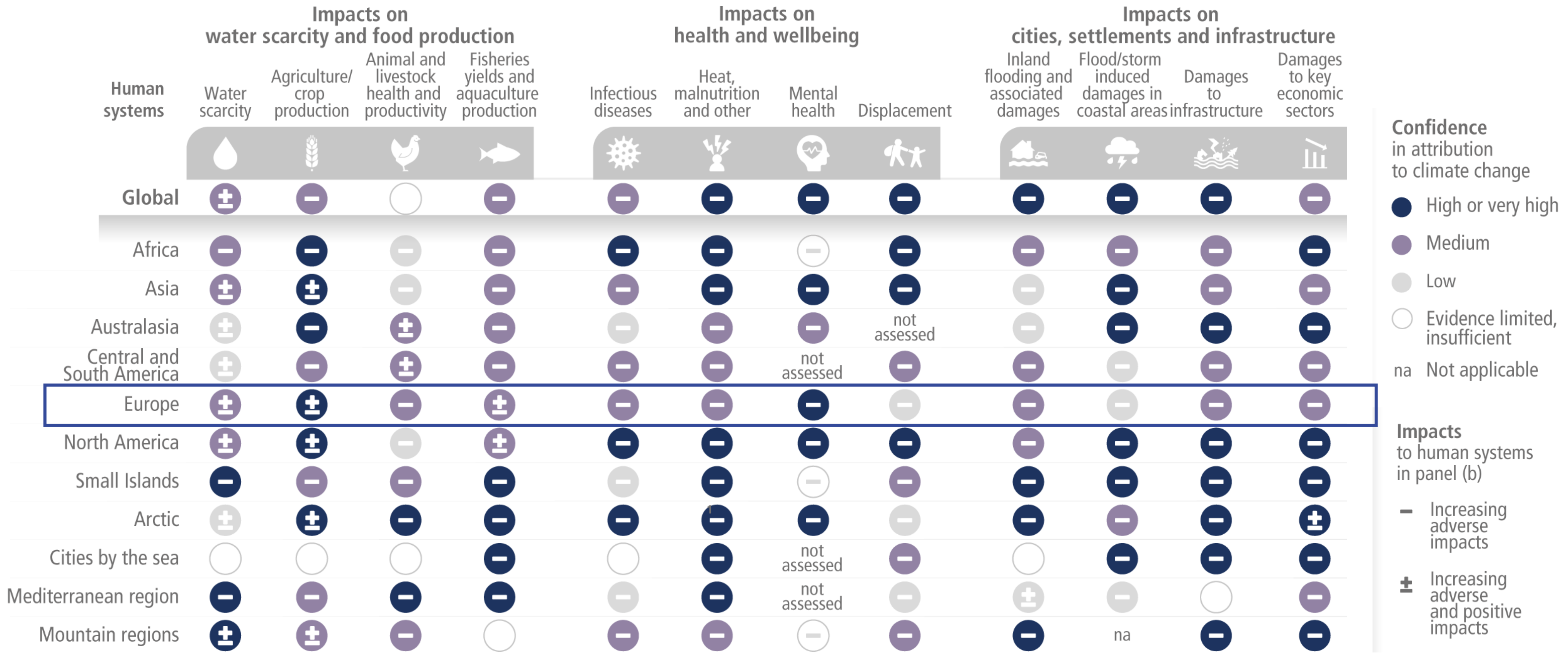


Assuming low to no adaptation

Impacts in Europe

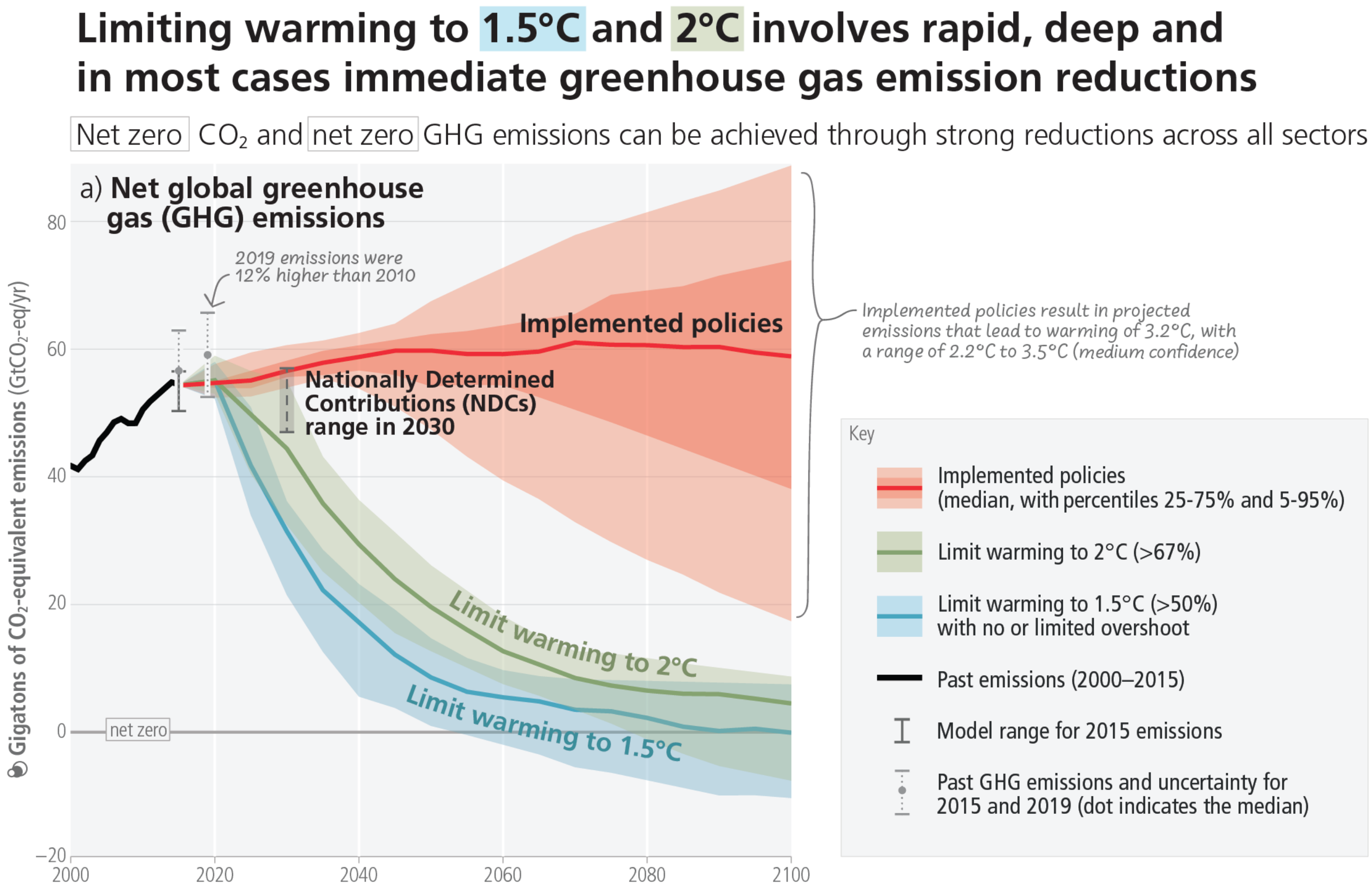
From WG II Summary for Policy Makers

(b) Observed impacts of climate change on human systems



Mitigation scenarios

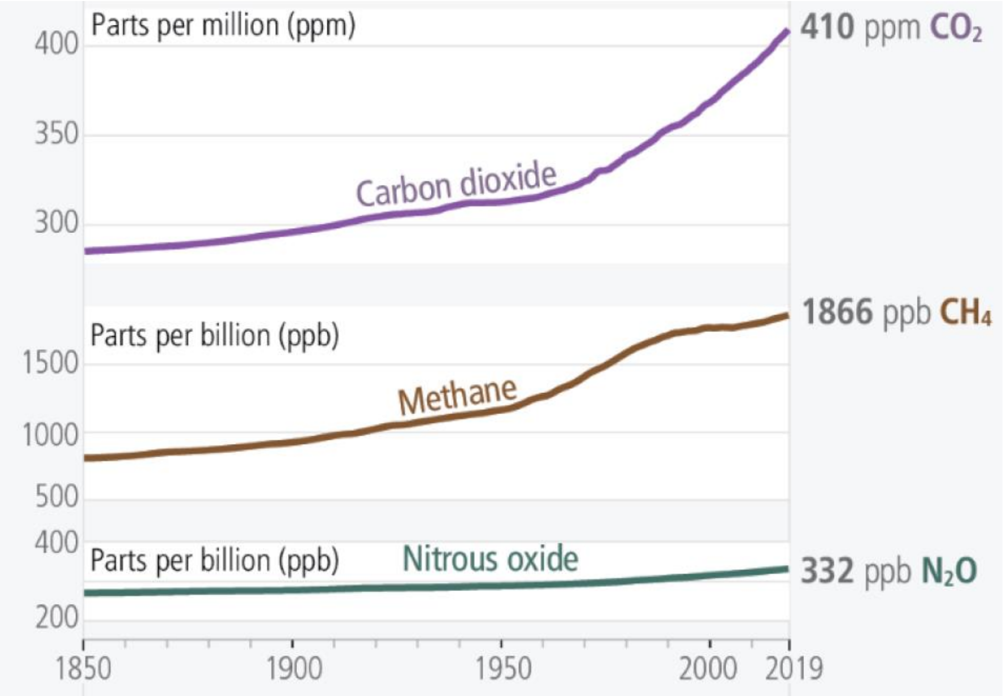
To reach net-zero Green House Gas (GHG) emissions

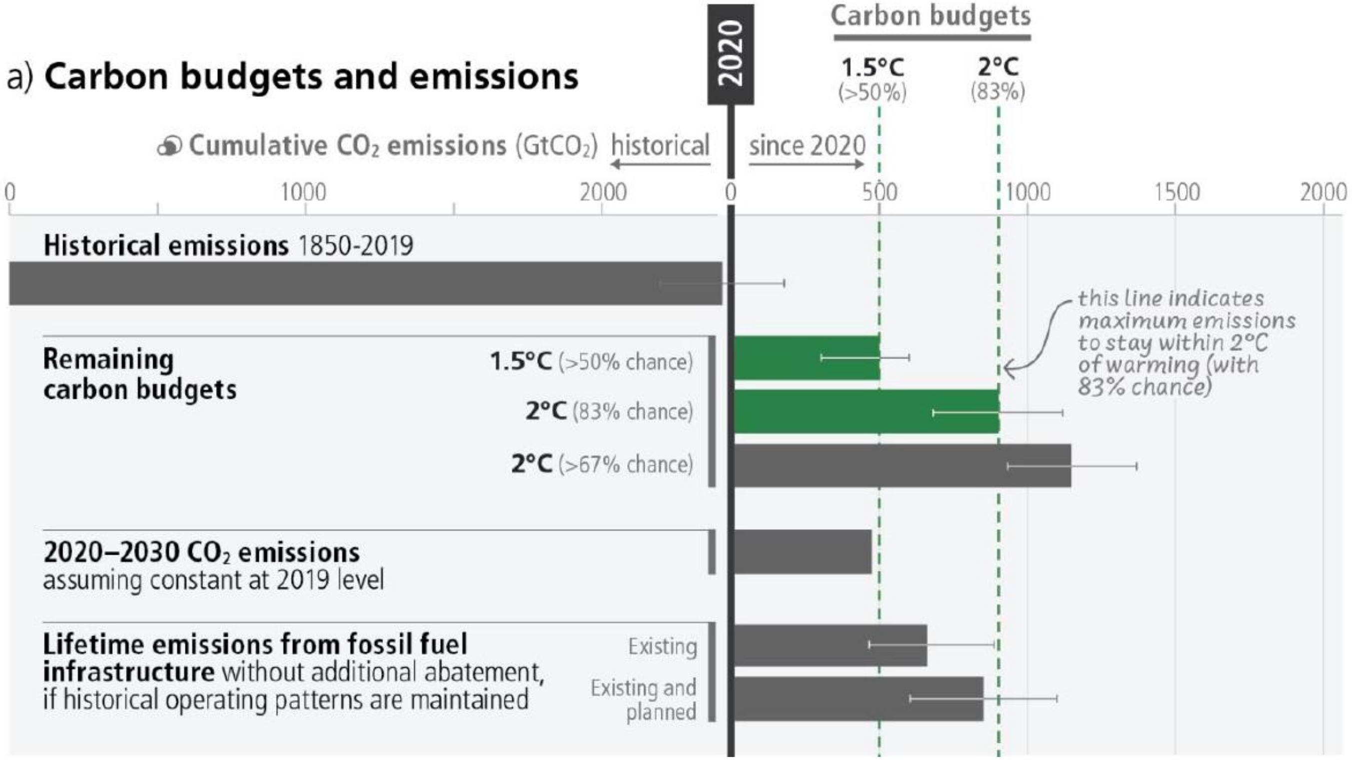


→ So far implemented policies by far do not reach 1.5-2° C-only global warming targets
→ Strong reductions across all sectors needed

Cumulative effect of CO_2 emissions

Every ton of CO_2, CH_4, N_2O, or flourinated gases add to global warming

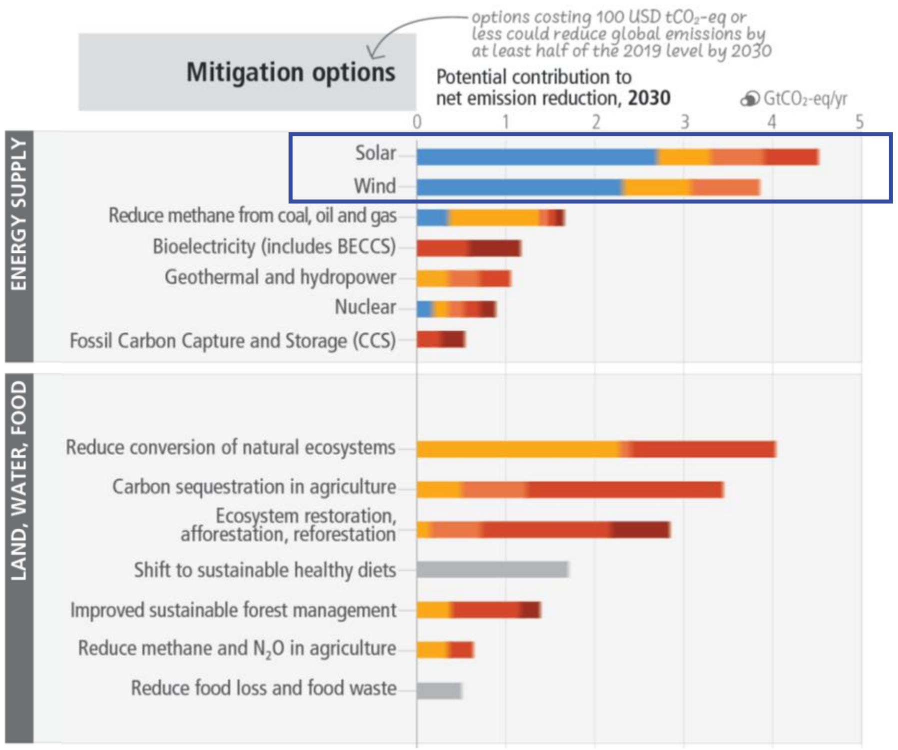


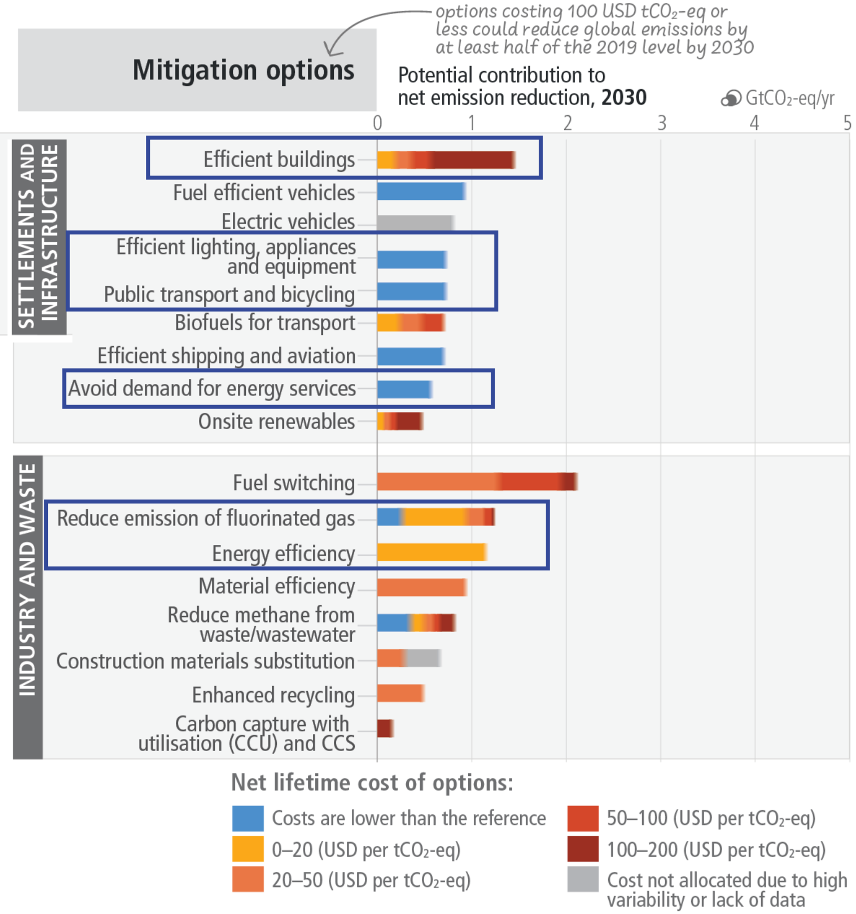


→ Global net anthropogenic GHG emissions in 2019: 59 ± 6.6 $GtCO_2$-eq
→ If continue as before, remaining carbon budget will be used up in 2030

Mitigation potentials

Cost estimates of different mitigation options





→ Non-negligible emissions where high-energy physics (HEP) has an impact

CO_2 foot print of high energy physics

Only starting with the assessment

- Research institutes
  - CERN: 2 environmental reports published so far: 2017-2018, 2019-2020
  - DESY: First environmental report published: 2019-2021
- Experimental collaborations
  - LHCb Upgrade II TDR: Includes discussion on emissions
- Universities
  - University Hannover: Environmental reports since 1999
  - ETH Zurich: Environmental reports since 2004
  - University Freiburg: Environmental reports, starting 2018
  - …

→ We need know where our emissions are produced in order to reduce them

CERN environmental report 2019-2020

Key numbers

Energy

428 GWh

In 2019, CERN consumed **428 GWh** of electricity and **68 GWh** of fossil fuel. CERN's electricity consumption during the period was about 64% lower than when the accelerator complex is running.

The Laboratory is committed to **limiting rises in electricity consumption to 5%** up to the end of 2024 (baseline year: 2018), while delivering significantly increased performance of its facilities. CERN is also committed to increase energy re-use.

Water

2006 ML

In 2019, CERN drew **2006 megalitres (ML)** of water, mostly from Lake Geneva. This is about 47% less than in operational years.

The Laboratory is committed to **keeping its increase in water consumption below 5%** up to the end of 2024 (baseline year: 2018), despite a growing demand for water cooling of upgraded facilities.

Waste

57% recycled

In 2019, CERN eliminated 5589 tonnes of non-hazardous waste, of which **57% was recycled**. The Laboratory also eliminated 1868 tonnes of hazardous waste.

CERN's objective is to increase the current recycling rate.

Biodiversity

16 species of orchids

In 2019, a new species of orchid was discovered on CERN's sites, bringing the total to **16 species**. CERN land includes **258 hectares** of cultivated fields and meadows, **136 hectares** of forest and three wetlands.

Emissions

78 169 tCO_2e

In 2019, CERN's direct greenhouse gas emissions (scope 1) were **78 169 tonnes of CO_2 equivalent** (tCO_2e), which is less than half of the amount emitted annually over the period 2017-2018 when the accelerators were running.

Indirect emissions arising from electricity consumption (scope 2) were **10 672 tCO_2e**. In addition, indirect emissions from water purification, waste treatment, business travel, personnel commutes and catering (scope 3) were **12 098 tCO_2e.**

CERN's immediate target is to **reduce direct emissions by 28%** by the end of **2024** (baseline year: 2018).

→ Emissions roughly correspond to ~1000 homes‘ energy use for 1 year (US)
→ Larger if accelerator is running

CERN environmental report 2019-2020

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In 2019, a n…
was discove…
bringing the…
CERN land i…
of cultivated…
136 hectare…
wetlands.

Emissions

78 169 tCO_2e

In 2019, CERN's direct greenhouse gas …**nnes of** …ess than …over the …elerators …lectricity …**tCO2e.** …ater pu… …s travel, …scope 3) …**duce di-** …of 2024

Emissions In 2018

223 800 tCO_2e

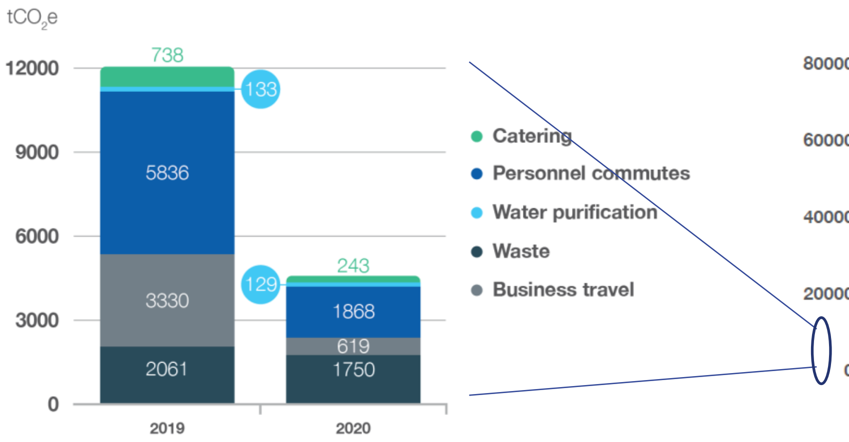
CERN's direct greenhouse gas emissions were **192 100 tonnes of CO_2 equivalent,** tCO_2e. Indirect emissions arising from electricity consumption were **31 700 tCO_2e.** CERN's immediate target is to reduce direct emissions by **28%** by the end of **2024** *(page 14).*

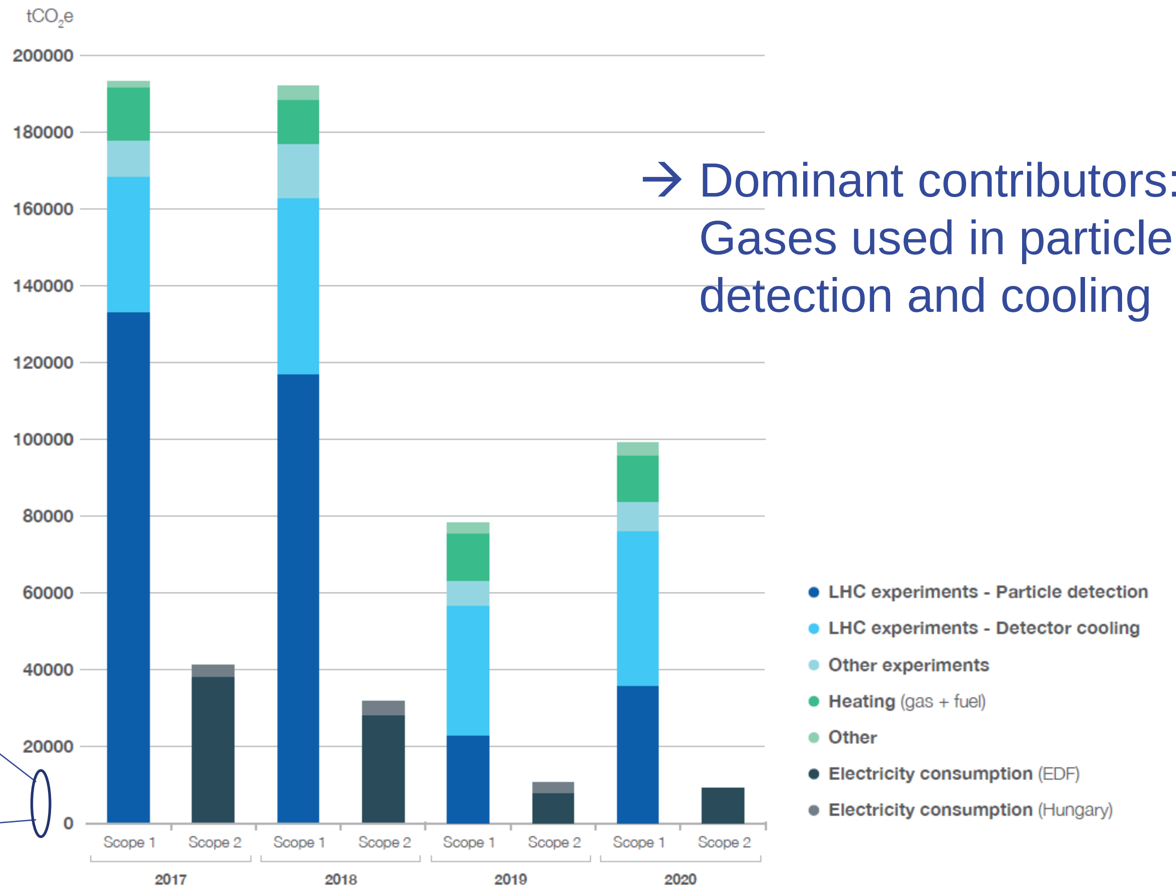
→ Emissions roughly correspond to ~1000 homes' energ…
→ Larger if accelerator is running

CERN emissions in more detail

Split into scope 1, 2, and 3 emissions – According to Greenhouse Gas Protocol

- Scope 1: Direct emissions from facilities and vehicles
- Scope 2: Indirect emissions related to electricity, steam, heating, or cooling
- Scope 3: Other indirect emissions up- or downstream, such as business travels, personnel commutes, catering





→ Dominant contributors: Gases used in particle detection and cooling

Gases and electricity at CERN

Global warming potential (GWP) of gas

- How much energy will be absorbed by 1t of the gas in 100 years compared to 1t of CO_2?
- Gases used at CERN

GROUP	GASES	tCO_2e 2019	tCO_2e 2020	GWPs (*)
PFC	CF_4, C_2F_6, C_3F_8, C_4F_{10}, C_6F_{14}	43277	45678	6500, 9200, 7000, 7000, 7400
HFC	CHF_3 (HFC-23), $C_2H_2F_4$ (HFC-134a), HFC-404a, HFC-407c, HFC-410a, HFC R-422D, HFC-507	17540	34899	11700, 1300
Other F-gases	SF_6, NOVEC, R1234ze	3840	5377	23900
CO_2	CO_2	13512	13046	1
TOTAL SCOPE 1		78169	98997	

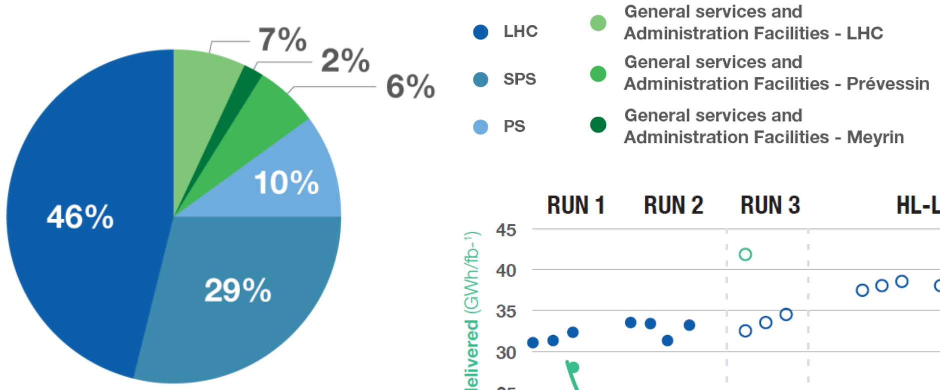
- Significant GWPs for the used gases

→ Already very small leaks have a major impact

(*) https://unfccc.int/process/transparency-and-reporting/greenhouse-gas-data/greenhouse-gas-data-unfccc/global-warming-potentials

Main users of electricity

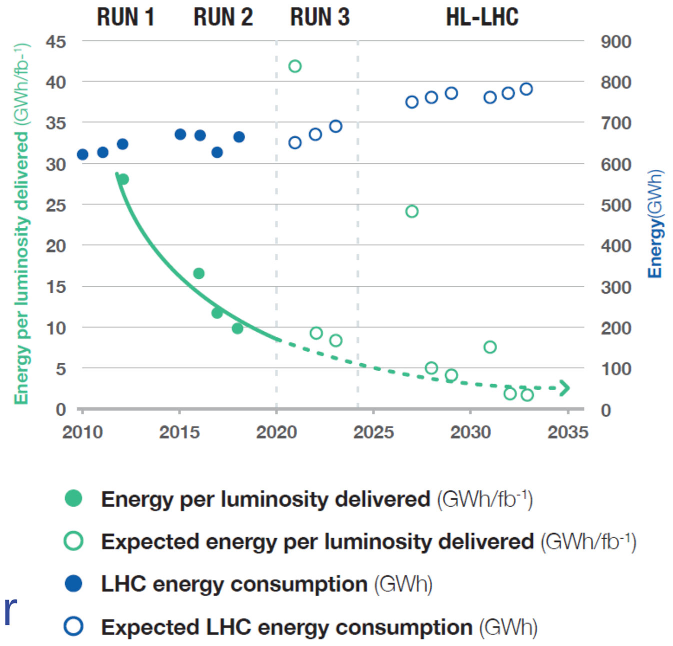
- In 2018, in total 1251GWh:



→ Accelerators require 85% of electricity

→ Improving in efficiency with years

→ Consider 87.9% as carbon free from French nuclear power



DESY environmental report 2019-2021

5 fields of action

- Buildings and infrastructure
- Research
- Governance
- Human resources
- Supporting processes

charta der vielfalt

DIGITAL DESY.

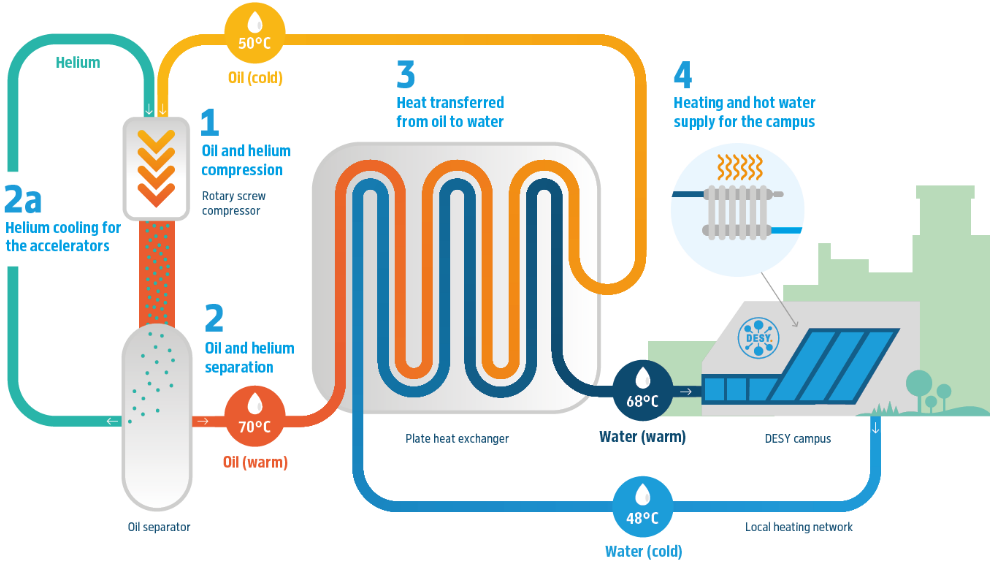
ca. 15 GWh
current annual consumption at DESY (for heat)

clean planet PROGRAM

Two topics at DESY in more detail

Waste heat from cryogenic plant

- Cooling of magnets for FLASH or European XFEL to -271°C



→ Produces > 10GWh/year
→ 200k EUR annual savings in energy costs
→ Could potentially be scaled to 129GWh/year
→ Could heat future Science City Hamburg Bahrenfeld

Switching to green electricity

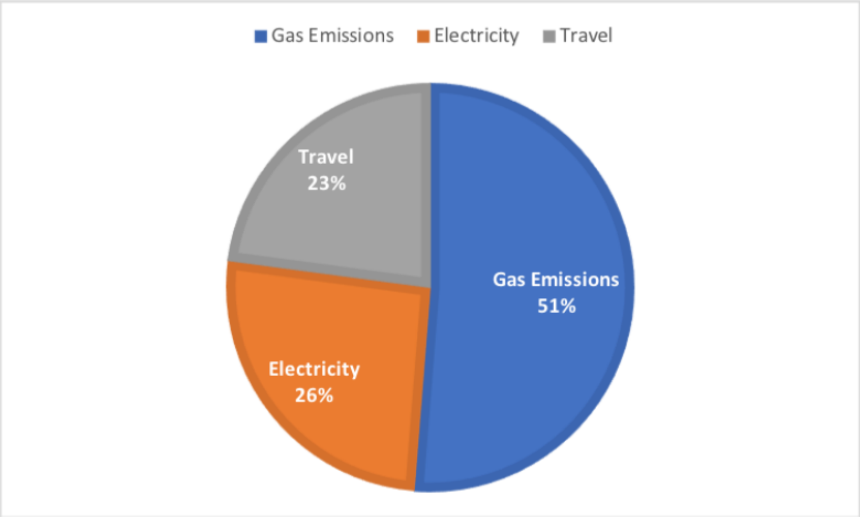
- Annual electricity consumption: ~120-170GWh (own estimate based on numbers in report)
- Switch from 2023 onwards to green electricity

- Up next: Improve energy efficiency

Environmental impact of Upgrade II of LHCb

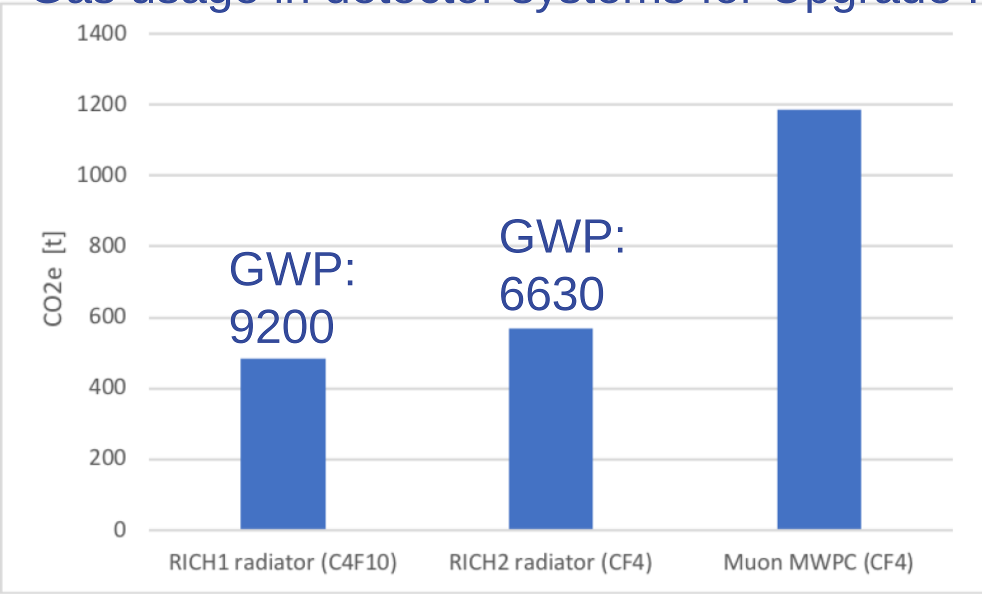
Discussion in the technical design report (TDR) of Upgrade II

- Total emissions in Run 3 of the LHC: 4400 tCO_2-eq. / year
- Expected relative contributions



→ Biggest contributor: Scope 1 – direct (gas) emissions

Gas usage in detector systems for Upgrade I



→ RICH1: Leak reduction campaign for Upgrade I already
→ RICH2: Move to CO_2 & leakless system for Upgrade II?
→ MWPC: Default mixture Ar 40%, CO_2 55%, CF_4 5% → Reduce CF_4 further?

Sustainability at KEK, Japan?

17 United Nations Sustainable Development Goals (SDGs)

- At the heart of the 2030 Agenda for Sustainable Development → Adopted by all UN member states in 2015

- Contribution by KEK, Japan

KEKのSDGsの取り組み

Via Google translate:
→ Large electricity consumption due to large-scale accerator experiments
→ Tackle “energy problem“, incl. energy saving, efficiency improvement & use of renewable energies
→ Contribution to peace through joint international experiments

QS World University Rankings: Sustainability 2023

First QS ranking based on social and environmental sustainability

- 8 indicators
  - Sustainable institutions
  - Sustainable education
  - Sustainable research
  - Equality
  - Knowlegde exchange
  - Educational impact
  - Employability and opportunities
  - Quality of life

World-wide

Overall Rank	University	Environmental Impact Rank	Social Impact Rank
1	University of California, Berkeley (UCB) Berkeley, United States	1	1
2	University of Toronto Toronto, Canada	3	7
3	University of British Columbia Vancouver, Canada	4	2

Europe

Overall Rank	University	Environmental Impact Rank	Social Impact Rank
4	The University of Edinburgh Edinburgh, United Kingdom	10	3
11	Uppsala University Uppsala, Sweden	14	=26
12	Lund University Lund, Sweden	13	36

Highest ranked German university:
→ Technical University of Munich – overall ranking: 109
→ Lot‘s of room to improve!

Learning from the best universities

University of California, Berkeley

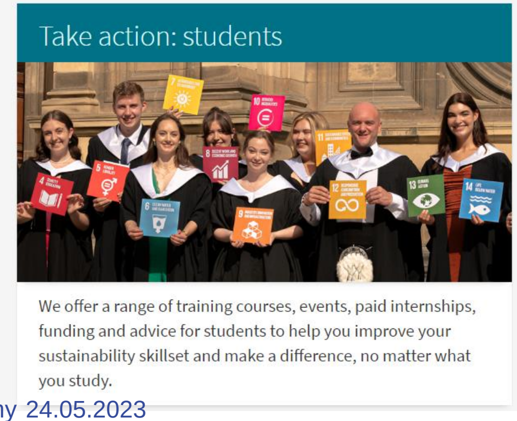
- Sustainability plan

→ Copying successful measures is explicitly wanted ☺

Target:
→ Climate neutrality from scope 1 & 2 sources by 2025
→ Climate neutrality from specific scope 3 sources by 2050 or sooner

University of Edinburgh

- Become a zero carbon and zero waste university

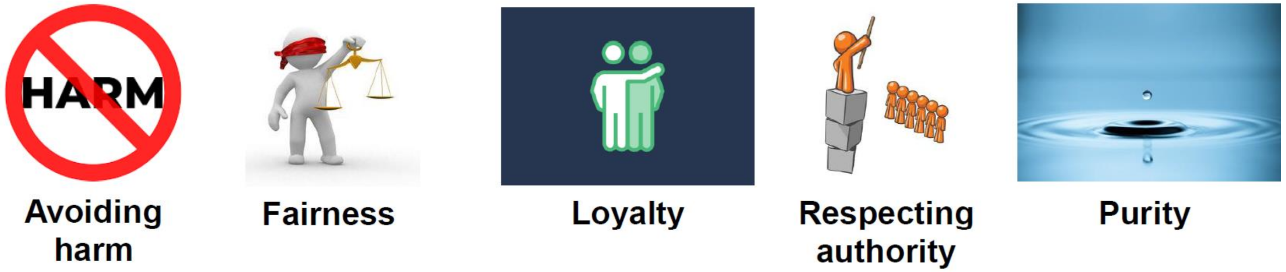


What barriers exist for getting involved?

Pyschological barriers to climate action

Source: Presentation by Prof. Brosch, at CERN and the environment workshop, Oct 2022

Example: Moral barrier
→ Broad categories of morality



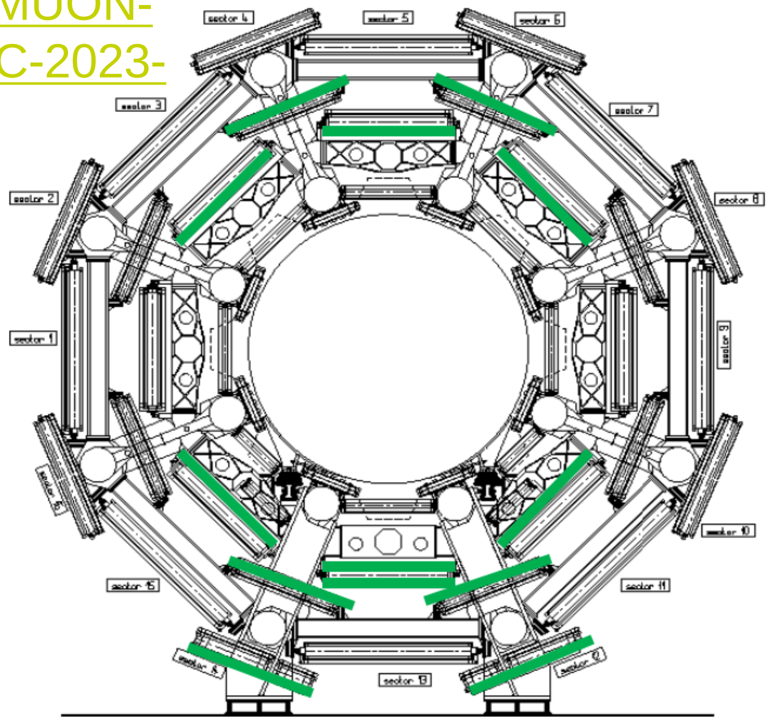
→ Most often addressed by climate crisis communication
→ Leaves out a huge part of the population

Left-leaning ⟷ Right-leaning
Political spectrum

→ Need to adjust messaging to include entire population!

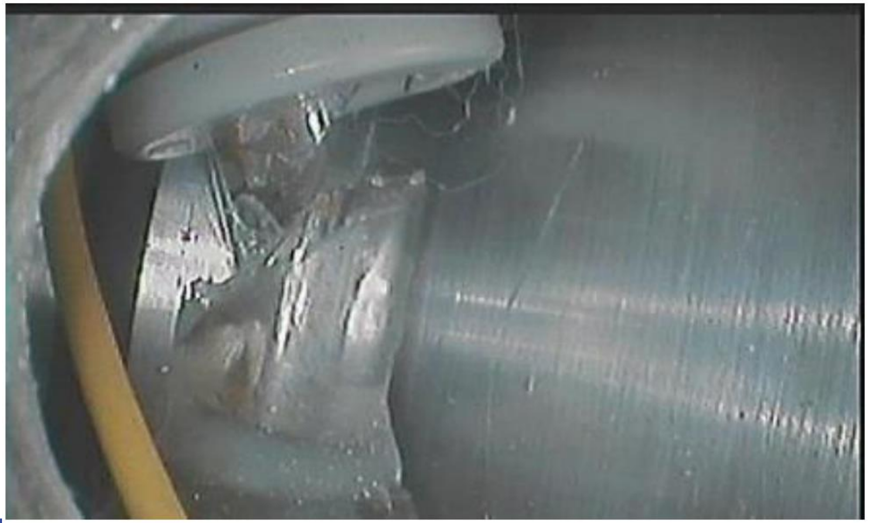
Hands-on: Fixing leaks in ATLAS

ATL-MUON-PROC-2023-001



Gas leaks in the ATLAS muon system

- Plastic connectors of the gas flow lines to the Resistive Plate Chambers (RPCs) → Tend to develop leaks
- 8000 potentially leaky connection points in ATLAS RPCs → Often difficult to reach → Break faster than can be repaired
- Gas mixture in RPCs: $C_2H_2F_4$+iso-C_4H_{10}+SF_6 → GWP ~ 1400 → Studies with replacing gas mixture not trivial!
  - 1l of RPC mixture ~ 5-6kg CO_2-eq. (*) → Loss of ~1000l/h → If constant throughout the year: ~44k-53k tCO_2-eq./year emissions → ~20-23% of 2018 emissions by CERN (own estimate)
- Campaign in ATLAS with new repair technique and teams of volunteers to fix leaks during end-of-year shutdowns
  - First test campaign early 2023: Reduction of RPC losses by 23%!
  - Continue with more volunteers and more sectors in next shutdown

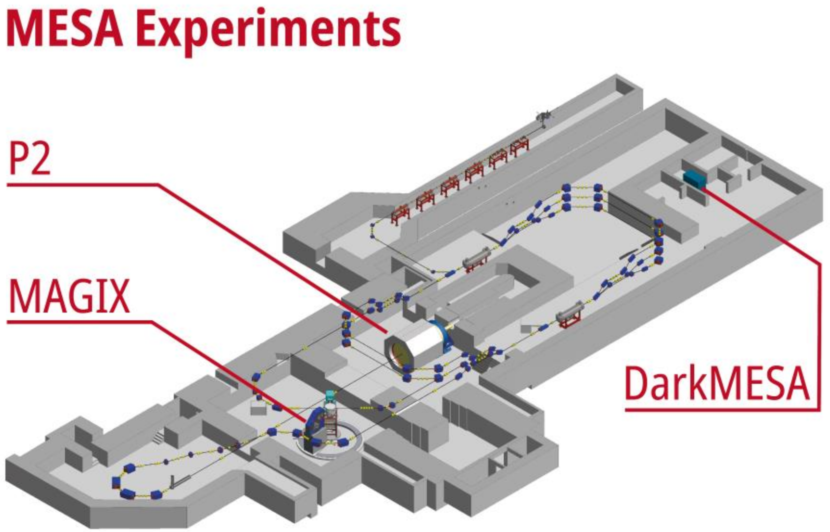


(*) Based on main component: $C_2F_2F_4$ → Conversion of l to kg → Convert to CO2-eq. by multiplying with GWP for HFC-134(a)

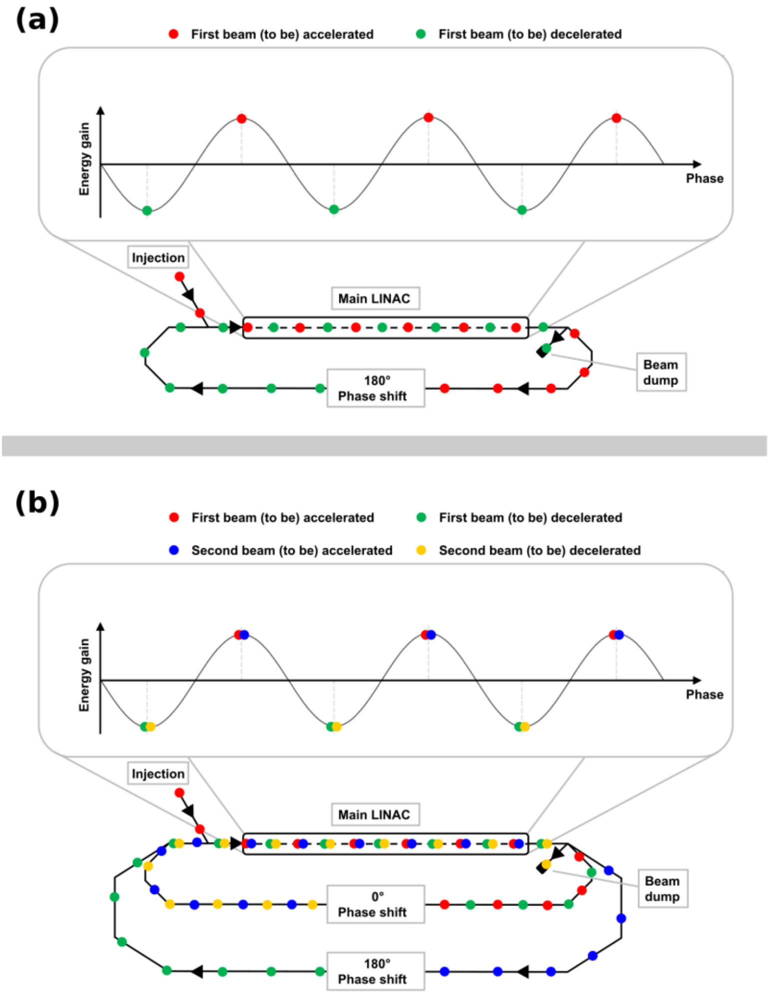
Sustainable accelerator development

Energy recovery linacs (ERL), e.g. MESA in Mainz

- Measure proton radius, search for dark photons
- Electron accelerator with 155MeV beam energy
- First to use ERL technology for research
- Accelerated electron‘s energy is won back → 2/3 of energy saved



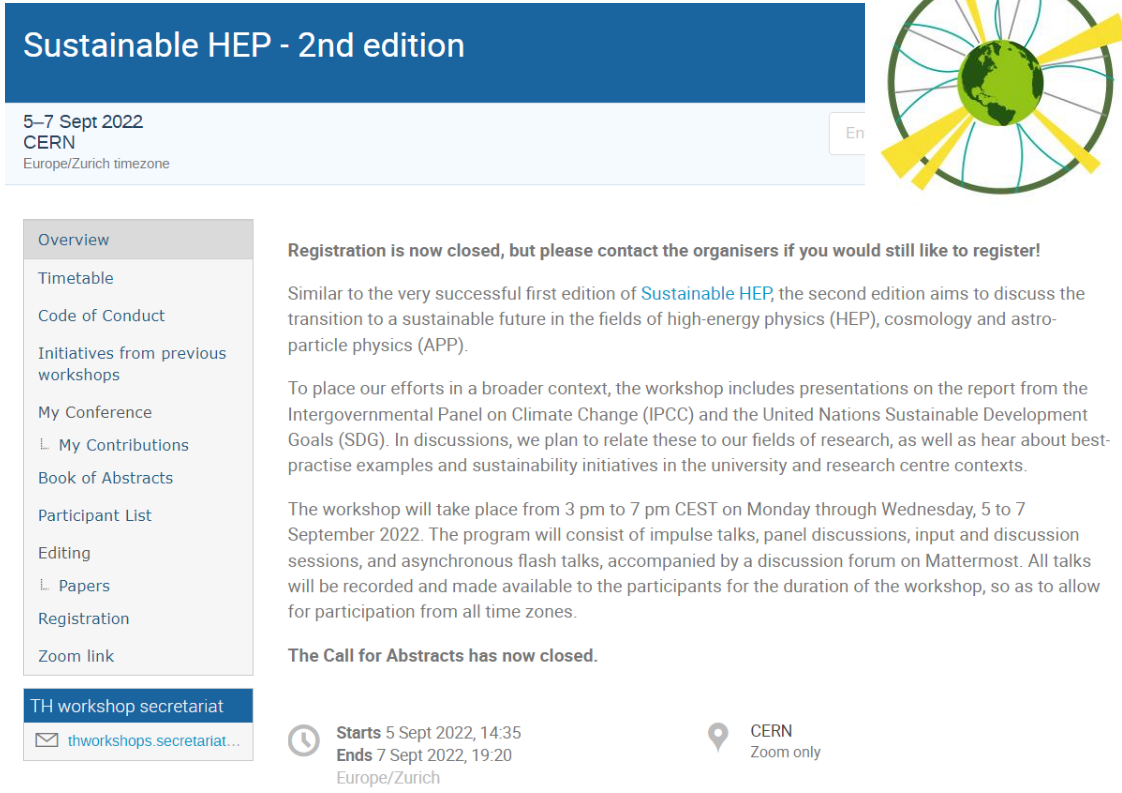
Idea of ERL as implemented in S-DALINAC (TU Darmstadt)



Presenting research on sustainability studies in HEP

Sustainable HEP Workshop series

- Kindly hosted by CERN, taking place fully online
- Format: 3 afternoons, with recording of presentations for asynchronous viewing, mattermost chat for discussions
  - Invited impulse talks, and best-practise examples
  - Panel discussion, sustainability initiatives presentation
  - Abstract submission for contributions
- Started in 2021, second edition 2022
  → Third edition still looking for organizers
  → Volunteers welcome ☺


Sustainable HEP - 2nd edition

5–7 Sept 2022
CERN
Europe/Zurich timezone

Overview
Timetable
Code of Conduct
Initiatives from previous workshops
My Conference
My Contributions
Book of Abstracts
Participant List
Editing
Papers
Registration
Zoom link

TH workshop secretariat
thworkshops.secretariat...

Registration is now closed, but please contact the organisers if you would still like to register!

Similar to the very successful first edition of Sustainable HEP, the second edition aims to discuss the transition to a sustainable future in the fields of high-energy physics (HEP), cosmology and astro-particle physics (APP).

To place our efforts in a broader context, the workshop includes presentations on the report from the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Sustainable Development Goals (SDG). In discussions, we plan to relate these to our fields of research, as well as hear about best-practise examples and sustainability initiatives in the university and research centre contexts.

The workshop will take place from 3 pm to 7 pm CEST on Monday through Wednesday, 5 to 7 September 2022. The program will consist of impulse talks, panel discussions, input and discussion sessions, and asynchronous flash talks, accompanied by a discussion forum on Mattermost. All talks will be recorded and made available to the participants for the duration of the workshop, so as to allow for participation from all time zones.

The Call for Abstracts has now closed.

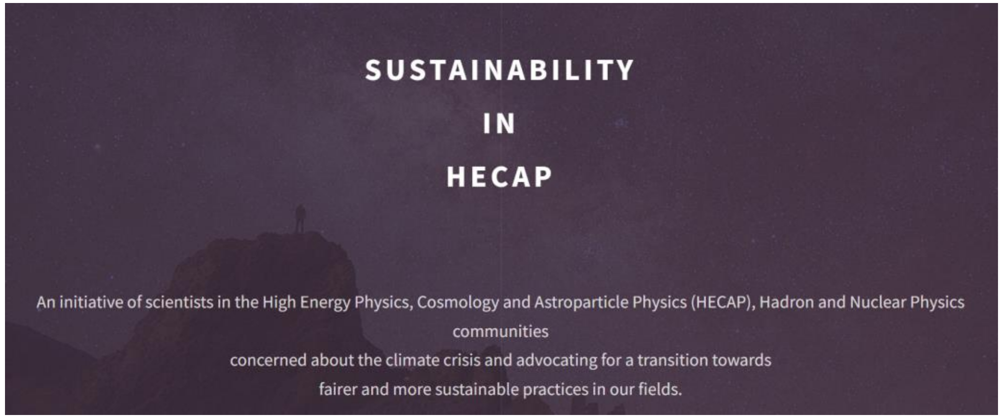
Starts 5 Sept 2022, 14:35
Ends 7 Sept 2022, 19:20
Europe/Zurich

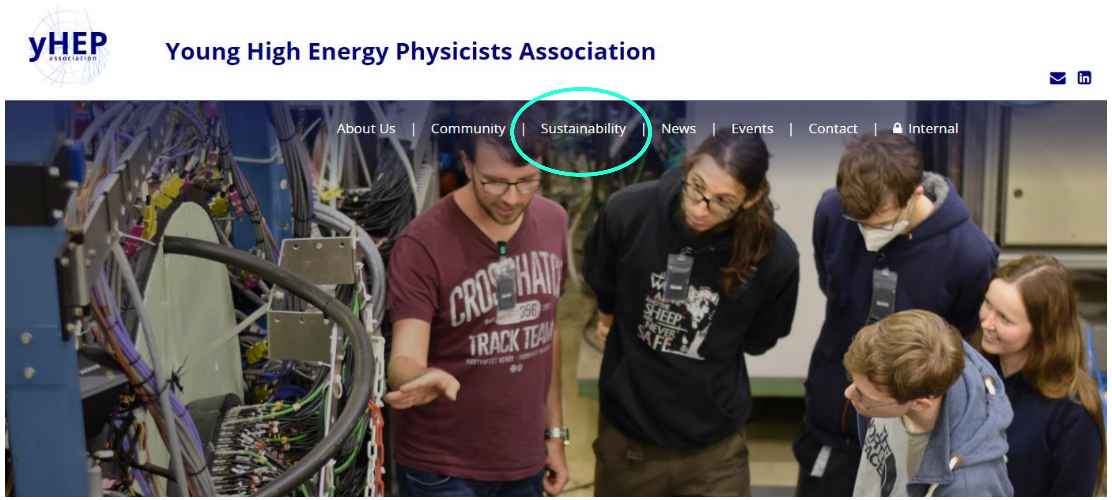
CERN
Zoom only

Community statements regarding sustainability

In HEP(-related) research

- Sustainability in HECAP
  - Overview and recommendations for improvements on Computing, Energy, Food, Mobility, Research Infrastructure and Technology, Resources and Waste
- yHEP statements on environmental sustainability in science
  - Collection of recommendation touching on similar topics as above – collected based on suggestions from young high energy physicists
- Strategy paper planned from ErUM-data workshop
  - Next week: Sustainability in the Digital Transformation of Basic Research on Universe & Matter
  - Computing-focused





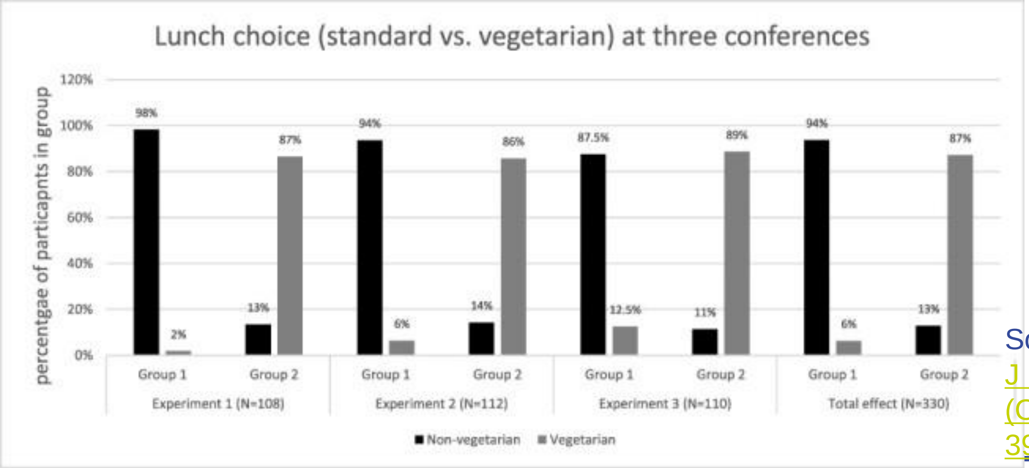
Impact of conference / workshop / etc organisation

Ideas for sustainable events

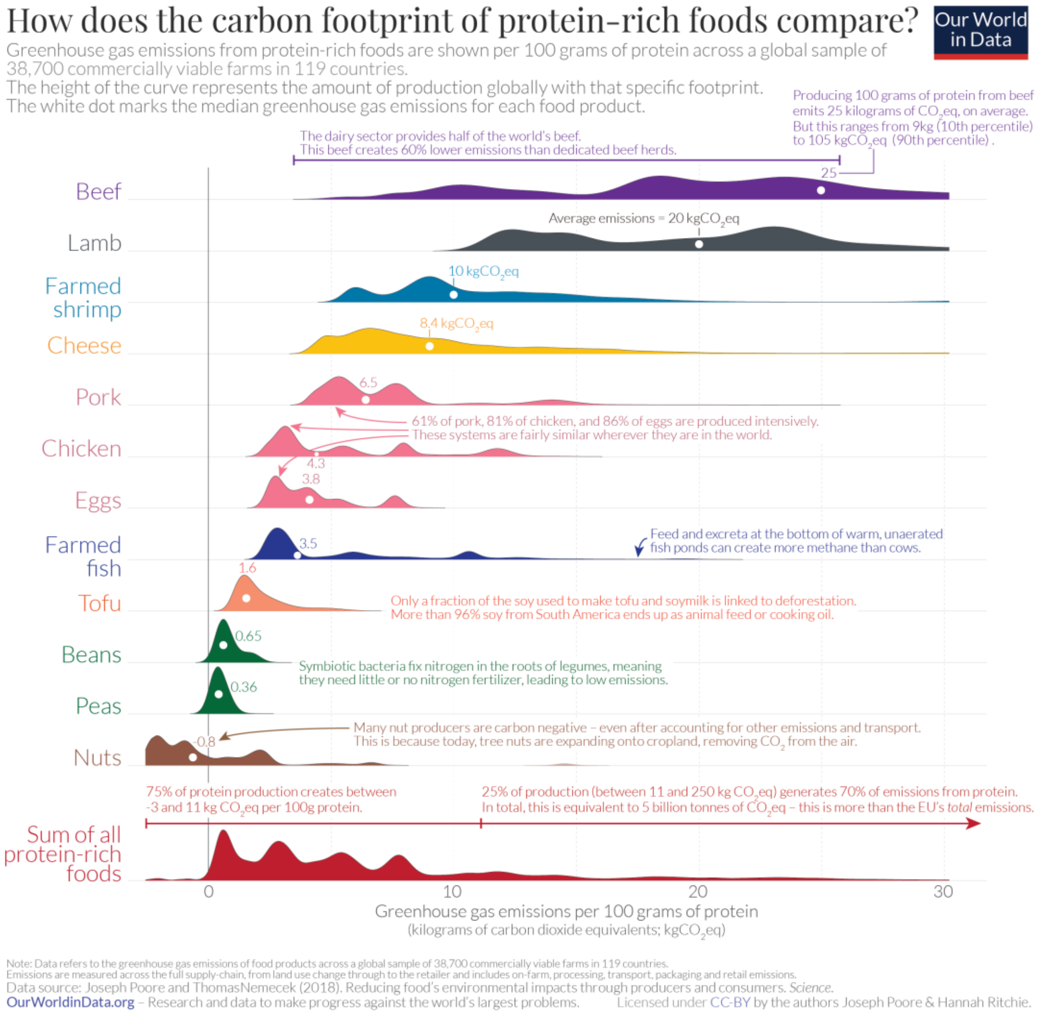
- Guideline developed by ETH Zürich
  - One important aspect: Catering

Carbon footprint of food

- Highest for red meat: Beef, lamb
- Idea: Adjusting default option of food choice at conference



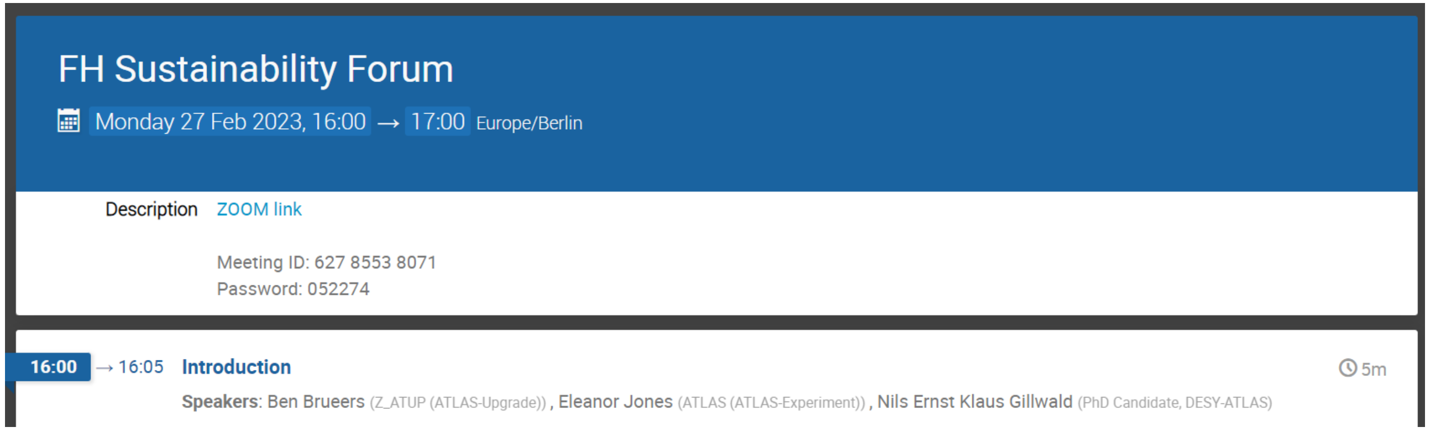
Source: J Public Health (Oxf). 2021; 43(2): 392–397



How to get involved?

Join or start a sustainability forum, e.g.:

- ATLAS sustainabilty forum
- DESY-FH sustainability forum
- yHEP sustainability effort
- Find out what exists for Belle II already



→ Ask for CO_2 emission numbers from your collaboration
→ Ask for CO_2 emission numbers from your university or lab, e.g. KEK
→ Get involved!

Questions?

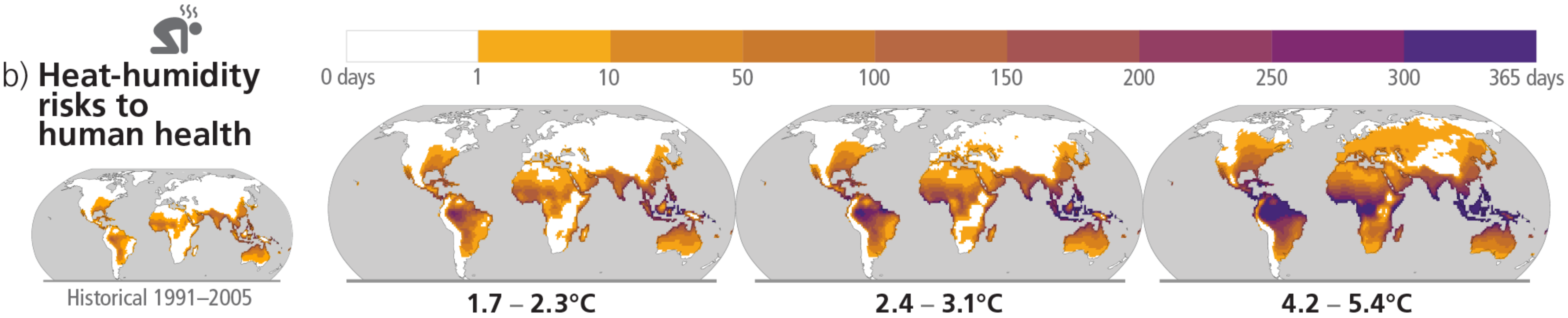
Thanks for your attention

Sources

Collected (non-complete set of) links (if not indicated on the slide):

- Climate simulation movie: https://data.giss.nasa.gov/modelE/sc07/
- Keeling curve versions: https://keelingcurve.ucsd.edu
- Global warming potentials: https://unfccc.int/process/transparency-and-reporting/greenhouse-gas-data/greenhouse-gas-data-unfccc/global-warming-potentials
- Global carbon budget: https://www.globalcarbonproject.org

From IPCC report



Days per year where combined temperature and humidity conditions pose a risk of mortality to individuals[3]

[3]Projected regional impacts utilize a global threshold beyond which daily mean surface air temperature and relative humidity may induce hyperthermia that poses a risk of mortality. The duration and intensity of heatwaves are not presented here. Heat-related health outcomes vary by location and are highly moderated by socio-economic, occupational and other non-climatic determinants of individual health and socio-economic vulnerability. The threshold used in these maps is based on a single study that synthesized data from 783 cases to determine the relationship between heat-humidity conditions and mortality drawn largely from observations in temperate climates.

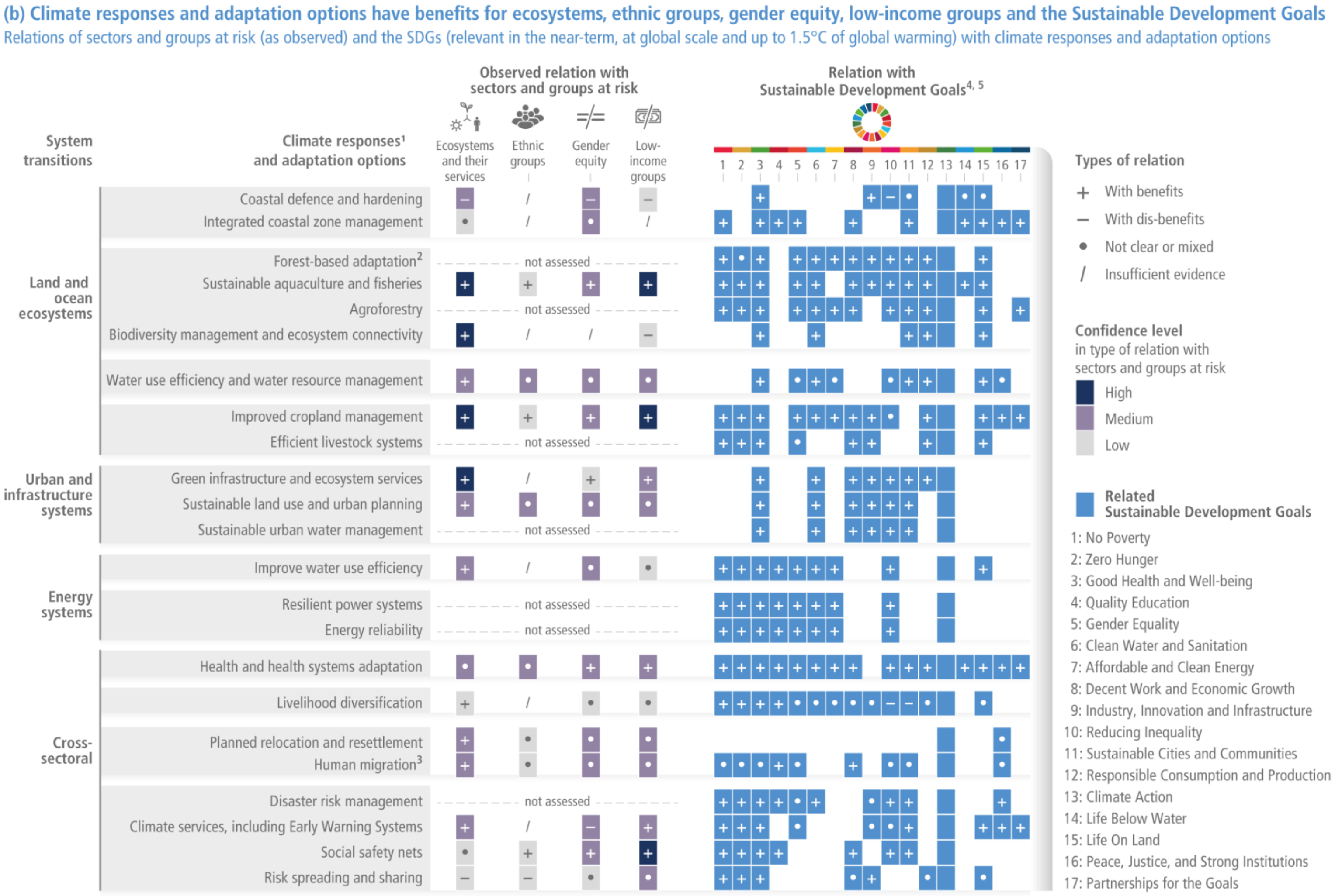
Shared socio-economic pathways (SSP)

Box SPM.1, Table 1: Description and relationship of scenarios and modelled pathways considered across AR6 Working Group reports. {Cross-Section Box.2, Figure 1}

Category in WGIII	Category description	GHG emissions scenarios (SSPx-y*) in WGI & WGII	RCPy** in WGI & WGII
C1	limit warming to 1.5°C (>50%) with no or limited overshoot***	Very low (SSP1-1.9)	
C2	return warming to 1.5°C (>50%) after a high overshoot***		
C3	limit warming to 2°C (>67%)	Low (SSP1-2.6)	RCP2.6
C4	limit warming to 2°C (>50%)		
C5	limit warming to 2.5°C (>50%)		
C6	limit warming to 3°C (>50%)	Intermediate (SSP2-4.5)	RCP 4.5
C7	limit warming to 4°C (>50%)	High (SSP3-7.0)	
C8	exceed warming of 4°C (>50%)	Very high (SSP5-8.5)	RCP 8.5

* See footnote 27 for the SSPx-y terminology.
** See footnote 28 for the RCPy terminology.
*** Limited overshoot refers to exceeding 1.5°C global warming by up to about 0.1°C, high overshoot by 0.1°C-0.3°C, in both cases for up to several decades.

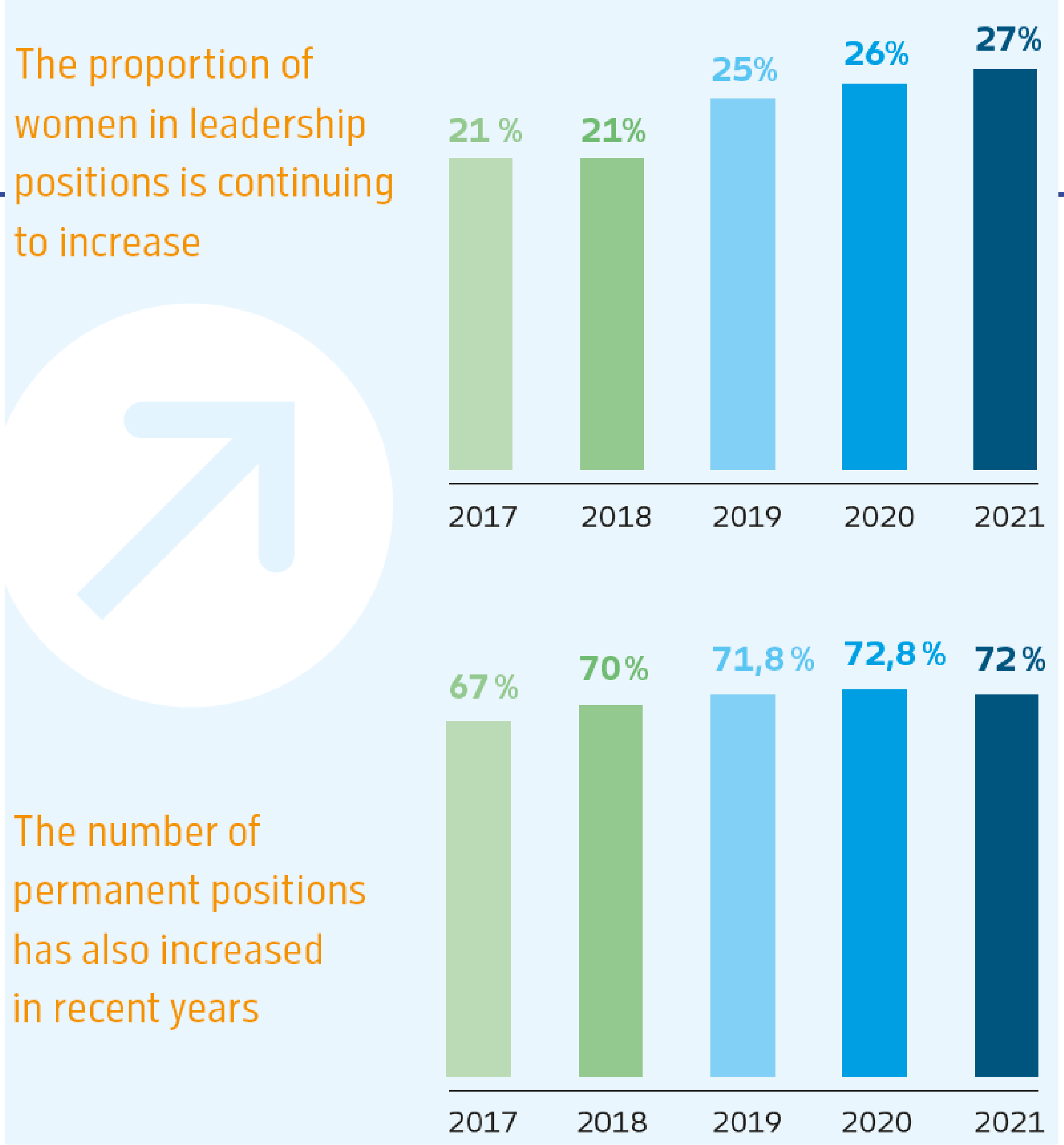
Relation to SDGs



Footnotes: [1] The term response is used here instead of adaptation because some responses, such as retreat, may or may not be considered to be adaptation. [2] Including sustainable forest management, forest conservation and restoration, reforestation and afforestation. [3] Migration, when voluntary, safe and orderly, allows reduction of risks to climatic and non-climatic stressors. [4] The Sustainable Development Goals (SDGs) are integrated and indivisible, and efforts to achieve any goal in isolation may trigger synergies or trade-offs with other SDGs. [5] Relevant in the near-term, at global scale and up to 1.5°C of global warming.

DESY employment

Positive development



LHCb travel emissions

Including LHCb collaboration weeks and international conferences