Environmental sustainability in basic research: a perspective from HECAP+

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Reflection document

arXiv:2306.02837 (coming soon to JINST).

Sustainable HECAP+ Initiative: Grassroots initiative of a small group of concerned physicists from across High Energy Physics, Cosmology, Astroparticle Physics, and Hadron and Nuclear Physics.

Scope: **research-related** and **collateral emissions.**

Environmental sustainability in basic research

A perspective from HECAP+

Sustainable HECAP+ Initiative

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 3.0, 5 April 2024

The document (arXiv:2306.02837)

Hardware
Software
Infrastructure

Low-CO_2 energy
Energy saving & recuperation

Food production
Food service

Commuting
Business travel

Accounting & reporting
Tech improvements

Resources
Waste

Summary discussions, best practices, case studies and recommendations for

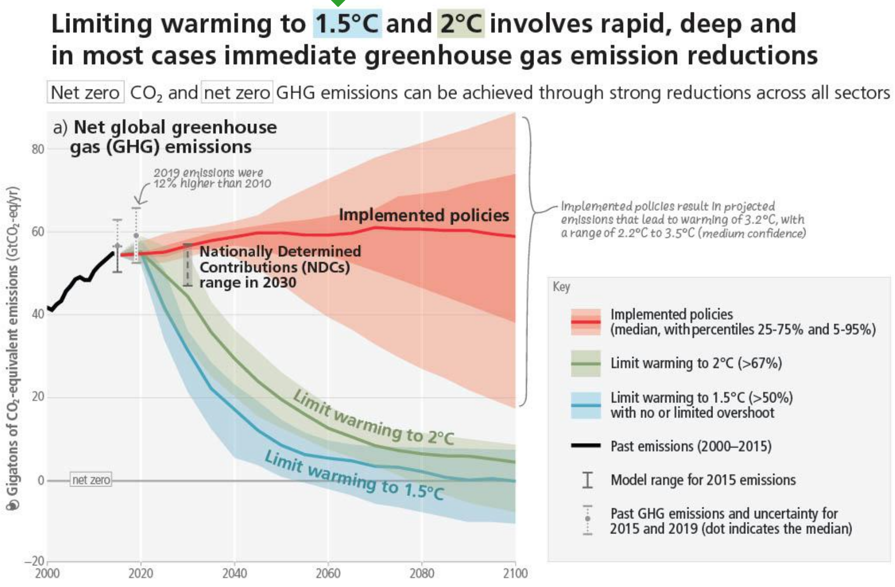

Individuals


Groups


Institutions

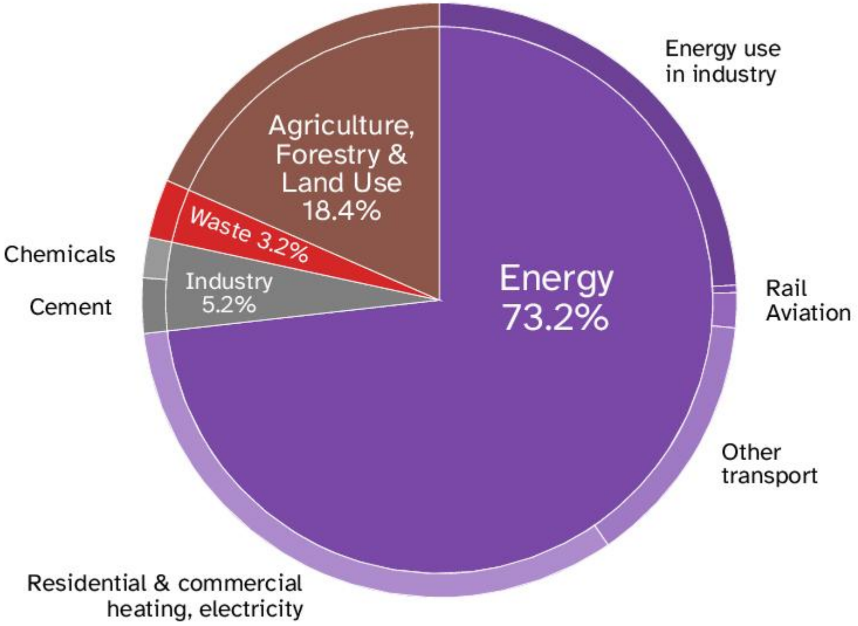
Requires approx 50% reduction in net CO_2 emissions by **2030.**

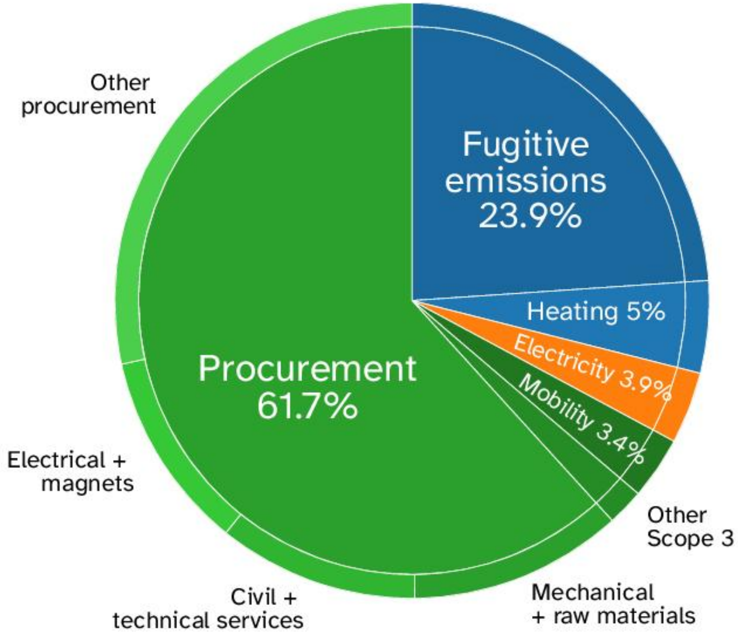
[IPCC 2023]



Demand-side mitigation “can reduce global GHG emissions in end-use sectors (food, land transport, buildings) by 40–70% by 2050 compared to baseline scenarios”, and can reduce electricity demand by 70%.

Total GHG emissions



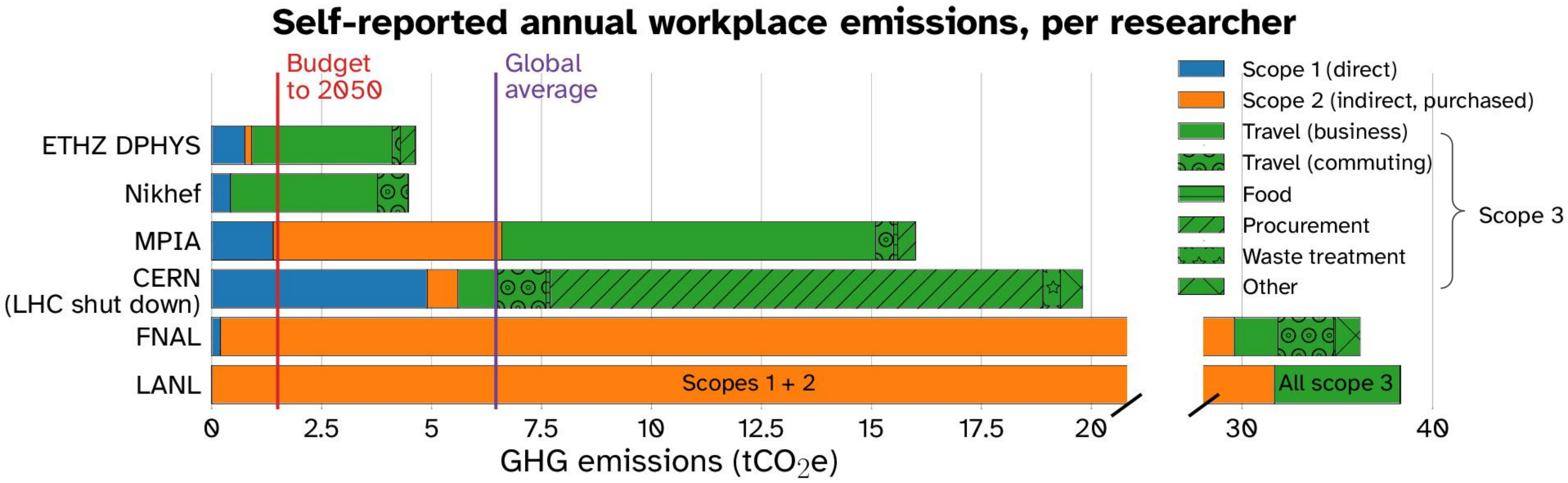


Global, 2016
49.4 $GtCO_2e$
6.3 tCO_2e/capita

CERN, 2019
0.27 $MtCO_2e$
15 tCO_2e/researcher

Cern emissions divided equally among 17,000 users to obtain per researcher emissions

[Adapted from Ritchie 2020] [CERN Environmental Report 2021]



[Institutional environmental reports, see article for references].

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

Scope 3 emissions incomplete for all but CERN.

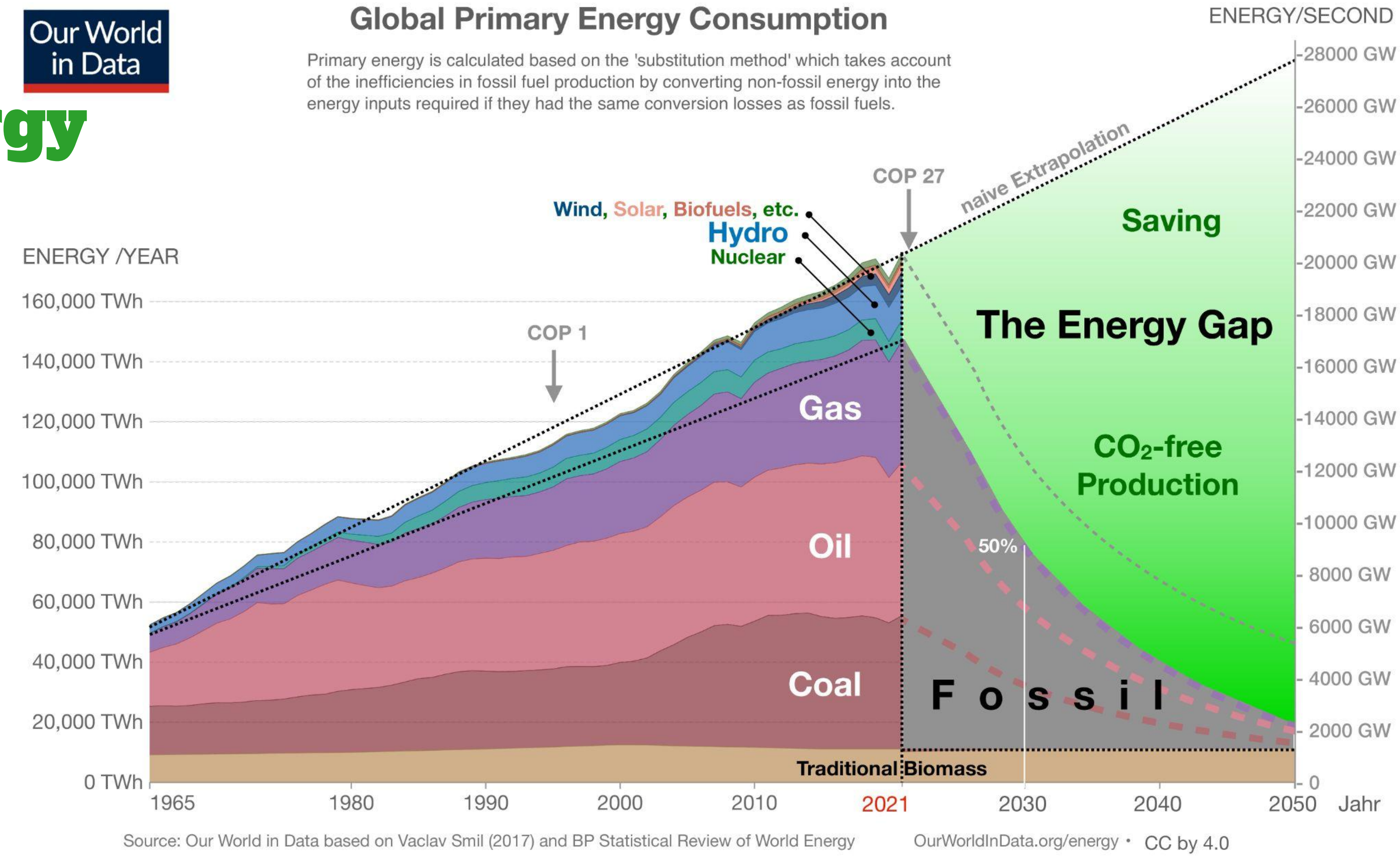
CERN's **direct** and **indirect emissions** approximately **double** when LHC is running [CERN Environment Report 2021].

Quantitative emissions reports for institutions outside Europe hard to find.

BIG science = BIG energy + BIG infrastructure

(+ BIG data)

Energy



Adapted from [Ritchie 2020]

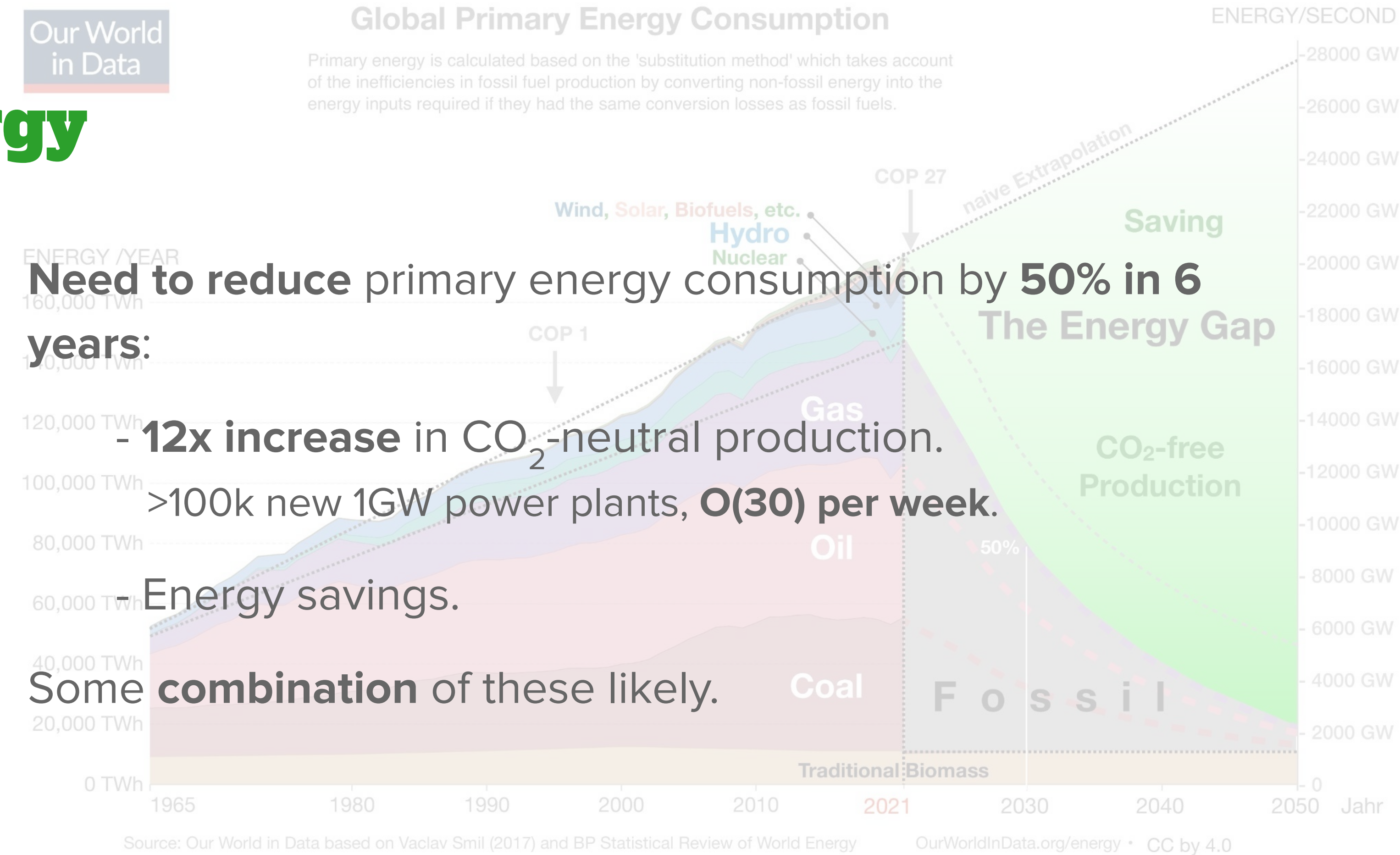
Energy

Need to reduce primary energy consumption by **50% in 6 years**:

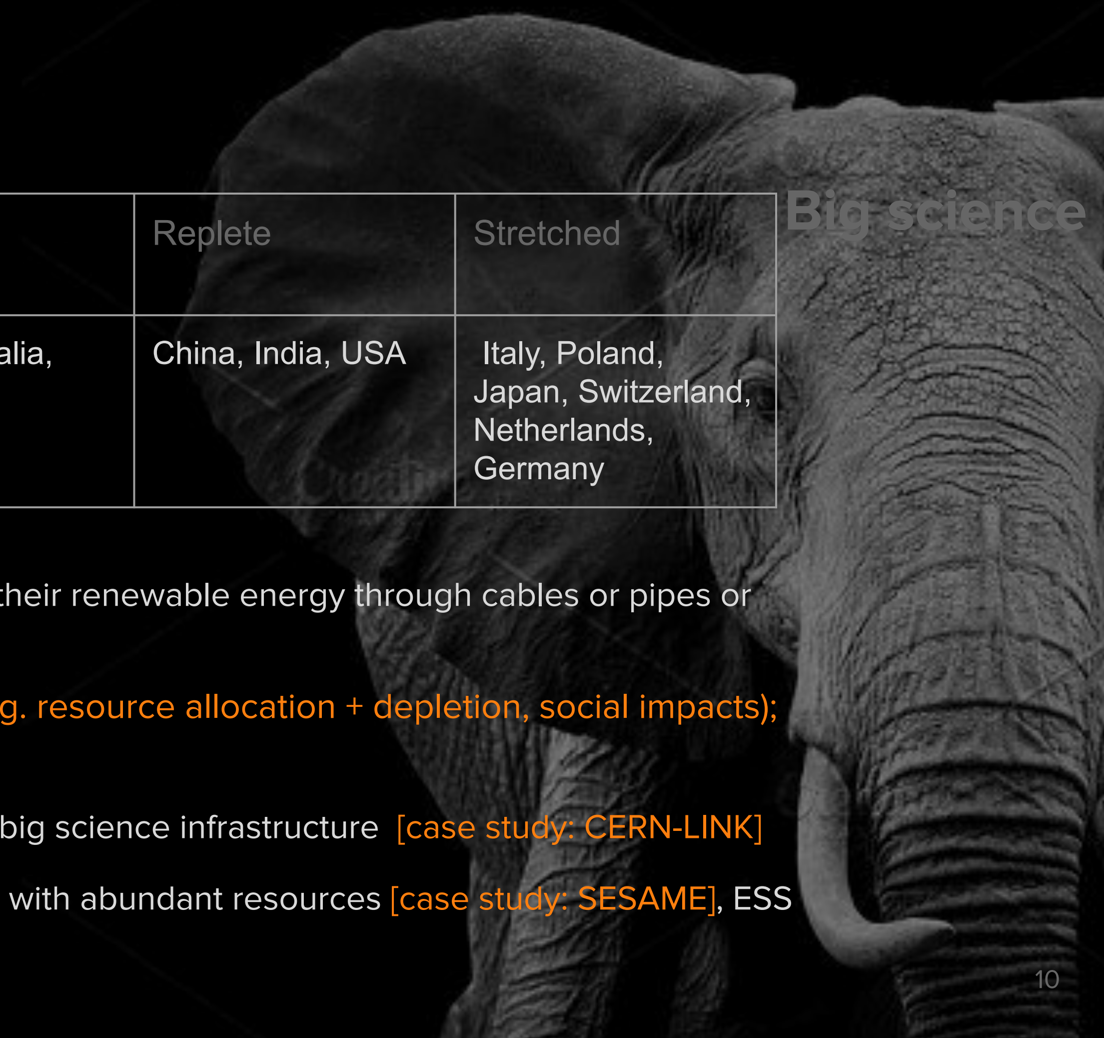
- **12x increase** in CO_2-neutral production.
  >100k new 1GW power plants, **O(30) per week**.

- Energy savings.

Some **combination** of these likely.



Energy



Renewable potential	Super-abundant	Abundant	Replete	Stretched
Country	Namibia, Botswana, Ethiopia	Chile, Australia, Morocco	China, India, USA	Italy, Poland, Japan, Switzerland, Netherlands, Germany

“Some [stretched countries] may elect to import their renewable energy through cables or pipes or ships” [Carbon Tracker Initiative 2021]

CAUTION: broader aspects of sustainability (e.g. resource allocation + depletion, social impacts); grid stability; ...

Explore feasibility of import by cable for existing big science infrastructure [case study: CERN-LINK]

To consider: build new infrastructure in countries with abundant resources [case study: SESAME], ESS in Lund.

Research infrastructure and technology

Comprehensive **Life Cycle Assessment** (LCA) should be integral to all projects at the design phase.

However, **limited availability** of relevant data.

Highlights:

- seeking out best practices and innovation
- working with industry partners

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.
- Promote knowledge exchange on sustainability initiatives between groups and institutions, including decision-makers, designers and operators of projects, setups and infrastructure.

(partial) LCA for monocrystalline silicon wafer

Used as tracking sensors in particle detectors, and as starting point for semiconductor chips.

Industry since moved to countries with **carbon intensive grids**, with less regulated halide emissions.

Bespoke production process, **proprietary,** fast-moving technology. LCA information not provided in public databases.

Output	Quantity	Output	Quantity
monocrystalline Si wafer	0.70 kg	**Emissions to air**	
Impact Assessment		particulates (PM10)	1.71E-2 kg
energy renewable	213 MJ	SO_2	0.137 kg
energy total	4850 MJ	CFC-11	1.3E-5 kg
GHG emissions	319 $kgCO_2e$	PFC-14	5.17E-6 kg
acidification	0.369 $kgSO_2e$	PFC-116	6.50E-7 kg
Waste		dioxins	1.18E-11 kg
FGD residues (landfill)	2.79 kg	lead	1.51E-5 kg
production waste	2.32 kg	acid (as H+)	4.60E-4 kg
sewage sludge	4.89E-3 kg	nitrogen oxides	0.309 kg
ash	11.0 kg	cadmium	9.8E-7 kg
waste (landfill)	1263 kg	nickel	2.72E-5 kg
nuclear waste	3.97E-4 kg	ammoia	9.66E-4 kg
Emissions to water		nitrous oxides	8.89E-3 kg
lead	3.28E-10 kg	mercury	3.24E-6 kg
phosphorus	9.24E-7 kg	fluorides	8.65E-4 kg
nitrogen total (excluding N_2)	5.45E-5 kg	polycyclic aromatic hydrocarbons	9.38E-10 kg
mercury	2.51E-11 kg	chlorides	1.47E-2 kg
chromium	3.28E-6 kg	H_2S	6.08E-6 kg
chemical oxygen demand	0.352 kg	CO_2 (fossil)	299 kg
biological oxygen demand	9.87E-3 kg	CO (fossil)	6.27 kg
arsenic	2.06E-11 kg	CH_4 (fossil)	0.571 kg
adsorbable organic halides	8.68E-8 kg	other volatile organic compounds	1.79E-2 kg
inorganic salts and acids	0.014 kg	arsenic	3.49E-6 kg

Outputs from production of 1 m^2 monocrystalline silicon wafer. Germany, 2005 [ProBas database]

Computing

A significant part of our research infrastructure, contributes to resource use, energy consumption and e-waste.

Impact increasing due to growth in capacity of hardware and software tools, and size of datasets.

Highlights:

- Right-sizing hardware needs & reassessing life cycles
- Improving data-processing efficiency
- Green scheduling
- Heat recovery

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 discussions on E-waste, right to repair and sustainable procurement in 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 [42].

Energy

Energy use cuts across all our research activities.

Highlights:

- Monitoring, reporting and assessing
- Accreditation, e.g. ISO, LEAF
- Prioritising energy efficiency and recovery

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 sustainable and 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

Demand-side measures can **almost halve** food-related emissions to 2050. [IPCC 2023]

A **sensitive topic**, but e.g. “substituting all beef meals at R1 [CERN] with farmed fish or chicken would result in reduction of its annual carbon footprint by 528 tCO_2e (....) approximately **260 return flights from London to New York**.”

Highlights:

- consider environmental impact of food choices in conference and cafeteria catering
- minimise food waste

Recommendations — Food

Individual actions:

- Reduce consumption of animal products, especially those that result in the highest emissions, e.g., ruminant meat, and dairy, where alternative sources of nutrition are equitably available.
- Minimise food waste.

Further group actions:

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

Further institutional actions:

- Undertake comprehensive and transparent local audits of the sustainability of food service.
- 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.
- Strive for zero food waste by, e.g., 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

Another **sensitive topic**, and an example of how tensions can arise between environmental sustainability, and e.g. productivity, EDIA, ...

Highlights:

- reprioritising business travel
- using remote technologies
- prioritising low-carbon travel for unavoidable travel
- overhauling career requirements for hypermobility

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.

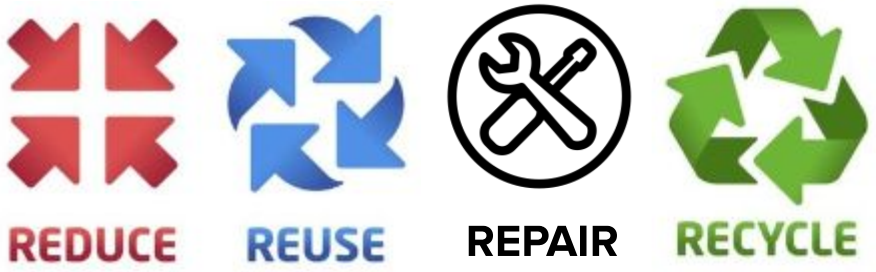
Resources and waste

Experimental infrastructure is resource-intensive: with emissions due to raw material **extraction**, **processing** and **disposal**.

Procurement emissions are **challenging to address**, since they relate to emissions in the supply chain, both up- and downstream.

Highlights:

- demand-side reduction
- Sharing, repairing, reusing and refurbishing
- Prioritising suppliers with sustainable sourcing and operating policies



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 food service or 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.

Outlook

Progress has been rapid:

- Partial LCA for ILC, CLIC design by Arup [Evans+ 2023]; extended to include **components**, and **LCA for FCC** has been commissioned [V. Boisvert ECFA talk].

- Horizon Europe-funded project iSAS [talk by J. Hondt tomorrow]

- Sustainability-focused working group commissioned by LDG, to provide input for European Strategy Update. [talk by M. Titov and C. Bloise tomorrow]

- Parallel **and** plenary sessions on sustainability at e.g. ICHEP.

- Sustainability-focused physics jobs advertised and filled.

- New developments in sustainability tools e.g. CERN module for Labos1point5, Green Computing tool.

- Sharing of resource-intensive simulations in Lattice and Cosmology - ongoing efforts in HEP.

Opportunities

- Consensus on weight given to sustainability in project (design) assessment.
- Big science $\stackrel{?}{=}$ big energy.
- Use combined purchasing power to drive sustainability in supply chain.

Get involved:

First interdisciplinary workshop on Sustainability in Computing, planned for 2025.

Community submission on sustainability to European Strategy Update.

Resources

For complete references to the various institutional environment reports used, please see the document arXiv:2306.02837.

IPCC, 2023: Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001.

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