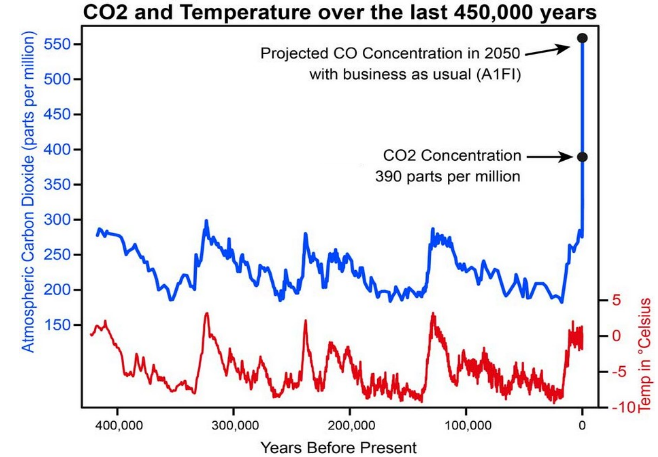
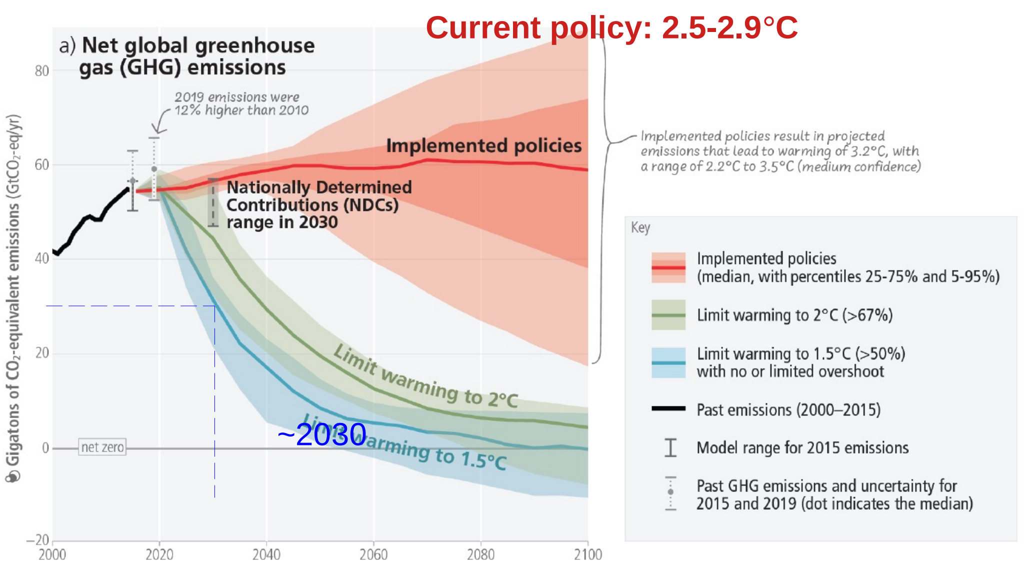
# Environmental sustainability in basic research: A perspective from particle, nuclear and astroparticle physics

Kristin Lohwasser (U of Sheffield)
on behalf of the HECAP+ Initiative
19th July 2024, ICHEP, Prague

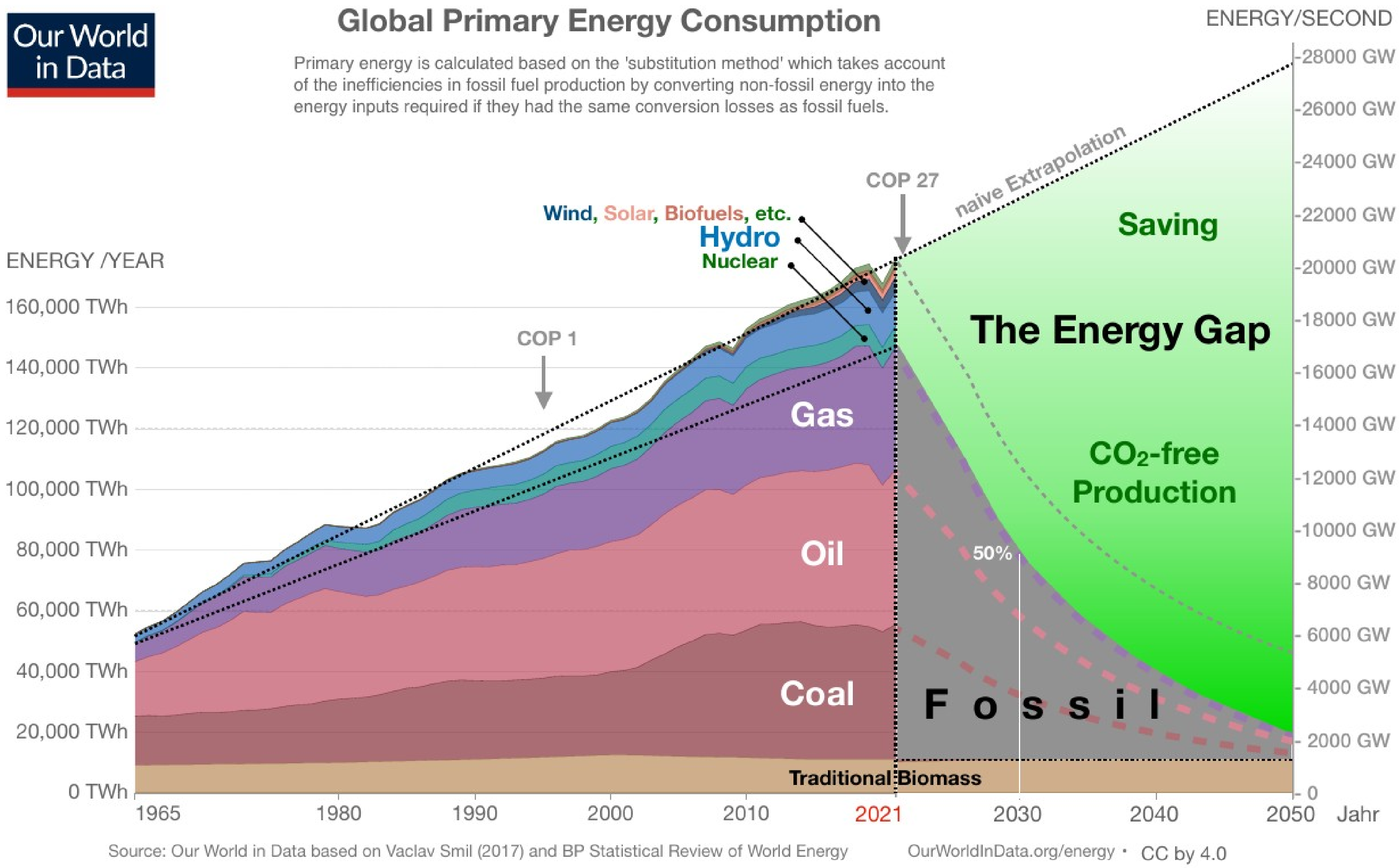
# Climate change in a nutshell

- Temperatures rising with $CO_2$ and other gases in atmosphere
- Causing more frequently drought, floods, high temperatures **with billions of damages**
- **Paris agreement:** Hold global average temperature **well below 2°C** above pre-industrial levels and pursue efforts to **limit the temperature increase to 1.5 °C**
- **Make finance flows consistent** with pathway towards **low emissions and climate-resiliant development**
- **Reduction to zero emissions around 2100**
  → A lot of time?
  → 50% of the reduction should be achieved by ~2030
  → **in 6 years**




# The energy gap



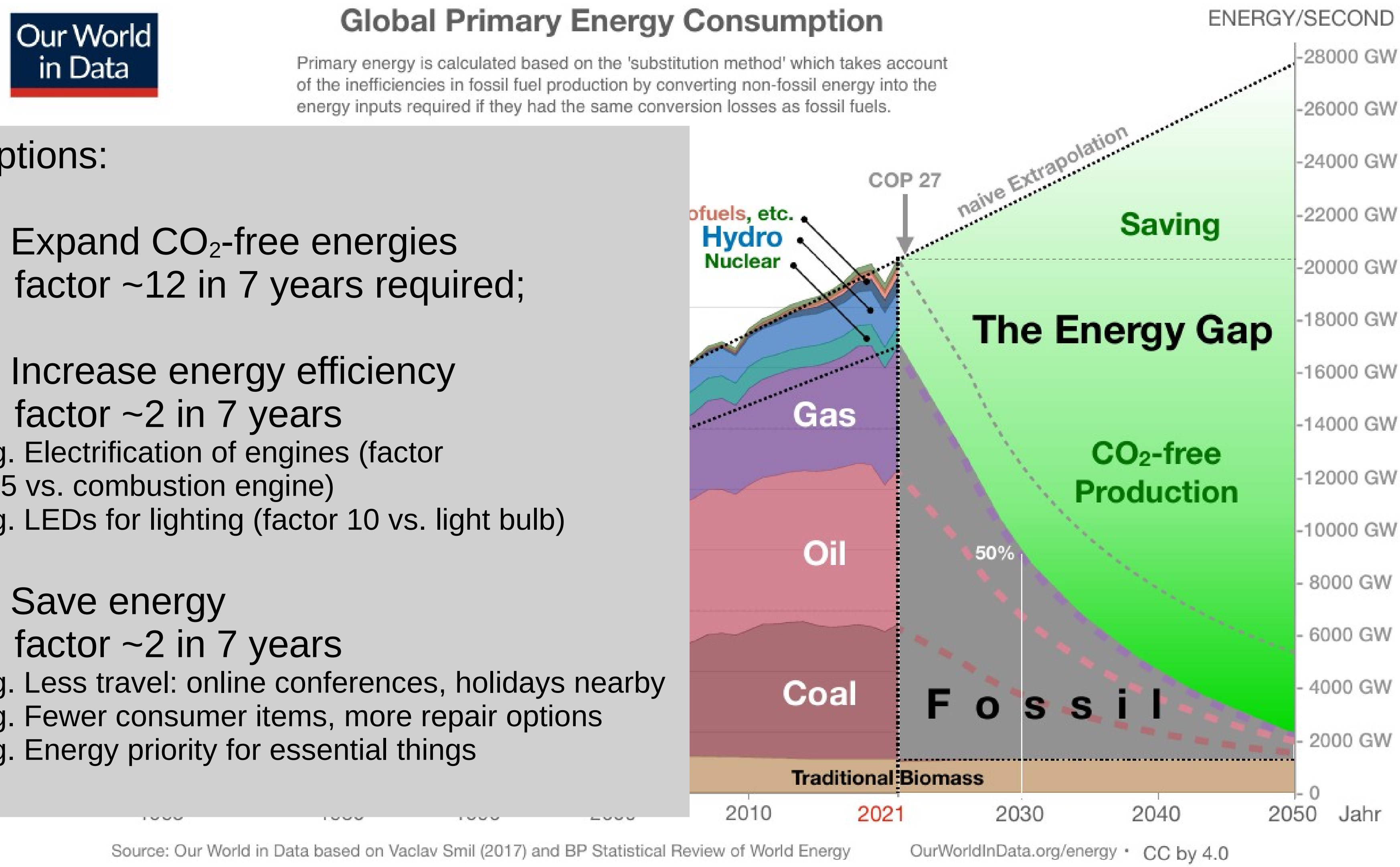
# The energy gap

Options:

1) Expand $CO_2$-free energies
→ factor ~12 in 7 years required;

2) Increase energy efficiency
→ factor ~2 in 7 years
e.g. Electrification of engines (factor 3-5 vs. combustion engine)
e.g. LEDs for lighting (factor 10 vs. light bulb)

3) Save energy
→ factor ~2 in 7 years
e.g. Less travel: online conferences, holidays nearby
e.g. Fewer consumer items, more repair options
e.g. Energy priority for essential things



# What does this mean for particle physics?

- Reflection document following Sustainable HEP workshops
  https://indico.cern.ch/event/1004432/ (1st edition)
  https://indico.cern.ch/event/1160140/ (2nd edition)
- Gives an overview over current status of sustainability in HECAP+ (High Energy Physics, Cosmology
  and Astroparticle Physics + Hadron and Nuclear Physics)
- 158 pages
- Linked to UN sustainability goals
- Accepted by JINST


**Environmental sustainability in basic research**

**A perspective from HECAP+**

**https://sustainable-hecap-plus.github.io/**

**Abstract**
The climate crisis and the degradation of the world's ecosystems require humanity to take immediate action. The international scientific community has a responsibility to limit the negative environmental impacts of basic research. The **HECAP+ communities** (**High Energy Physics, Cosmology, Astroparticle Physics, and Hadron and Nuclear Physics**) make use of common and similar experimental infrastructure, such as accelerators and observatories, and rely similarly on the processing of big data. Our communities therefore face similar challenges to improving the sustainability of our research. This document aims to reflect on the environmental impacts of our work practices and research infrastructure, to highlight best practice, to make recommendations for positive changes, and to identify the opportunities and challenges that such changes present for wider aspects of social responsibility.

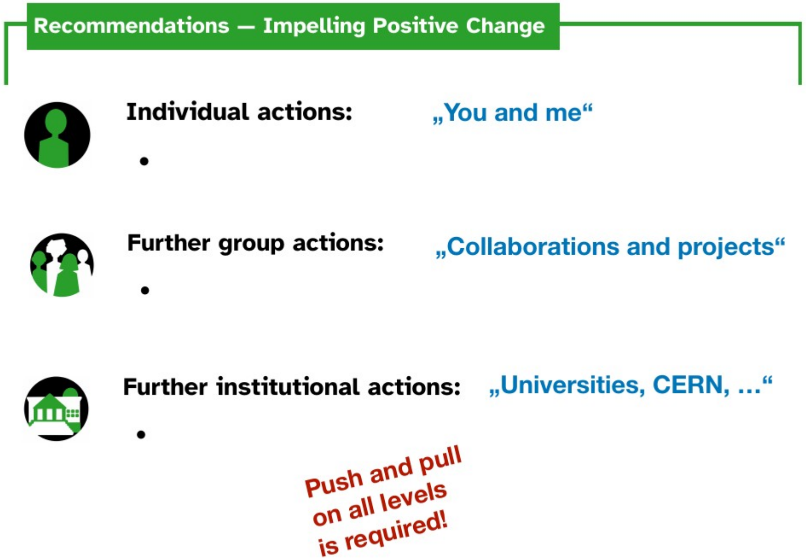
**Version 1.0, 5 June 2023**

Please read this document in electronic format where possible and refrain from printing it unless absolutely necessary. Thank you.

# What does this mean for particle physics?

Reports in alphabetical order on:
→ Computing
→ Energy
→ Food
→ Mobility
→ Research Infrastructure and Technology
→ Resources and Waste

(including also **Best practices**, **Case studies** and very general **Recommendations**)

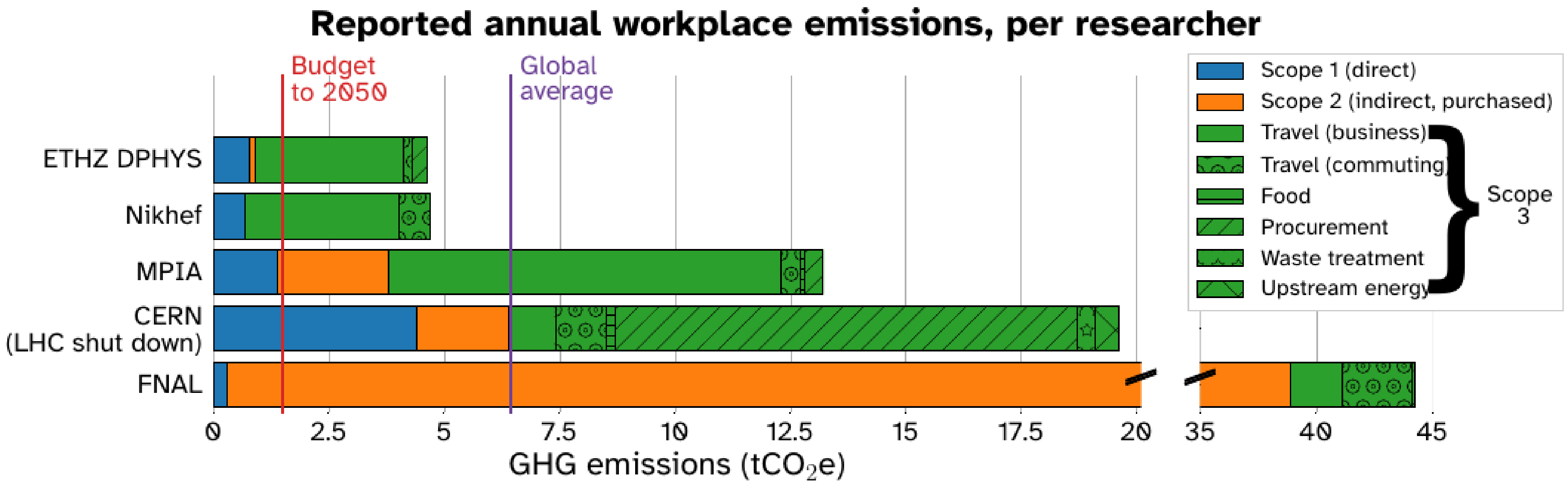



**Assessing, reporting on, defining targets for, and under-taking coordinated efforts to limit our negative impacts on the world's climate and ecosystems must become an integral part of how we plan and undertake all aspects of our research.**

# Workplace emissions in HECAP+

- Comparisons between institutes interesting, but also down to local and specific circumstances
  - CERN: no travel to experimental site
  - MPIA (Max-Planck Astronomy): Travel to Chile
  - Nikhef: paying for electricity from renewables (from a large provider who sells also a large amount of fossil fuel electricity)
  - Fermilab: Extremely $CO_2$-intensive energy sources

Scope 1: gases
Scope 2: electricity
Scope 3: the rest




2019 data, save MPIA (2018), and ETHZ business travel (average 2016-2018).

# Computing

7 AFFORDABLE AND CLEAN ENERGY 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE 12 RESPONSIBLE CONSUMPTION AND PRODUCTION 13 CLIMATE ACTION

- **Hardware:**
  **Manufacturing 50% - 80% of a devices CO2e footprint (server vs. laptop)**
  → Infrastructure to **keep, reuse, recycle, repair**! Extend use lifecycle

- **Infrastructure:**
  **Well managed, centralized systems optimized for specific (HEP) applications key to address challenges**
  → Optimized PUE (=Power Usage effectiveness → Total Power/Energy used by IT)
  → Current **best centres:** 1.05-1.2 mainly due to heat recovery from cooling system for heating **(HECAP+ best practice examples: GSI green cube 1.07, CERN data centre: 1.5 (1.1 planned), Swiss National supercomputing (1.2 at 25% full load)**
  → world average ~1.55, WLCG assumed 1.45
  → well maintained data centres reacting to production and other grid loads, can help balance grid

- **Software:**
  **HECAP+ Code relies on libraries and public codes, general frameworks and software infrastructure provided by experts in the experiments.**
  → Likelihood Inference Neural Network Accelerator (LINNA) for efficiency saved **$300,000 in energy costs and around 2,200 tCO2** in first-year for Rubin Observatory's Legacy Survey of Space and Time (LSST) analyses (https://dx.doi.org/10.1088/1475-7516/2023/01/016)
  → **Dedicated efforts can have a huge impact and directly measurable!**

# Energy: Low Carbon Sources

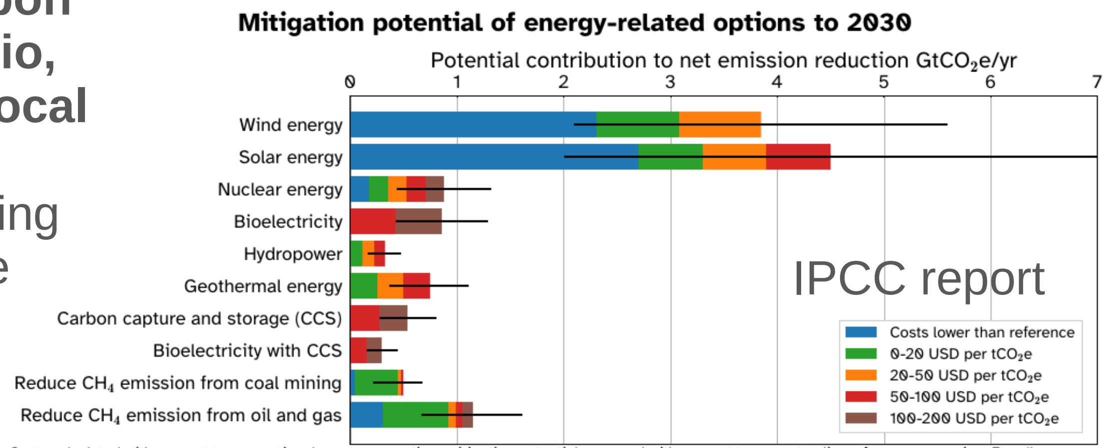
- **Procuring energy from low carbon sources (wind, solar, nuclear, bio, hydropower) relies heavily on local circumstances and supplier**
  → renewable energy might hit ceiling
  → sometimes unclear, if purchase indeed promotes green energy

- **Case study: Solar@CERN**
  → CERN has 653 buildings with a total roof area of 421,000 m² (red)

  → approximately 80 GWh annual electricity generation potential

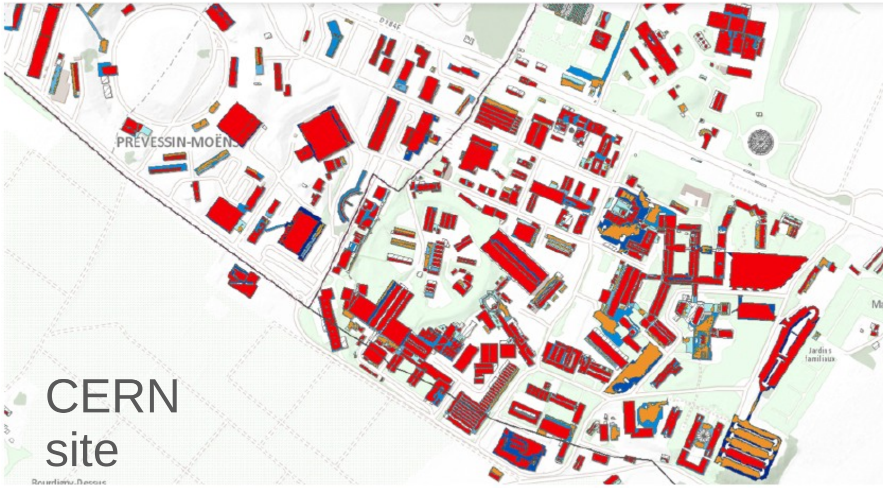
  → 18% of CERN's basic (non-LHC) electricity demand could be produced locally with solar power. Other projects are conceivable

  → SESAME: fully solar powered




Costs calculated with respect to conventional power generation; mitigation potential assessed with respect to current policy reference scenarios. For all measures save emissions reductions, the cost categories are indicative, and estimates depend heavily on factors such as geographical location, resource availability and regional circumstances. Relative potentials and costs will vary across countries and in the longer term.

**factor ~12 in 7 years required**



# Energy: Savings

- **Energy savings necessarily need to be dealt with also under the other topical headers**
  → e.g. computing, technology

- **Needs “only” a factor of 2 in 7 years**

  →but significant development effort compared to scaling up from-the-shelf renewable energies

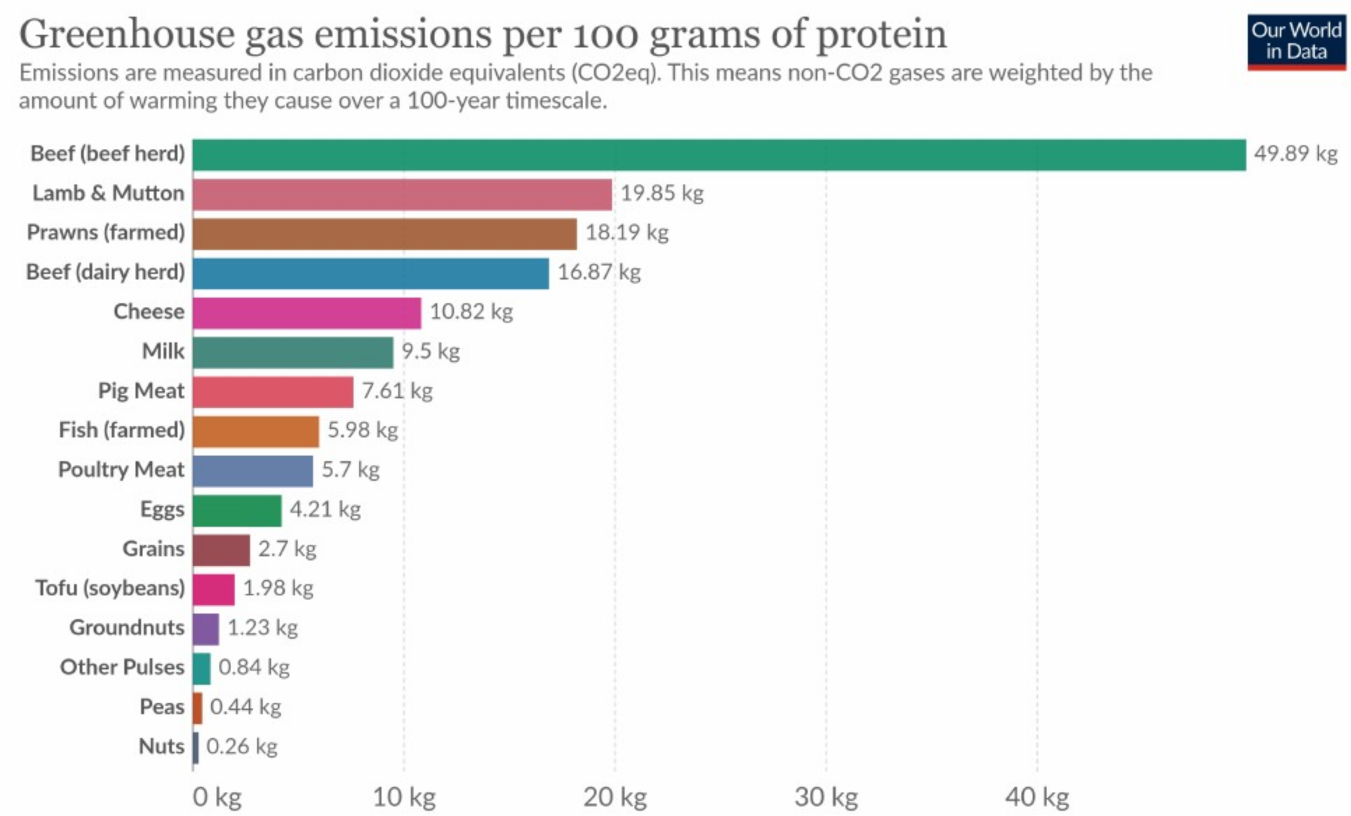
  → e.g. Cornell-BNL ELR Test Accelerator Facility (efficient accelerator design)

  → e.g. plasma wakefield acceleration

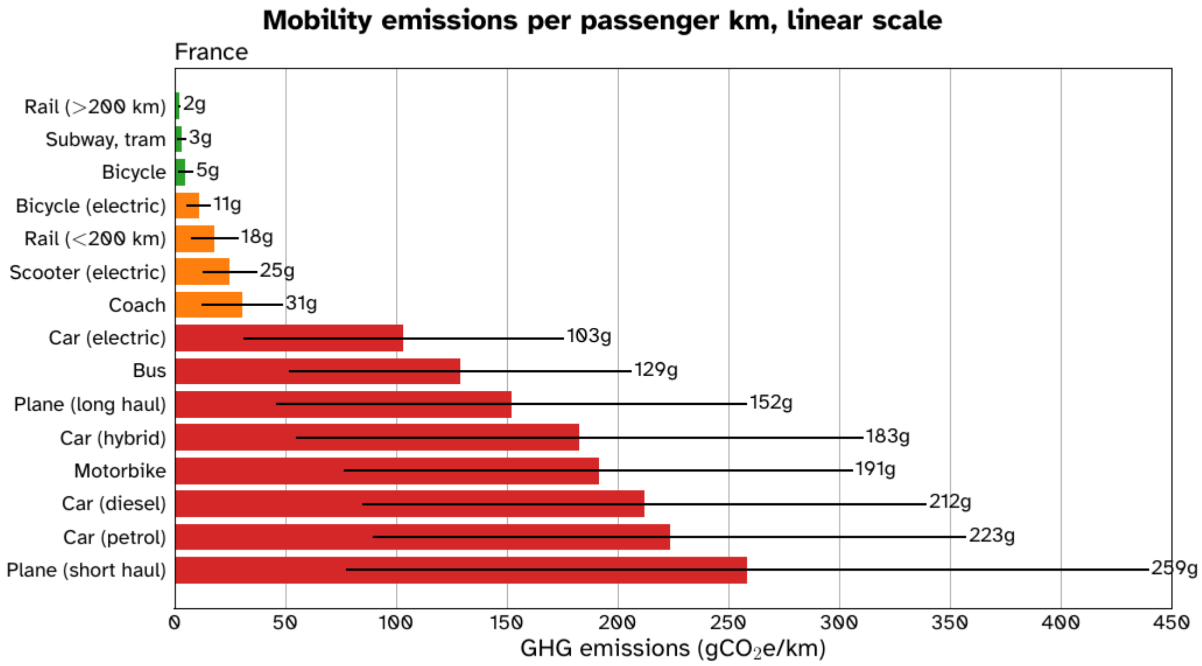
  →overview on general R&D on energy recovery linacs: doi.org/10.23731/CYRM-2022-001.185

# Food


- **Animal agriculture** responsible for just over half of GHG emissions from the food sector and accounts for ¾ of global agricultural land use but provides 1/5 of world's calories, and <40% of protein supply
- Sensitive topic, but a number of soft measure could be taken



# Mobility


- **Choice of transport is important**
  **Choice to travel is important:** Work from home / remote conferences

Global scientific endeavour such as HECAP+ will always mandate some amount of long-distance travel

**Downsides** to hypermobility, aside sustainability concerns:
→ Visa rules and high long-haul travel costs challenging, esp. for researchers from Global South.
→ Travel difficult for people with disabilities, health impairments or caring responsibilities.

# Research Infrastructure and Technology

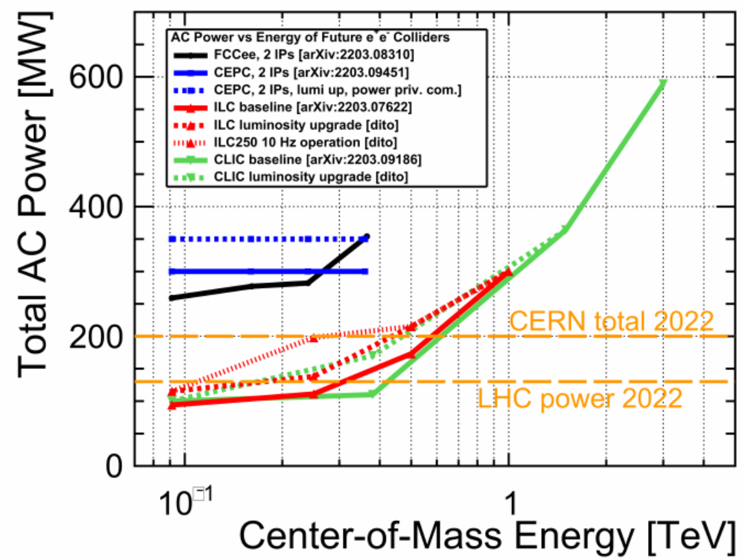
## Accounting and Reporting

- Limited availability of data on emissions and resources consumption for basic research infrastructure, existing data is not standardised

  → Overall assessments of sustainability and comparisons of individual technologies challenging.

- **Implementation of effective life cycle assessment across the HECAP+ community could provide data for ongoing assessment of technologies and research infrastructure projects**

- A number of plannend and finalized assessments:
  → European Southern Observatory (ESO)
  → Giant Radio Array for Neutrino Detection
  → Relativistic Ultrafast Electron Diffraction and Imaging (RUEDI) facility (STFC)
  → Compact Linear Collider (CLIC)




- **French lab initative: https://labos1point5.org**

# Research Infrastructure and Technology

- **Gases**

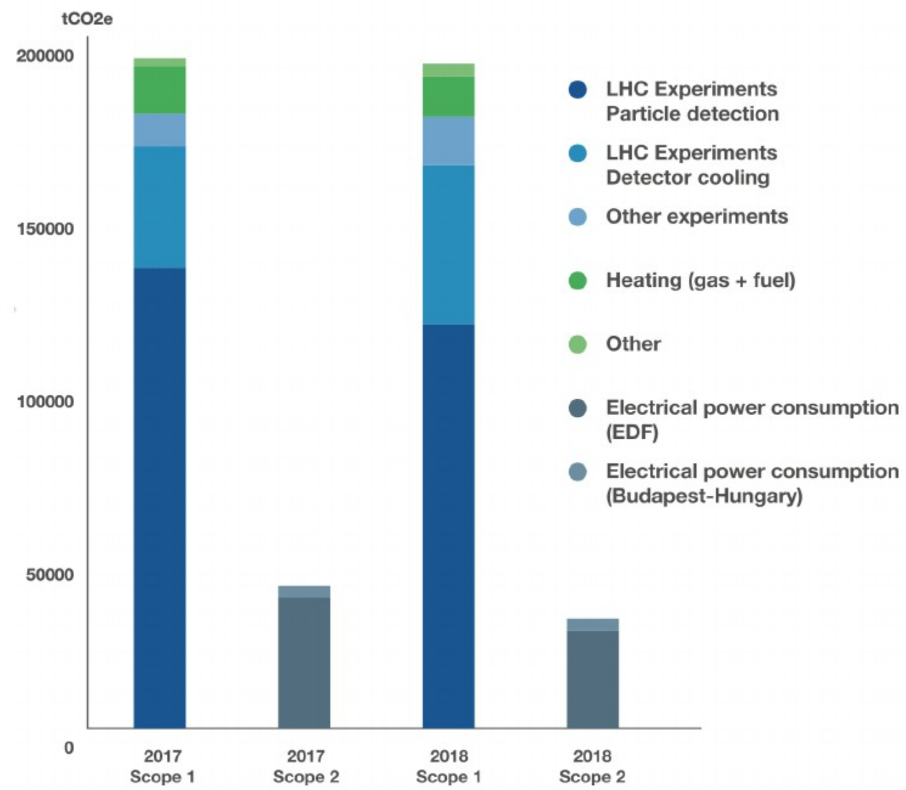
- Greenhouse Gas (GHG) emissions from gases other than $CO_2$ are a major driver of emissions at CERN

- Main cause are RPC chambers in ATLAS and CMS as they contain HFC-134a (due to large areas, ***but also Ship and Dune plan RPC muon chambers***)

- HFC emissions are 6% of the Swiss emissions, about twice the size of Luxembourg's and a bit less than half of Latvia's emissions (2017-2018)

- Future LHC detectors (Phase-II Upgrades) will switch to CO2 cooling

- Gas replacements less obvious, but active research on replacement gases ongoing



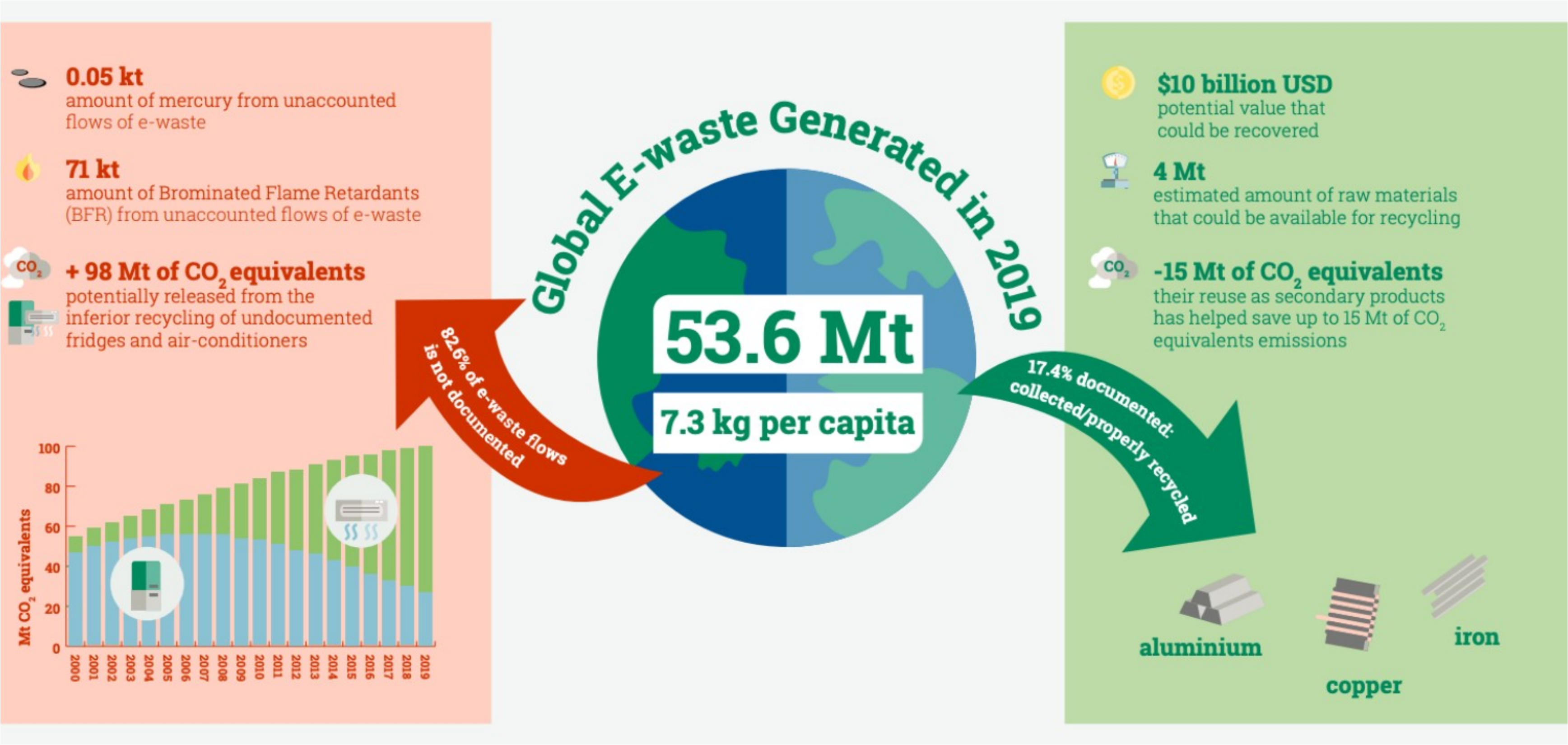

| Name | Chemical Formula | Lifetime [years] | Global warming potential (GWP) [100-yr time horizon] |
|---|---|---|---|
| Carbon dioxide | $CO_2$ | – | 1 |
| Dimethylether | $CH_3OCH_3$ | 0.015 | 1 |
| Methane | $CH_4$ | 12 | 25 |
| Sulphur hexafluoride | $SF_6$ | 3,200 | 22,800 |
| Hydrofluorocarbons (HFCs) | | | |
| HFC-23 | $CHF_3$ | 270 | 14,800 |
| HFC-134a | $C_2H_2F_4$ | 14 | 1,430 |

# Resources

- Procurement accounts for almost two-thirds of annual emissions at CERN and probably a similar size for other institutions
- **Mined materials** have largest impacts, materials used in HECAP+ experiments are produced with high environmental and societal costs (e.g., cobalt for magnets, rare earths for permanent magnets, niobium)
- Formal discussions of use and impact at recent workshop on Rare Earth Elements: iFAST - https://indico.desy.de/event/35655
- **Best practise:**
**CERN is in the process of defining a new environmentally responsible procurement policy**
- Sustainability certification from suppliers, with highest impacts

# Waste

- ~3% of global GHG emissions is due to solid waste disposal despite 60% decrease in the amount of waste land-filled in the EU
- The fastest-growing portion of EU waste output is E-waste → Improving life time here is key (EU legislation incoming)



# Some conclusions

- **We (as a community) have made big progress and substantial improvements**
  (considering the constraints potentially as much as e.g. google/amazon)

- **But is it enough to achieve 50% overall reduction of CO2e?**

- **3 handles:**
  **Green energy → factor of 12**
  **Energy efficiency → factor of 2**
  **Energy saving → factor of 2**

- **Will need a hard look and many, many sacrifices**

- **Will require a concerted effort and dedicated funding**
  **→ but as a community we are certainly better placed than other fields of science (which are/will also come under scrutiny)**

**Need framework with benchmarks and goals and**
**Ability to *shape* (institutional/funding) constraints to allow achieving goals**

**Climate benchmarks that need to be met**
**(→restricted physics exploitation scenarios, what can we sacrifice?)**

# Reminder

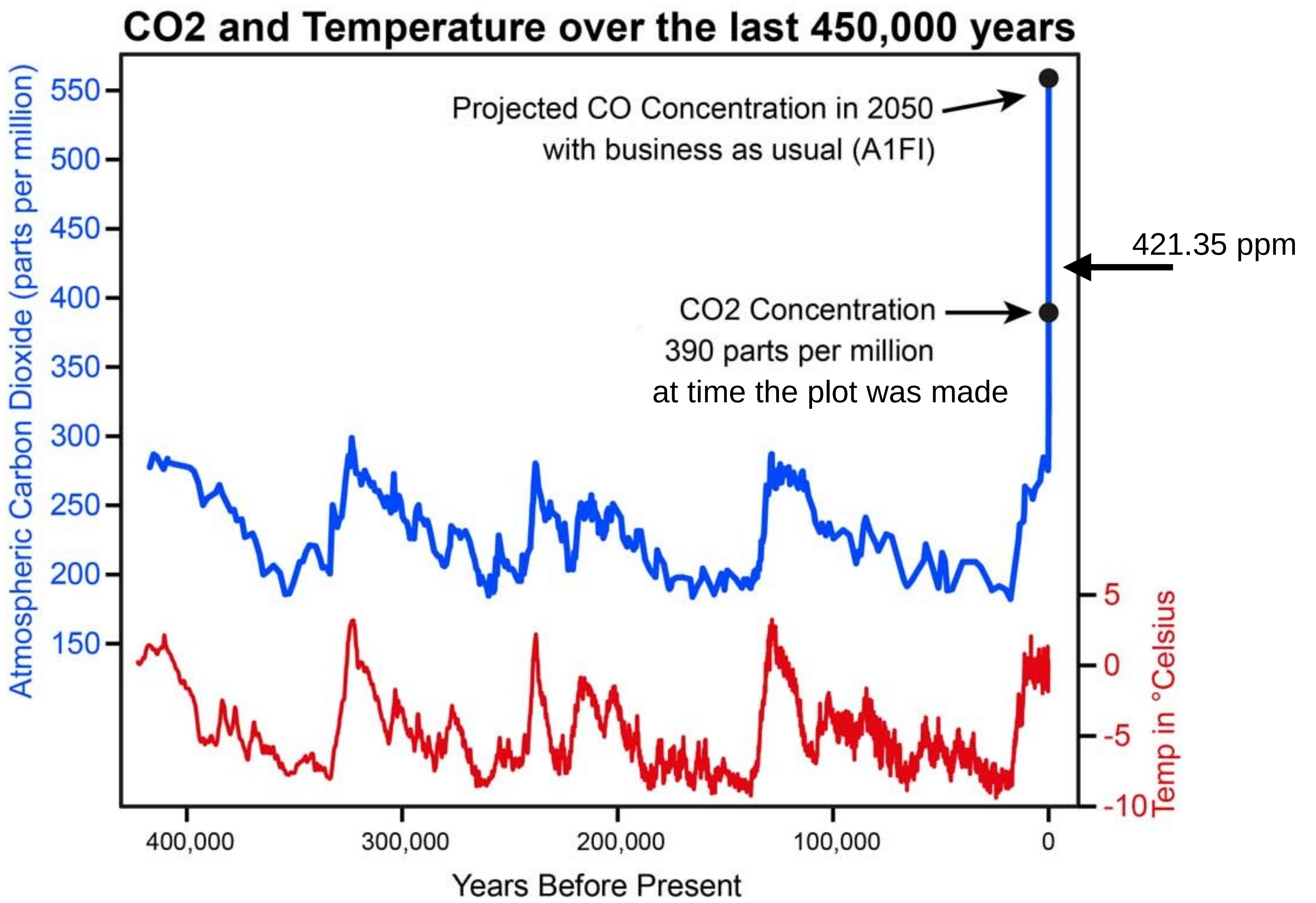
**Paris agreement is in principle legally binding**
**→ pressure on us / our savings might need to be increased**
**→ gives us negotiating power if we have a clear plan and strategy with demonstrable impacts and realistically achievable objectives in line with 1.5°C**
**→ There will be no (fundamental) science if climate breaks down***

**Assessing, reporting on, defining targets for, and under-taking coordinated efforts to limit our negative impacts on the world's climate and ecosystems must become an integral part of how we plan and undertake all aspects of our research.**

* „We predict with high confidence the [ Atlantic Meridional Overturning Circulation (AMOC)] tipping to happen 2025 – 2095 (95% confidence range, 15 Feb 2024) https://www.nature.com/articles/s41467-023-39810-w


Thank you

# Climate Change: We are outside the “normal” range



# What are the current impacts

- We see impacts of rising temperatures: Drought, floods, high temperatures, severe weather events **with billions of damages**

- **Storm Daniel** - deadliest Mediterranean tropical-like cyclone:
  - more than two billion euros in damage,
  - devastation in Greece's most fertile plain (20% of harvest destroyed with also long-term damage to fields due to silt)
  - more than 4000 death in Lybia
  - up to 10-50 time more likely due to climate change

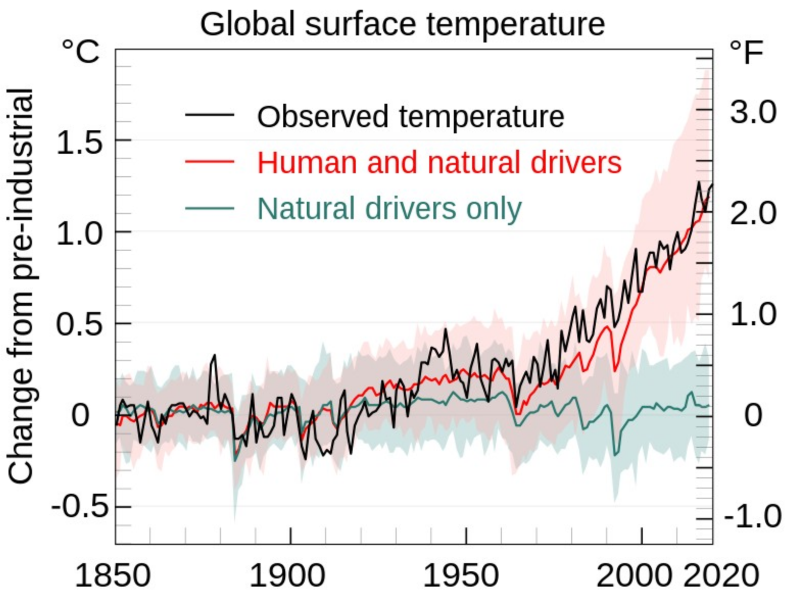
- Whilst not all of these extreme weather events are caused by climate change, their occurrence will get more and more frequent

# Weather or Climate?

- Whilst extreme weather events have a finite probability and therefore “just” can happen, this **finite probability is strongly influenced by climate conditions**

  → ”extreme event attribution / attribution science”→ new field of study in meteorology and climate science using statistical methods and concepts not completely foreign to particle physicists.

- Using the framework of attribution science, the current level of climate change is fully attributed attributed to human activity




- Climate sets the probability (like a cross-section)
- Weather is a single event (like a collision) drawn from that cross-section
- Can attribute probabilities of (signal or background -- or rather human-made versus natural climate) to a single weather event

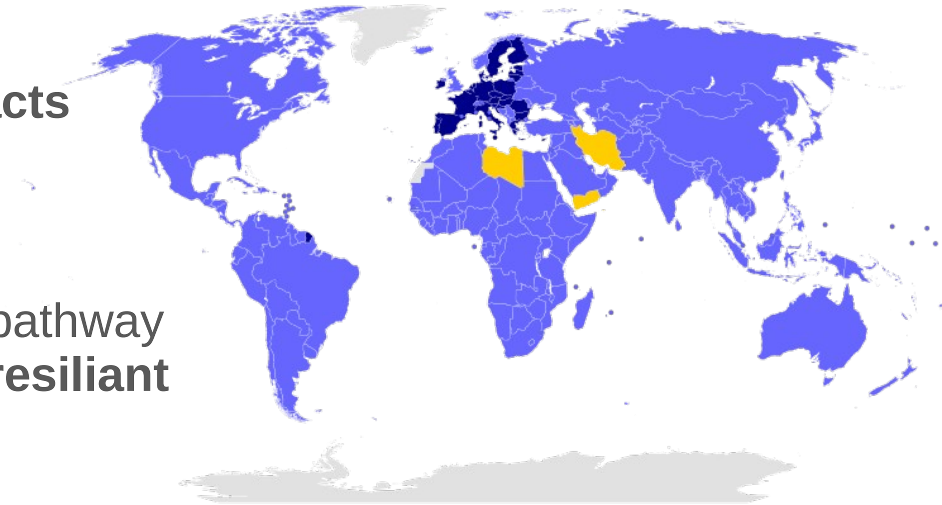
# Political consequences

- **The 2015 Paris Agreement**
  → Drafted 30 November – 12 December 2015 in Le Bourget, France
  → Effective 4 November 2016 after more than 55 UNFCCC parties, accounting for 55% of global greenhouse gas emissions had ratified and acceded
  → 195 signatories

- Hold global average temperature **well below 2°C** above pre-industrial levels and to pursue efforts to **limit the temperature increase to 1.5 °C**

- Push ability to **adapt to adverse impacts and foster climate resilience**

- **Make finance flows consistent** with pathway towards **low emissions and climate-resiliant developement**



Yellow: signed, not ratified

# Who are the emitters?

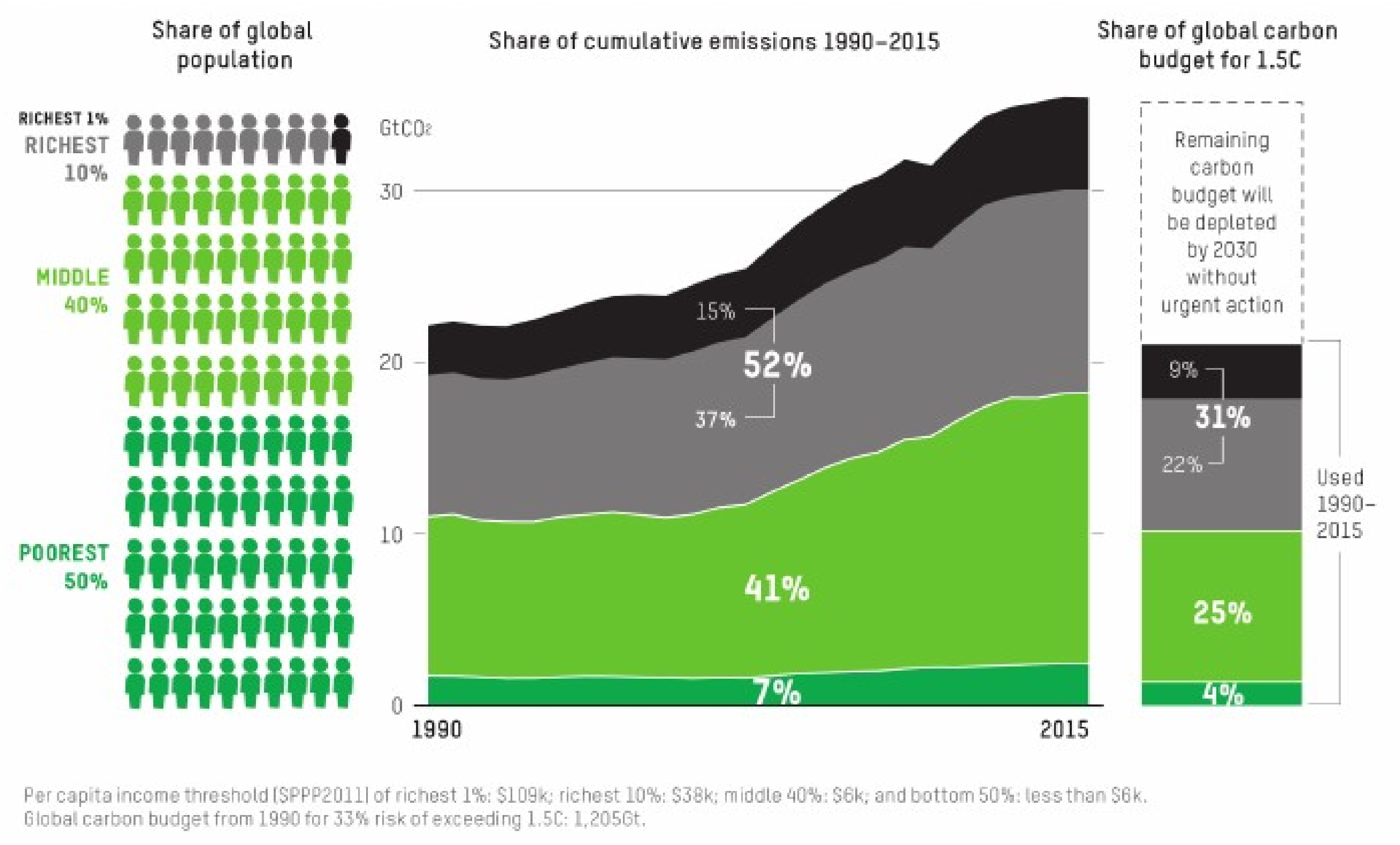



**Figure 1.2:** Share of cumulative emissions from 1990 to 2015 and use of the global carbon budget for 1.5°C linked to consumption by different global income groups. Figure reproduced from Ref. [9] with the permission of Oxfam.[a]

# What does this mean for particle physics?

Options:

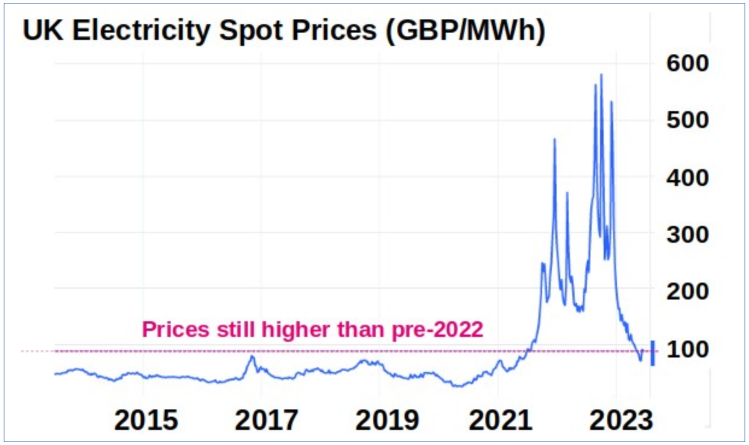
**1) Expand CO2-free energies (factor 12)**
Renewable power for computing: processors and cooling;
Consider district heating and site selection;
Job scheduling according to energy availability; ...

**2) Increase energy efficiency (factor 2)**
Optimised processors (clocks, GPUs),
architecture, cooling system,
software, ...

**3) Save energy (factor 2)**
Prioritise research questions
Optimise debugging, statistics and precision;
Modular and reusable software;
Modular and repairable hardware, reduce purchases;

# Can’t we just use green energy and not do anything?

- **Electricity prices are volatile**
- **EU projections from 2016 predict about 25% rise of prices (consumer)**
  → Cut 25% of the physics?
- And it’s not just electricity prices but also hardware




- **Costs of computing infrastructure evaluation 2032 (with 2021 as index)**
- Installed hardware based on computational requirements (15-20% increase/yr), Unit costs (10-20% decrease/yr), 5 years of lifetime
  → **Costs could rise between 0.5 – 5.5 (best vs. worst case scenario)**
- Electricity costs (based on average) consider inflation, power efficiency (30% decrease → no improvement), high prices+high inflation versus both dropping
  → **Costs could rise ranging by 1.6 – 3 – 7 (based on mid capacity)**

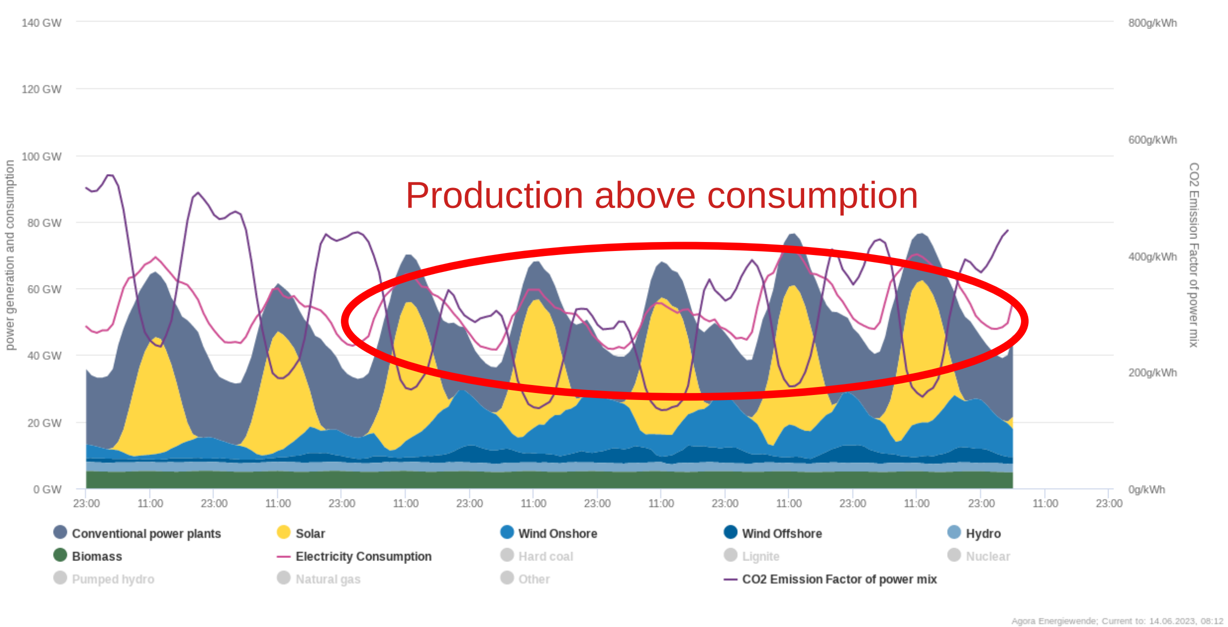
Chris Brew (RAL)

# Infrastructure

- **Usage of carbon-free energy paramount**

  → “Own” production (requires investment into solar + potentially storage)

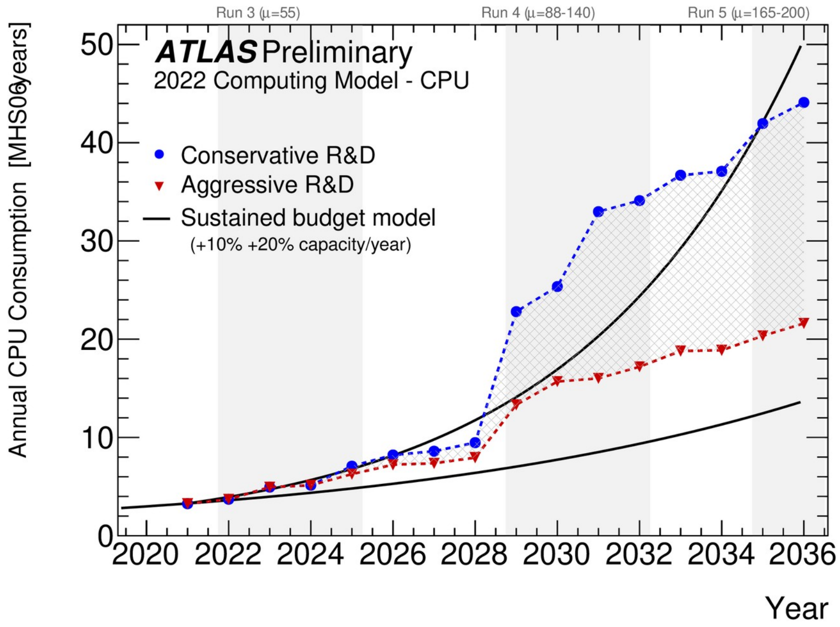
  → Regulation of load according to prices (“Follow the money” – R.W.), prices can be negative, but requires special tariff that can be used → well maintained data centres reacting to production and other grid loads, can help balance grid

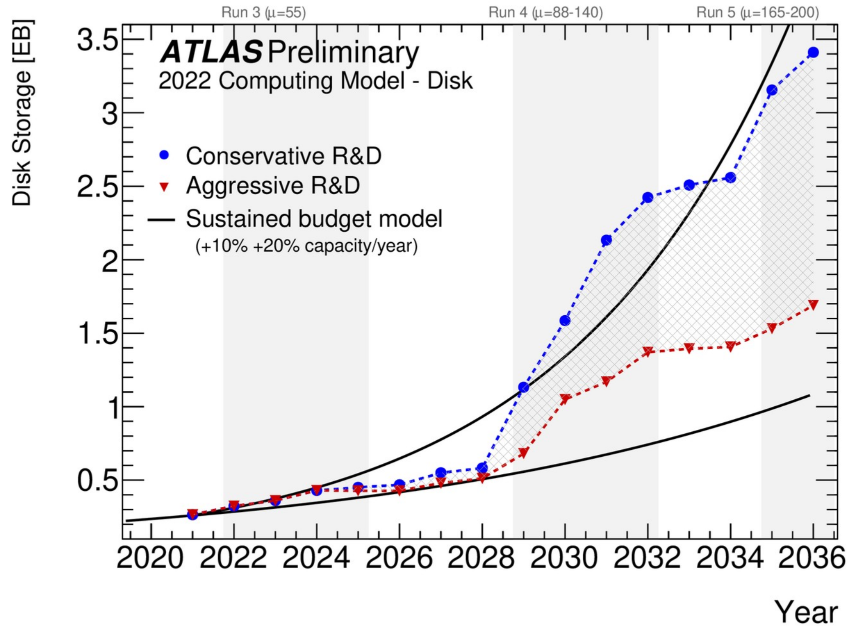



Lancium Computing centre
https://indico.desy.de/event/37480/contributions/138296/attachments/82407/108618/2023-05-30%20Concrete%20Action.pdf

# Computing

7 AFFORDABLE AND CLEAN ENERGY · 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE · 12 RESPONSIBLE CONSUMPTION AND PRODUCTION · 13 CLIMATE ACTION




→ **Increase by a factor of 10**

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/UPGRADE/CERN-LHCC-2022-005/

Projected evolution of compute usage from 2020 until 2036, under the conservative (blue) and aggressive (red) R&D scenarios. The grey hatched shading between the red and blue lines illustrates the range of resources consumption if the aggressive scenario is only partially achieved. The black lines indicate the impact of sustained year-on-year budget increases, and improvements in new hardware, that together amount to a capacity increase of 10% (lower line) and 20% (upper line). The vertical shaded bands indicate periods during which ATLAS will be taking data.

# “Classical” Software sustainability

- General sustainability => Re-useability and training

  → Institution for Research and Innovation in Software for High Energy Physics (IRIS-HEP) [44]

  → HEP Software Foundation

- **May provide an important platform for accelerating the inclusion of environmental considerations in software development. (examples e.g. are Sherpa speedup!)**

- Underwriting of FAIR principles: software (and data) should be Findable, Accessible, Interoperable and Reusable

- Sharing optimization workflows, **consulting services** for smaller experiments

# Agriculture impact

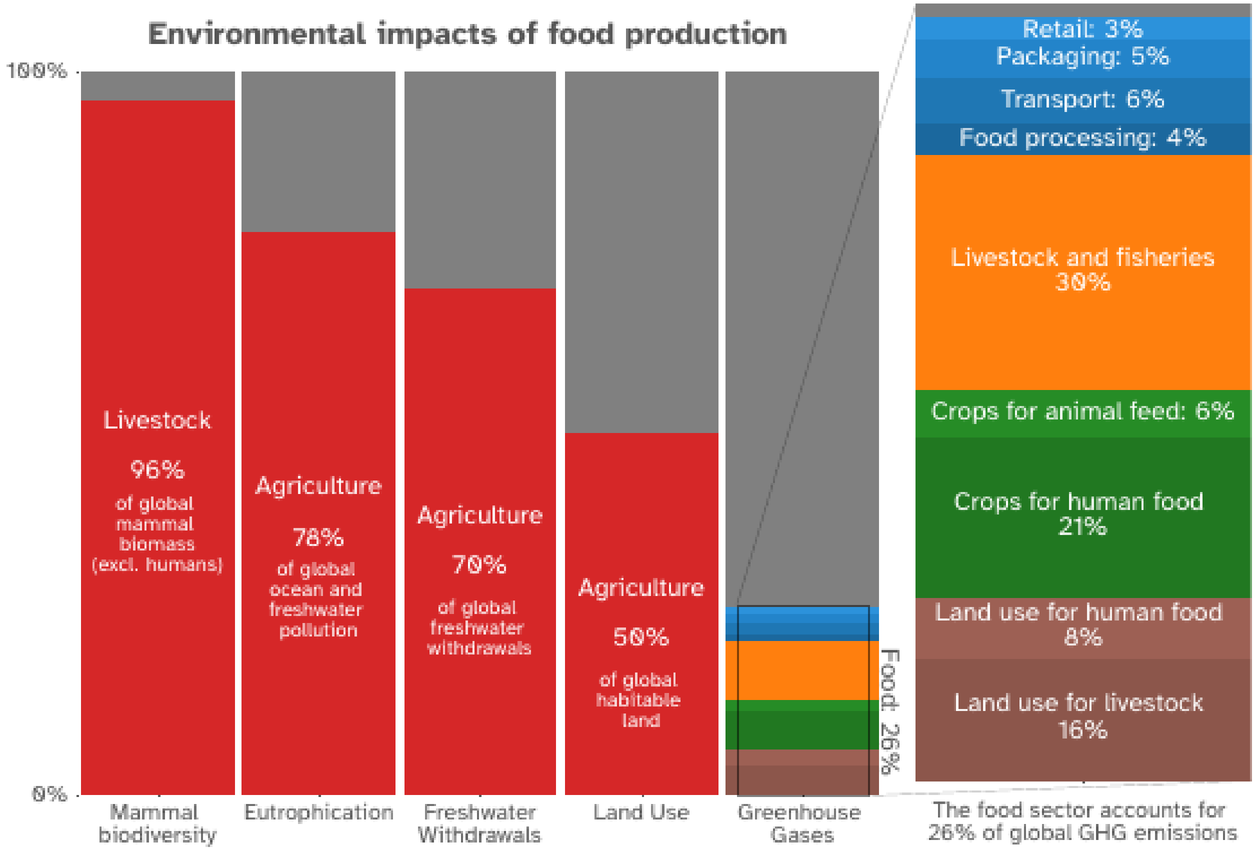



**Figure 4.1:** Environmental impact of food production, with fine-grained partitioning of GHG emissions by food sector. Figure modified from Ref. [119] under the terms of the Creative Commons Attribution 4.0 International (CC BY 4.0) license, based on data from Refs. [114] and [120].