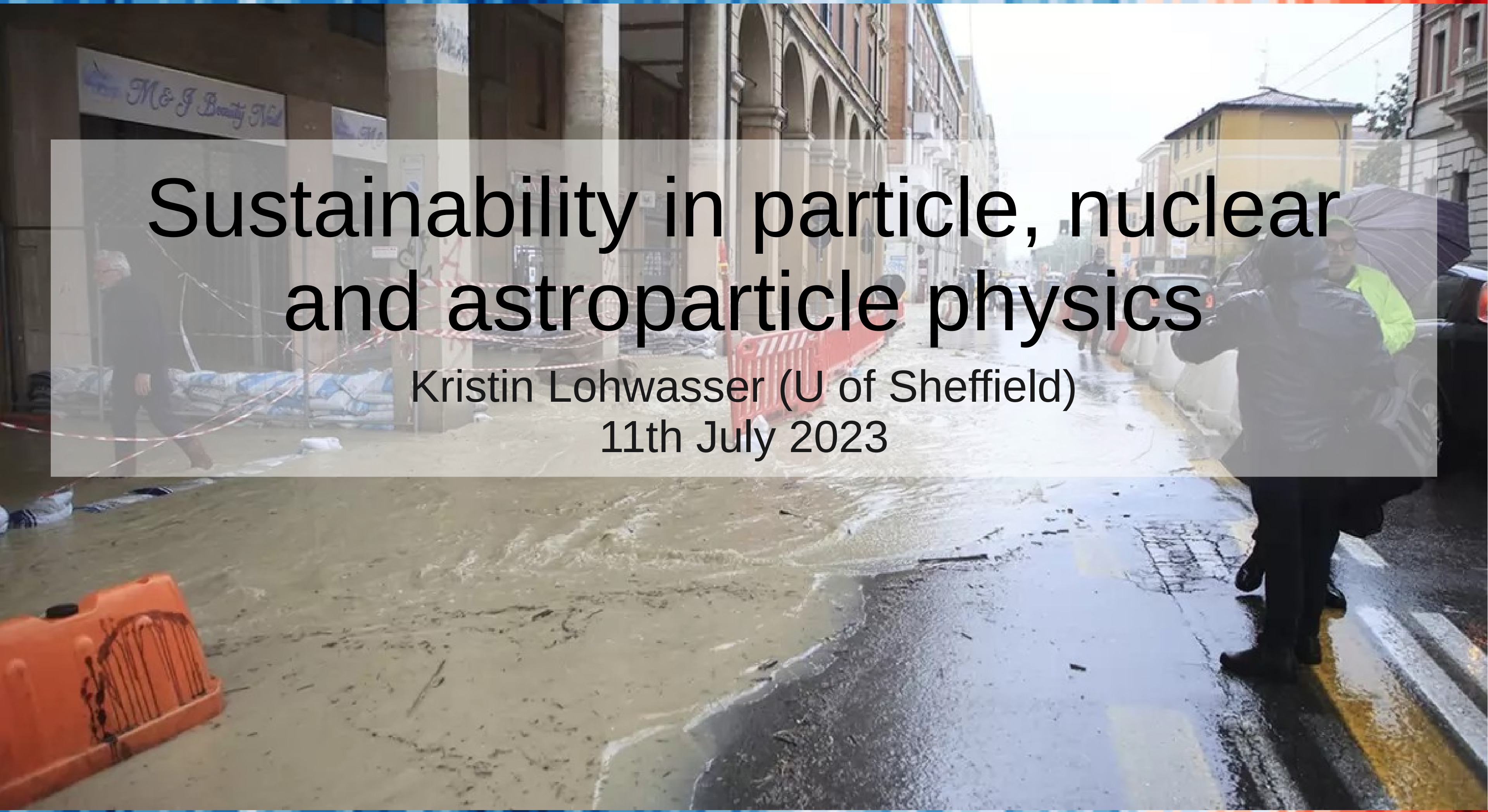
Sustainability in particle, nuclear and astroparticle physics

Kristin Lohwasser (U of Sheffield)

11th July 2023



Climate Change up close

- We see impacts of rising temperatures: Drought, floods, high temperatures, severe weather, e.g. here in Emilia Romagna in Mai 2023:

  →Rainfalls of 7 months in 2 weeks, in some places up to 6 months of rains in 36 hours
  → **at least 15 people dead**, 400 landslides, 42 cities flooded, **damage caused: €7 billion**
  → https://en.wikipedia.org/wiki/2023_Emilia-Romagna_floods

  And that is not even the most recent natural disaster, e.g. the first severe summer storm Polly hit the Netherlands earlier this month with an estimated **€100 million** of damages

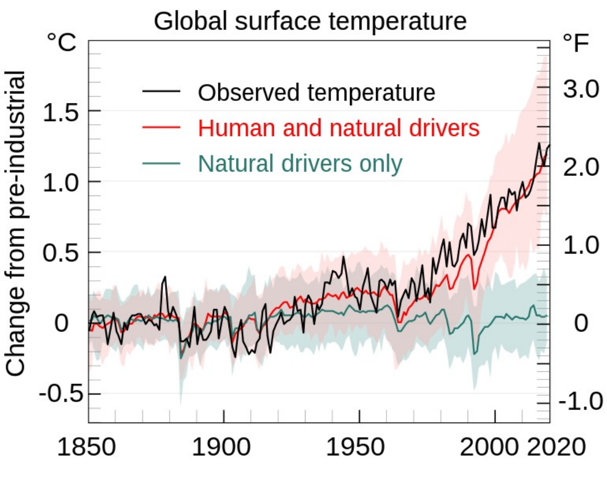
- Whilst not all of these extreme weather events are caused by climate change, their occurrence will get more and more frequent

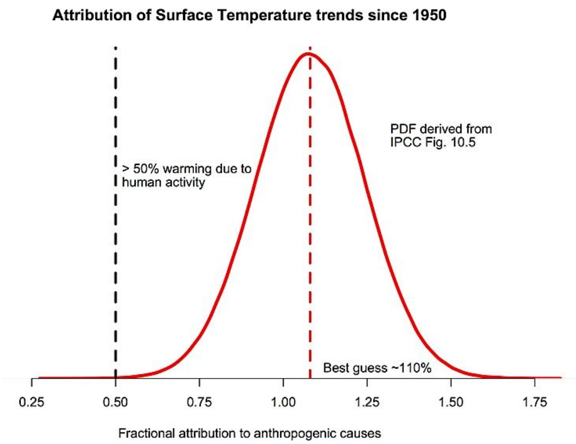
But is it Weather or Climate?

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

  → studied in 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.
  → https://en.wikipedia.org/wiki/Extreme_event_attribution

- 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

* should be honest and say since I first created these slides, studies have shown, limited impact of climate change on Bologna floods, though verdict on Dutch storms seems to be still out. Still good illustration of what weather desasters are. https://www.worldweatherattribution.org/limited-net-role-for-climate-change-in-heavy-spring-rainfall-in-emilia-romagna/

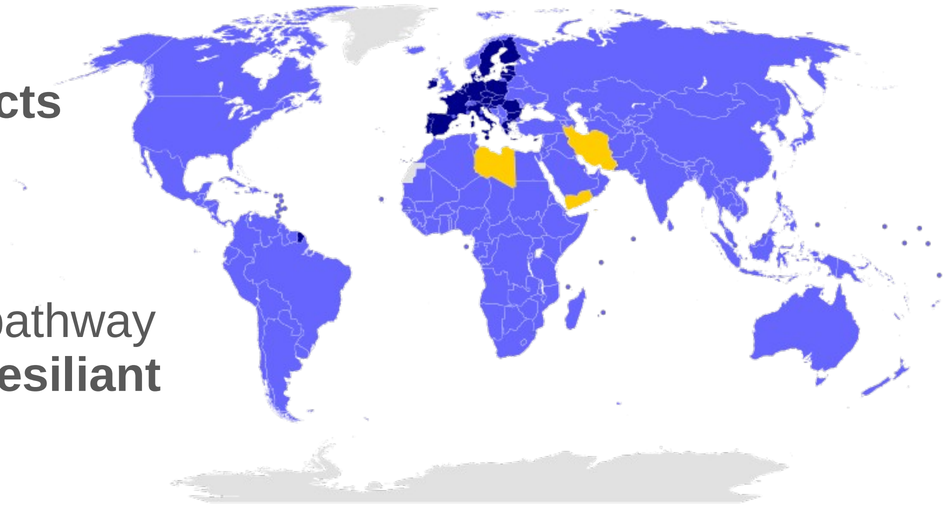
Political consequences

- **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**

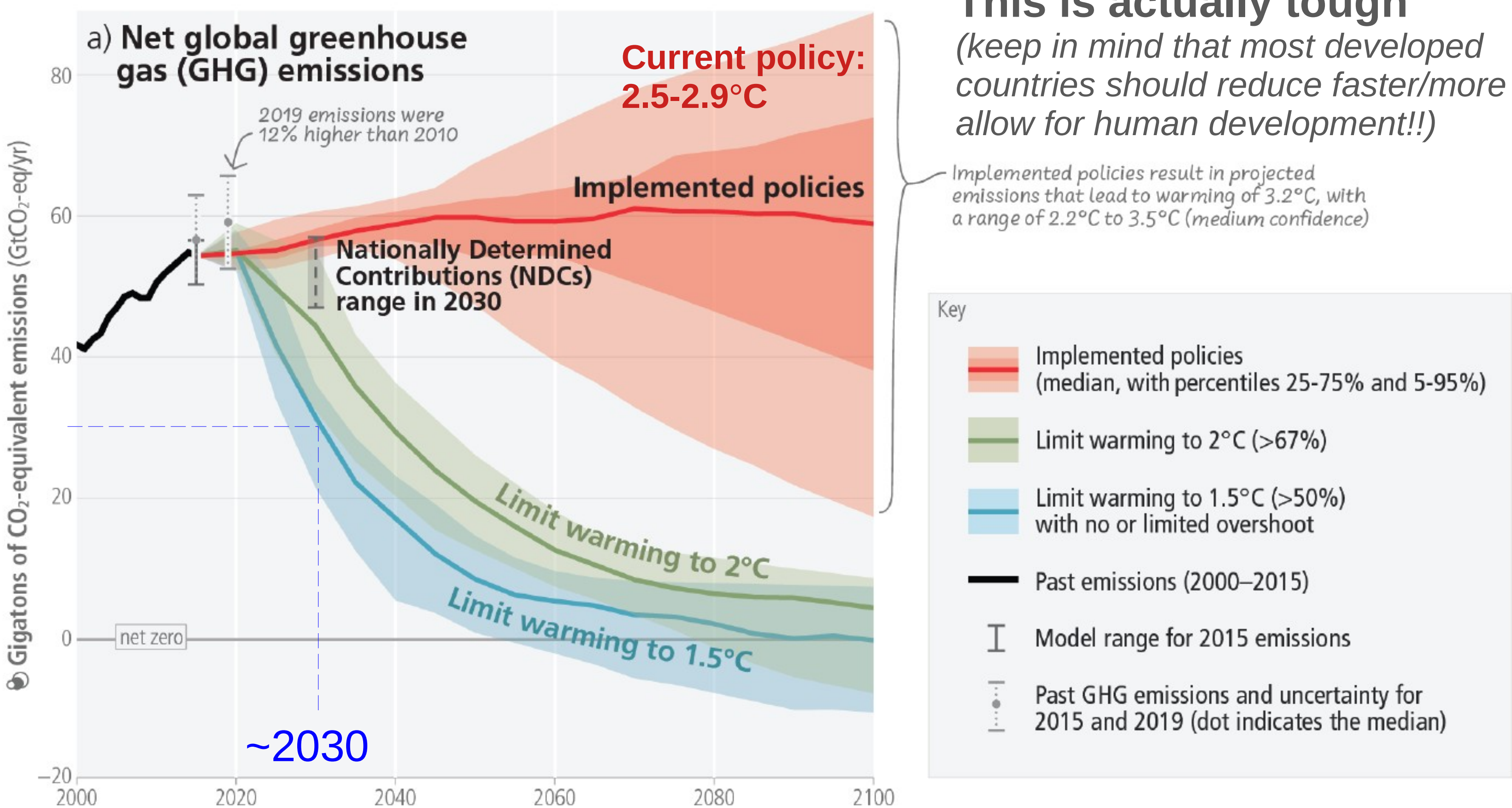


Yellow: signed, not ratified

Translation of Paris into Goals

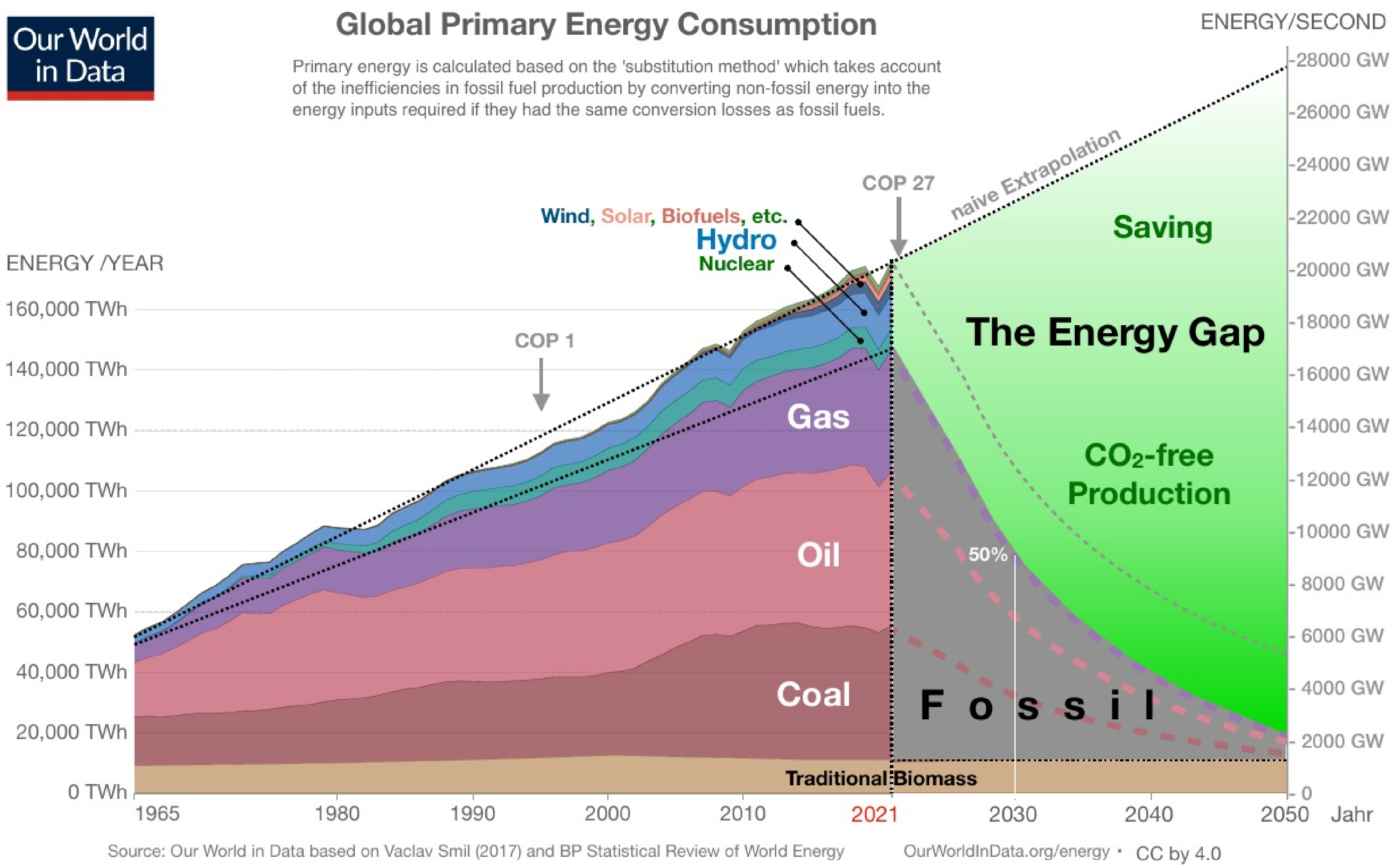
- **Reduction to zero emissions around 2100**
  → A lot of time?
  → 50% of the reduction should be achieved by ~2030 → **in 7 years**

This is actually tough
(keep in mind that most developed countries should reduce faster/more to allow for human development!!)

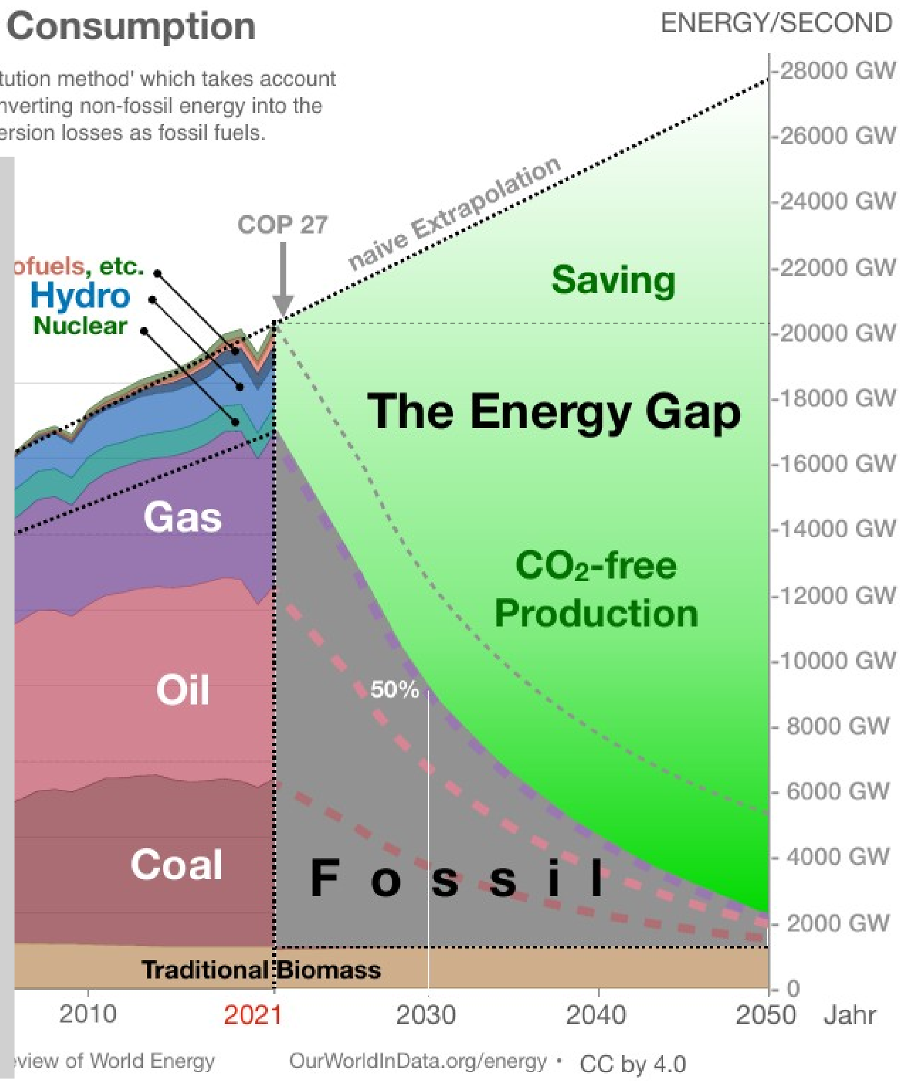


IPCC report: https://www.ipcc.ch/report/ar6/syr/

The energy gap



The energy gap



Options:

1) Expand CO2-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

For options 2)+3) an increase in renewables of a factor of 3 needed to cover increase from naive extrapolation is needed

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)

- Reports in alphabetical order on:
  → Computing
  → Energy
  → Food
  → Mobility
  → Research Infrastructure and Technology
  → Resources and Waste
  (including also **Best practices** and **Case studies**)


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.

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.

Other initiatives in Particle Physics

- It’s not a new topic: https://indico.esrf.fr/event/2/
  Sixth Workshop on Energy for Sustainable Science at Research Infrastructures

- **Indeed it has become a big topic even at the recent CHEP conference with activities triggered by the 2022 energy crisis**

- All European Academies (ALLEA) Working Group on Climate Sustainability, Report: https://doi.org/10.26356/climate-sust-acad

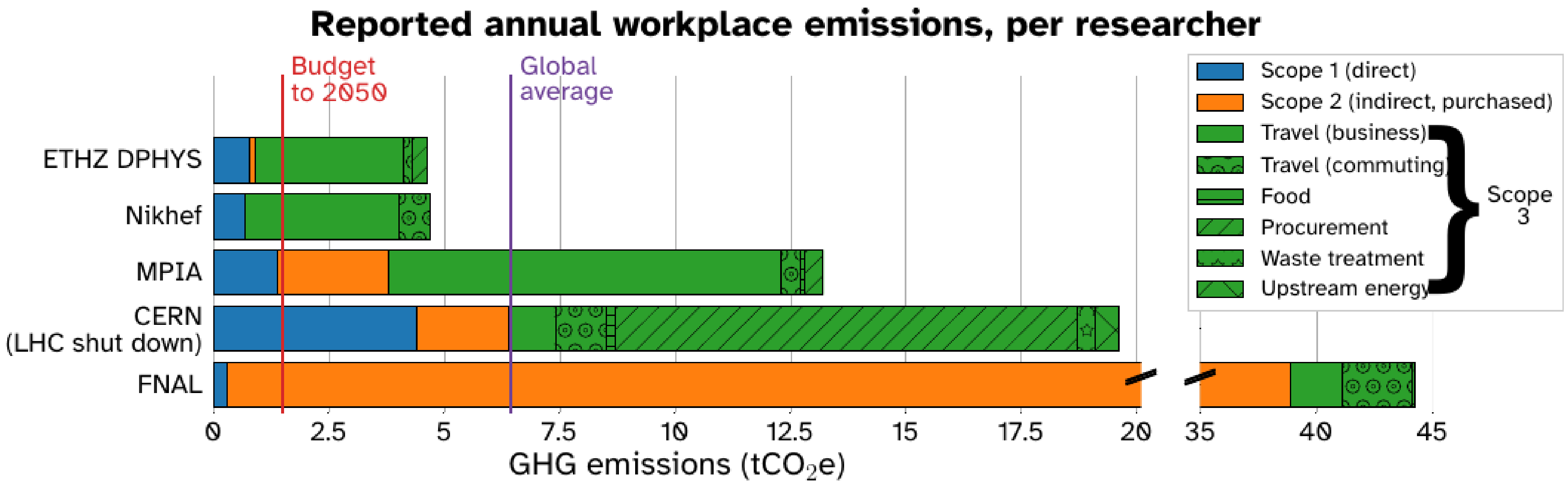
- Snowmass 2021: “Climate impacts of particle physics,” https://doi.org/10.48550/arXiv.2203.12389

- The young High Energy Physicists (yHEP) association (Germany) published "Recommendations on improvement of environmental sustainability in science": https://yhep.desy.de/sites/sites_custom/site_yhep-association/content/e61887/e122133/yHEPStatementonenvironmentalsustainabilityinScience_final.pdf

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)

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



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

Chap. 1.1 Best practise

- Nikhef (Dutch National Institute for Subatomic Physics in the Netherlands) has created a detailed roadmap to reduce its footprint https://www.nikhef.nl/wp-content/uploads/2022/08/Routekaart-Duurzaam-Nikhef-DEF.pdf
- Current footprint (2019): 1082 tCO_2e
- ~75% from travel
  15% from heating its central with gas
- Comprehensive plan to reduce emissions until 2030 with intermediate 2025 target
- Renovation of main building and using heat from nearby data centre will replace gas
- Air travel to be reduce by 50% until 2030, commuting climate-neutral

Computing: Hardware

- **Manufacturing 50% - 80% of a devices CO2e footprint (server vs. laptop)**
→ Infrastructure to **keep, reuse, recycle, repair**! Extend use lifecycle
→ staff extensive, on the level of single institution
→ on larger scale (clusters): potentially complicated to organise (especially when moving old hardware to a different cluster)

- **Use of certified products (e.g. TCO certification, though that probably already covers most of hardware)**

- **'Energy proportionality' is important:**
energy consumption should be proportional to computing performance over the full range of applications → hardware often most efficient at maximum performance load, but in practice often idle (combat with scheduling)

- **→ tests needed to find optimum usage, depending on architecture**

- Potential in reducing clock frequency ~about same amount of HEP work at significantly less energy consumption

Computing: Infrastructure

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

- **Well managed, centralized systems 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

- **Centralization here helps, in particular to run hardware optimized for specific (HEP) applications**

  → (HTC versus HCP which can make local resources difficult to use)

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

  → Regulation of load according to prices, 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

Computing: Software

- **HECAP+ Code relies on libraries and public codes, general frameworks and software infrastructure provided by experts in the experiments.**

- Strict requirements posed by the computing environment.

- **Best practise:**
  → using 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)

  → Factor 50 improvement in generation time for Sherpa generator (Optimized using SWIFT-HEP software grant with software engineers)

  → ATLAS reconstruction code improves by a factor of 2 using multi-threading

- **Dedicated efforts can have a huge impact and directly measurable!**

- Need sustained effort, continued recognition and dedicated, well-trained person power → need to use leverage with experiments, mechanisms to allow ***more*** people to make a career of these efforts **within** the field

Computing

These recommendations are out of necessity most general

They are obvious → many have been already made these past couple of days

How can they be put into action (in particular institutional ones) given dependence on funding agencies, national laws, etc. ?

Recommendations — Computing

Individual actions:

- Make sustainable personal computing choices by considering the necessity of hardware upgrades, the repurposing of hardware, and the environmental credentials of suppliers and their products.
- Assess and improve the efficiency and portability of codes by considering, e.g., the required resolutions and accuracy.
- Assess and optimise data transmission and storage needs.
- Follow best practice in open-access data publishing, prioritising reproducibility and limiting repeat processing.
- Read the section on E-waste (Section 7).

Further group actions:

- Right-size IT requirements and optimise hardware lifecycles.
- Schedule queueing systems with environmental sustainability in mind, so as to maximise the use of renewables, accounting for the geographical location of servers/data centres.

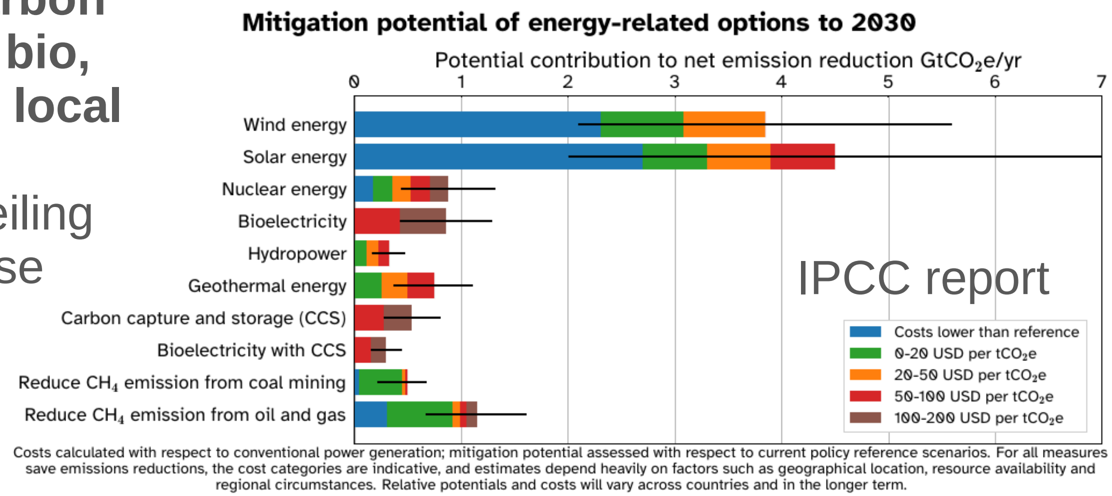
Further institutional actions:

- Ensure that environmental sustainability is a core consideration when designing and choosing sites for large computing infrastructure, such as data centres, including, e.g., the availability of renewables, the efficiency of cooling systems and the reuse of waste heat.
- Proceduralise the repair, upgrade and repurposing of existing computing, the de-inventorising of personal equipment for leaving personnel or for donation, and the responsible recycling of retired hardware.
- Select cloud computing services for their carbon emission mitigation policies.

Some of the above recommendations are based on those made by Jan Rybizki [34].

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



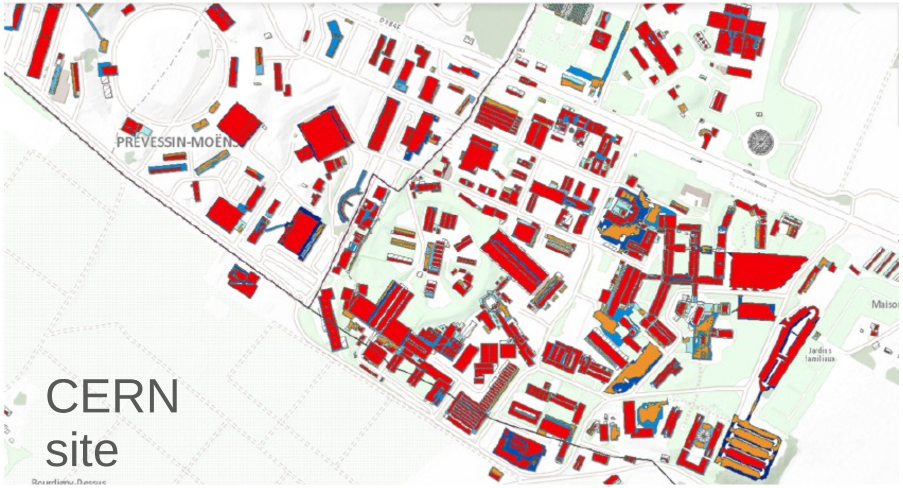
factor ~12 in 7 years required

- **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



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-shell 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

Recommendations — Energy

Individual actions:

- Save energy in all ways practicable, e.g., by avoiding unnecessary heating or cooling of workspace, and by turning off electrical items when not in use.
- Read the sections about computing (Section 2) and mobility (Section 5).

Further group actions:

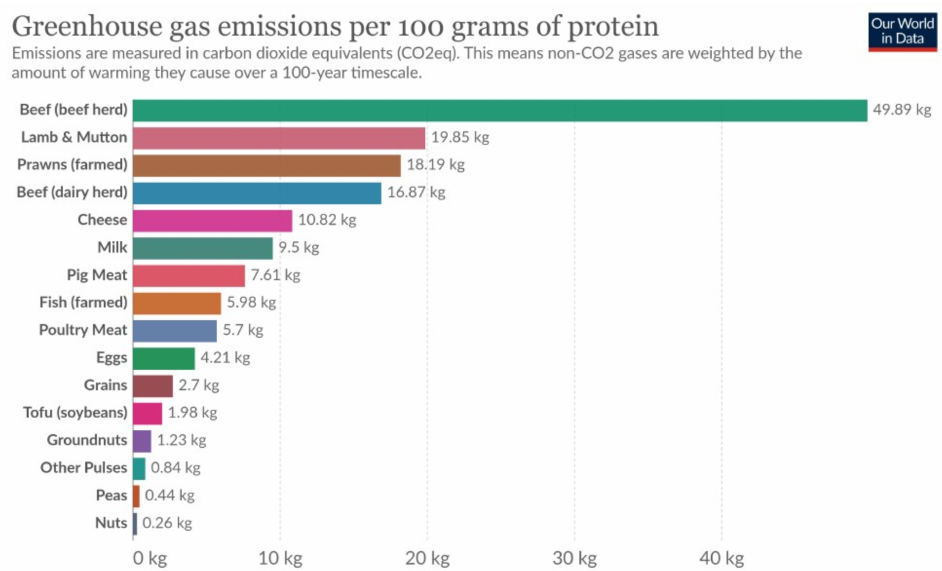
- Ensure that energy efficiency is a major focus in experimental design, and prioritise technologies that minimise consumption and maximise energy recovery.
- Monitor, report, and assess energy usage with the aim of reducing consumption and resulting emissions.
- Read the section on research infrastructure and technology (Section 6).

Further institutional actions:

- Ensure that energy efficiency is a major factor in the renovation of existing estates and the design and construction of new infrastructure.
- Prioritise moving to renewable energy sources via both local generation, and energy import and export.
- Collate and publish energy usage and emissions statistics, stratifying by source, e.g., heating, experimental infrastructure, computing, transportation, and procurement.
- Lobby for environmentally sustainable energy policy.

Food

- **Agriculture sector** uses 70% of the world's fresh water reserves and is responsible for large-scale deforestation.
- **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



Recommendations — Food

Individual actions:

- Reduce consumption of animal products, especially those that result in the highest emissions, e.g., ruminant meat, and dairy.
- Minimise food waste.

Further group actions:

- Prioritise plant-based options in conference catering, and optimise service method to reduce food waste.

Further institutional actions:

- Incentivise the consumption of plant-based products at on-site restaurants by increasing their variety and quality, and subsidising their cost.
- Highlight the environmental impact of food choices through service layout and labelling.
- Minimise food waste by providing multiple portion sizes and donating unused food.
- Read section on waste (Section 7) and limit food-service waste e.g., through industrial composting of biodegradable food containers.

Mobility: Commuting

- Heavily depends on where institute is located:

  → ETH Zurich: Urban centre with good public transport
  Practically no emissions from commuting (1/10 of business travel)

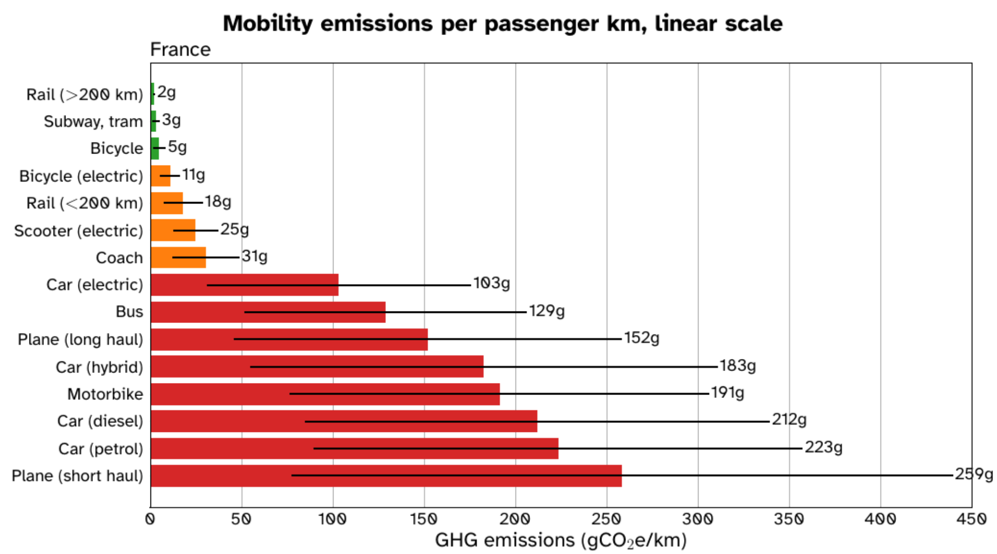
  → Fermilab / CERN: Rural (France site), poor connection, difficult to cycle
  Commuting and business travel are ~en par

- **Measures:**

  bicycle-friendly infrastructure
  (eg. showers and secured parking)

  telework

  push local authorities
  towards better public
  transit/cycling/carpool infrastructure.



- **Table with examples from institutions**

Mobility: Business travel

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

- Downsides to hypermobility, aside sustainability concerns:

  → Visa rules and prohibitive long-haul travel costs challenging, especially for researchers from the Global South.

  → Travel difficult for people with disabilities, health impairments or caring responsibilities.

- **Case studies**
  → Sustainable travel to CERN
  → Comparative travel emissions for ICHEP
  → Cosmology from Home

Recommendations — Mobility

Individual actions:

- Re-assess business travel needs, using remote technologies wherever practicable.
- Choose environmentally sustainable means of transport for daily commutes as well as unavoidable business travel, amalgamating long-distance trips where possible.

Further group actions:

- Define mobility requirements and travel policies that minimise emissions, while accounting for the differing needs of particular groups, such as early-career researchers or those who are geographically isolated.
- Re-assess needs for in-person meetings, and prioritise formats that minimise travel emissions and diversify participation by making use of hybrid, virtual or local hub participation, and optimising the meeting location(s).

Further institutional actions:

- Support environmentally sustainable commuting by improving on-site bicycle infrastructure, subsidising public transport and providing shuttle services.
- Disincentivise car travel where viable alternatives exist, facilitate car pooling, and provide on-site charging stations.
- Incentivise the reduction of business travel, e.g., by implementing carbon budgets with appropriate concessions.
- Ensure unavoidable travel is made via environmentally sustainable means through flexible travel policies and budgets, and the use of travel agents that offer multi-modal itineraries. Employ carbon offsetting only as a last resort.
- Remove any requirement on past mobility as an indication of quality in hiring decisions.
- Lobby for improved and environmentally sustainable local and regional transport infrastructure.

Research Infrastructure and Technology

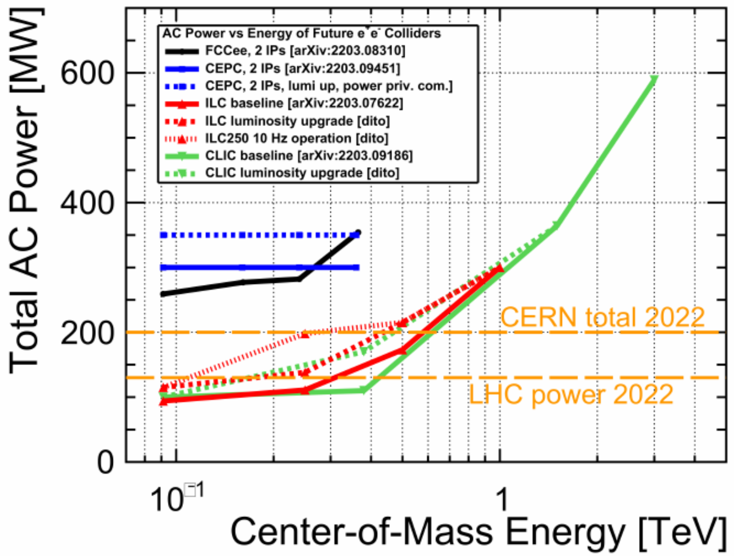
Accounting and Reporting

- 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**

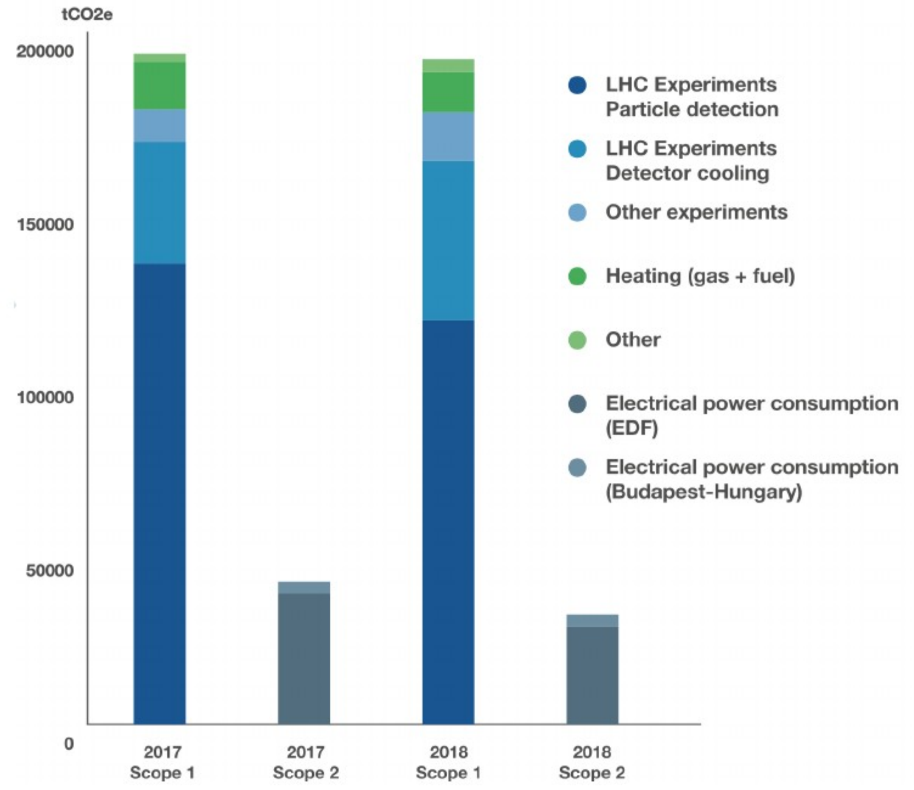
- Greenhouse Gas (GHG) emissions from gases other than CO_2 are a major driver of emissions at CERN

- 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

Research Infrastructure and Technology

- **Technological Improvements**

- Actively developed to improve carbon footprint of HECAP+

- Accelerator R&D one of the main examples

- Best practise: LHCb Upgrade TDR
  with heat recovery to hear Ferney-Voltaire
  removal of GEM detectors with large emissions output, new computing centre, work on software
  → **comprehensive work programme**

Recommendations — Research Infrastructure and Technology

Individual actions:

- Seek out new innovations and best practice.
- Rethink how the impact of frequently-used equipment can be reduced, and reduce "over-design" by reassessing safety factors and other margins to reduce resource consumption.
- Read section on resources and waste (Section 7).

Further group actions:

- Ensure that environmental sustainability is an essential consideration at all stages of projects, from initial proposal, design, review and approval, to assembly, commissioning, operation, maintenance, decommissioning and removal, using life cycle assessment and related tools.
- Engage with industrial partners who exemplify best practice and sustainable approaches.
- Appoint a dedicated sustainability officer to oversee project development, and institute regular meetings with a focus on environmental sustainability.

Further institutional actions:

- Critically assess the environmental impact of materials, construction and the operational life cycle as an integral part of the design phase for all new infrastructure.
- Provide training opportunities, required tools and technical support to assess and improve the environmental sustainability of project life cycles.
- Recognise and reward innovations that minimise negative environmental impacts, regardless of revenue.
- Promote knowledge exchange on sustainability initiatives between groups and institutions, including decision-makers, designers and operators of projects, setups and infrastructure.

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, to be implemented in 2023

- 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 landfilled in the EU
- The fastest-growing portion of EU waste output is E-waste → Improving life time here is key (EU legislation incoming)
- **Case studies / best practise:**

  → Concrete recycling at DESY

  → plastic-free conference with reusable tableware (according to UN life-cycle analysis it consistently outperforms single-use tableware in all categories, except water usage)

Recommendations — Resources and Waste

Individual actions:

- Limit purchases and consider environmental credentials such as repairability and recyclability of products in purchasing decisions.
- Service appliances regularly; share, repair, reuse and refurbish to minimise waste; sort and recycle.
- Read the sections on computing (Section 2), energy (Section 3), food (Section 4), and research infrastructure and technology (Section 6).

Further group actions:

- Adopt life cycle assessments and associated tools to assess environmental impact of all activities.
- Institute sustainable purchasing, usage and end-of-life policies in the management of group consumables, office supplies and single-use plastics e.g., in conference events (see also Section 7.2.3 and Best Practice 7.4).

Further institutional actions:

- Prioritise suppliers instituting sustainable sourcing and operating policies, with a particular focus on the raw materials processing stage (see Best Practice 7.1) and with the aim of creating demand for recycled (secondary) raw materials.
- Provide an institutional pool of infrequently-used equipment to avoid redundancy in purchasing.
- Proceduralise and prioritise repair of equipment, and enable through provision of tools and know-how.
- Assess waste generation and management for the design, operation and decommissioning of IT and infrastructure projects by right-sizing needs, establishing specific treatment channels for all waste categories, and setting recycling targets that include the recycling of all construction waste, see, e.g., Best Practice 7.3.

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 (not only in the computing sector)**

- **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

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.

Thank you

Who are the emitters?

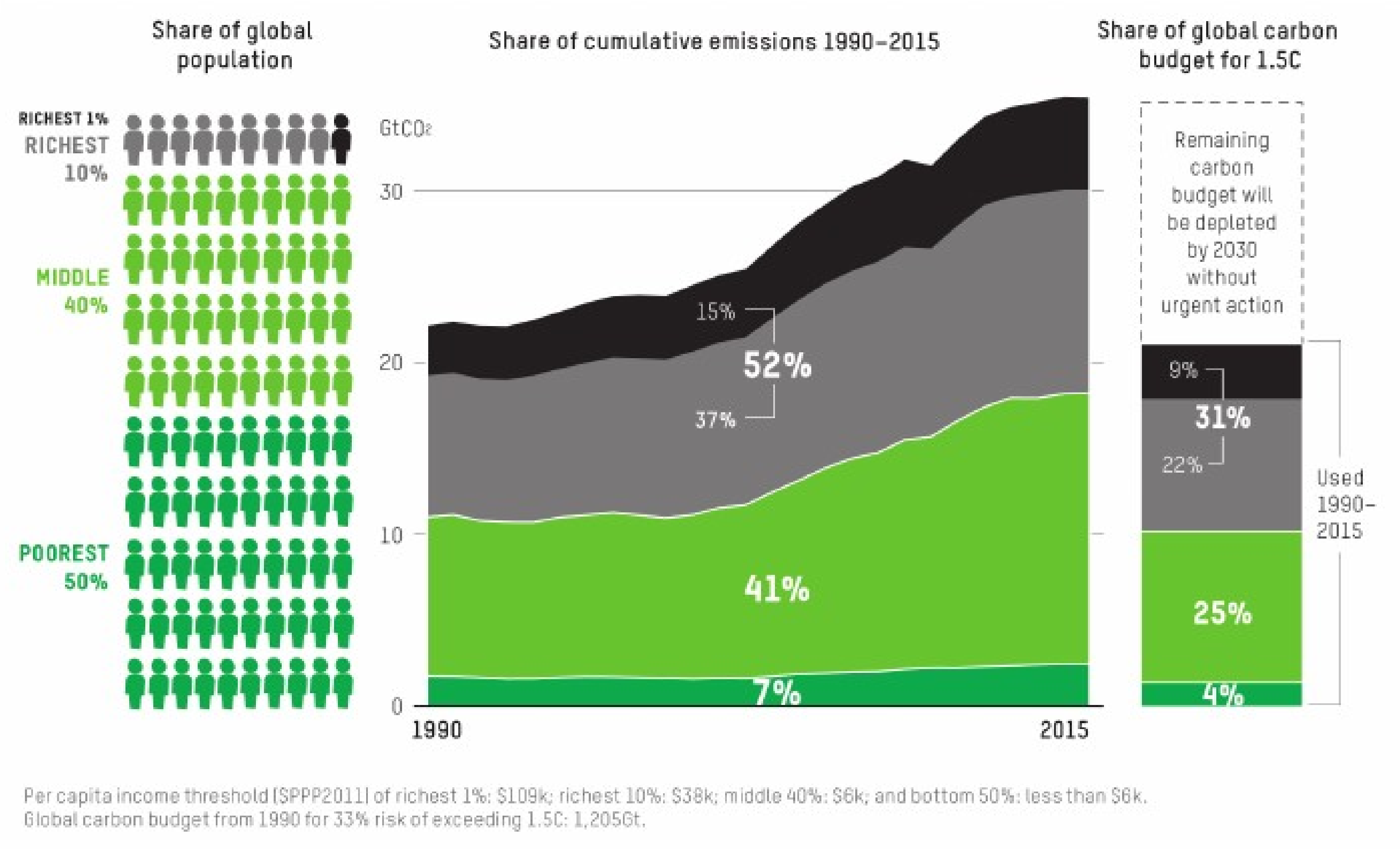


Figure 1.2: Share of cumulative emissions from 1990 to 2015 and use of the global carbon budget for 1.5°C linked to consumption by different global income groups. Figure reproduced from Ref. [9] with the permission of Oxfam.[a]

What does this mean for particle physics?

Options:

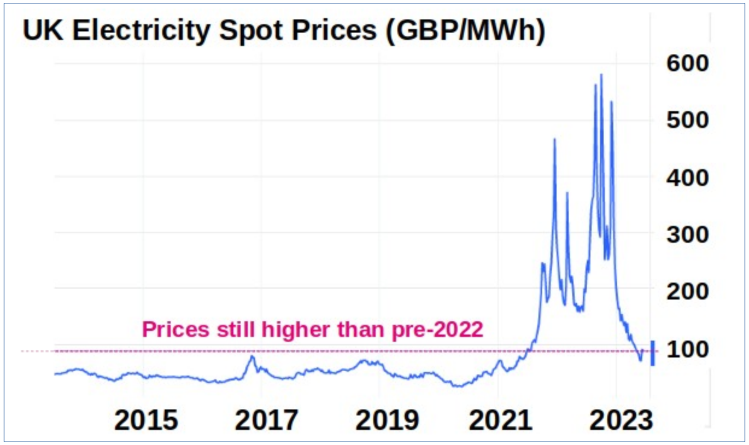
1) Expand CO2-free energies (factor 12)
Renewable power for computing: processors and cooling;
Consider district heating and site selection;
Job scheduling according to energy availability; ...

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)**

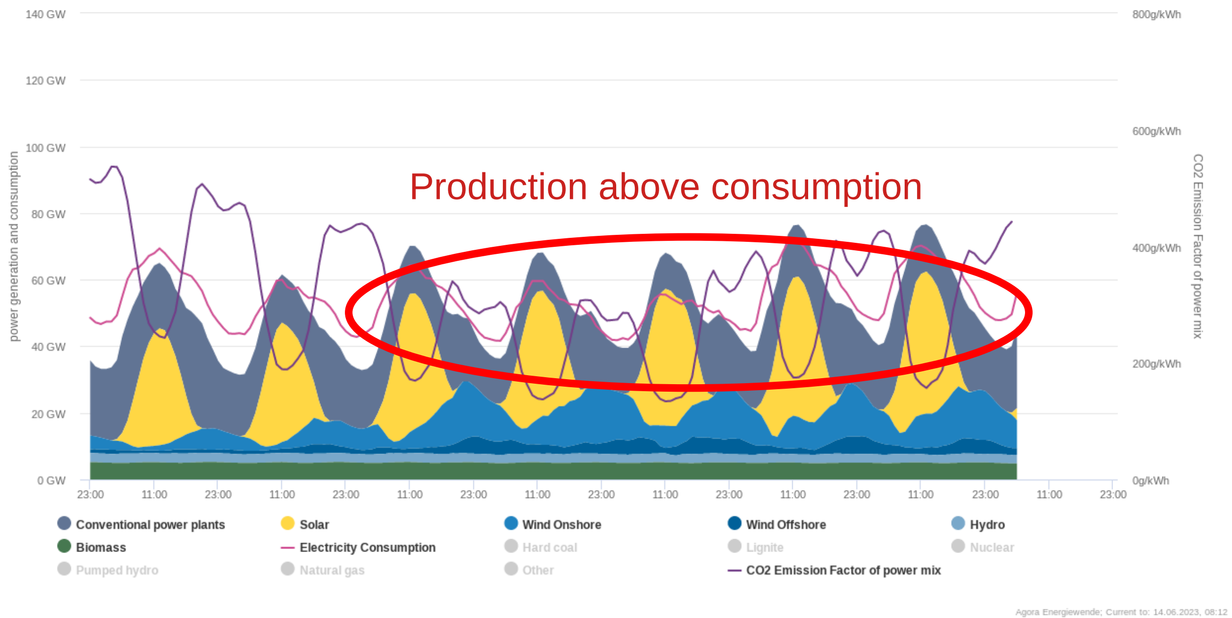
Chris Brew (RAL)

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

“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

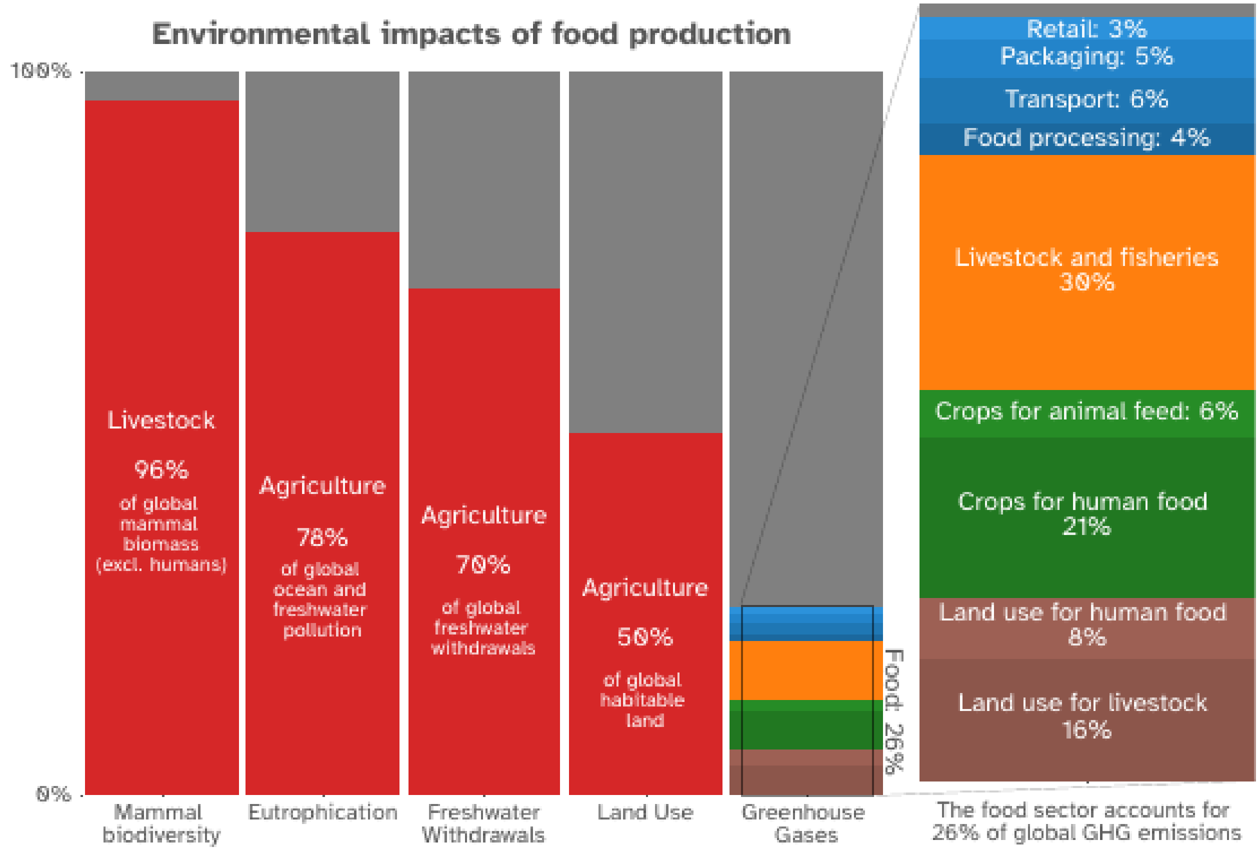


Figure 4.1: Environmental impact of food production, with fine-grained partitioning of GHG emissions by food sector. Figure modified from Ref. [119] under the terms of the Creative Commons Attribution 4.0 International (CC BY 4.0) license, based on data from Refs. [114] and [120].