Environmental impact of FCC

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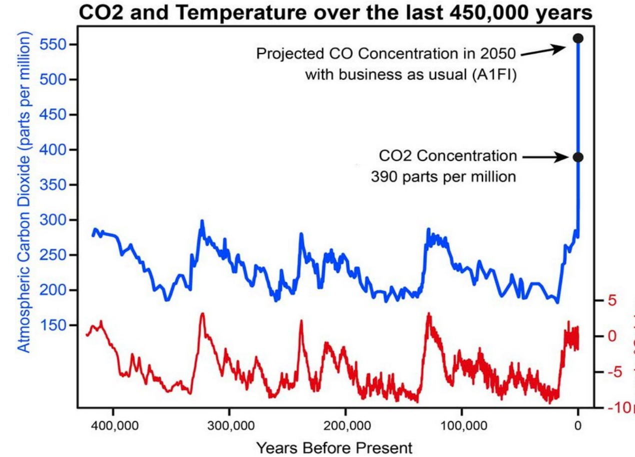
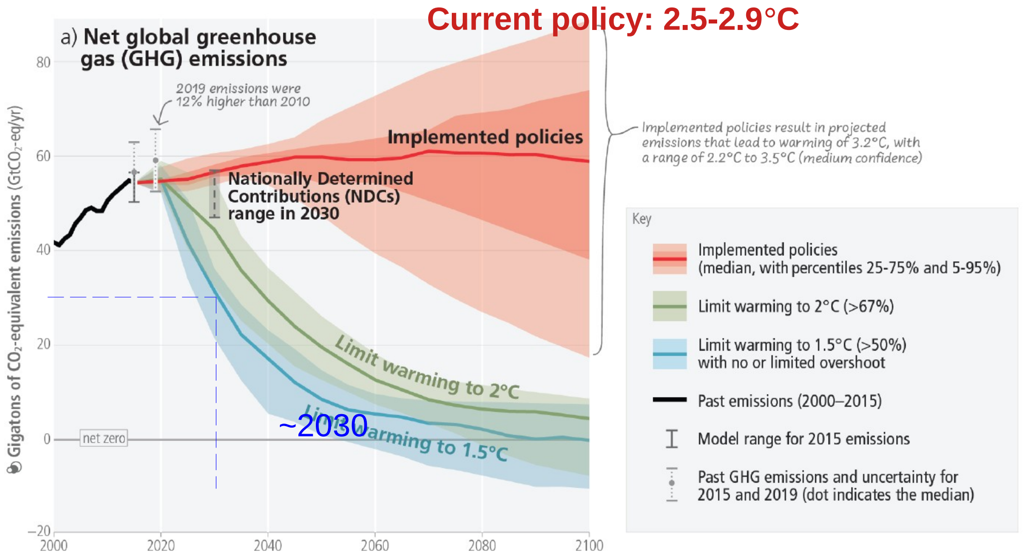
28/11/2024, HEP UK Forum

Disclaimer: I am not an active FCC member

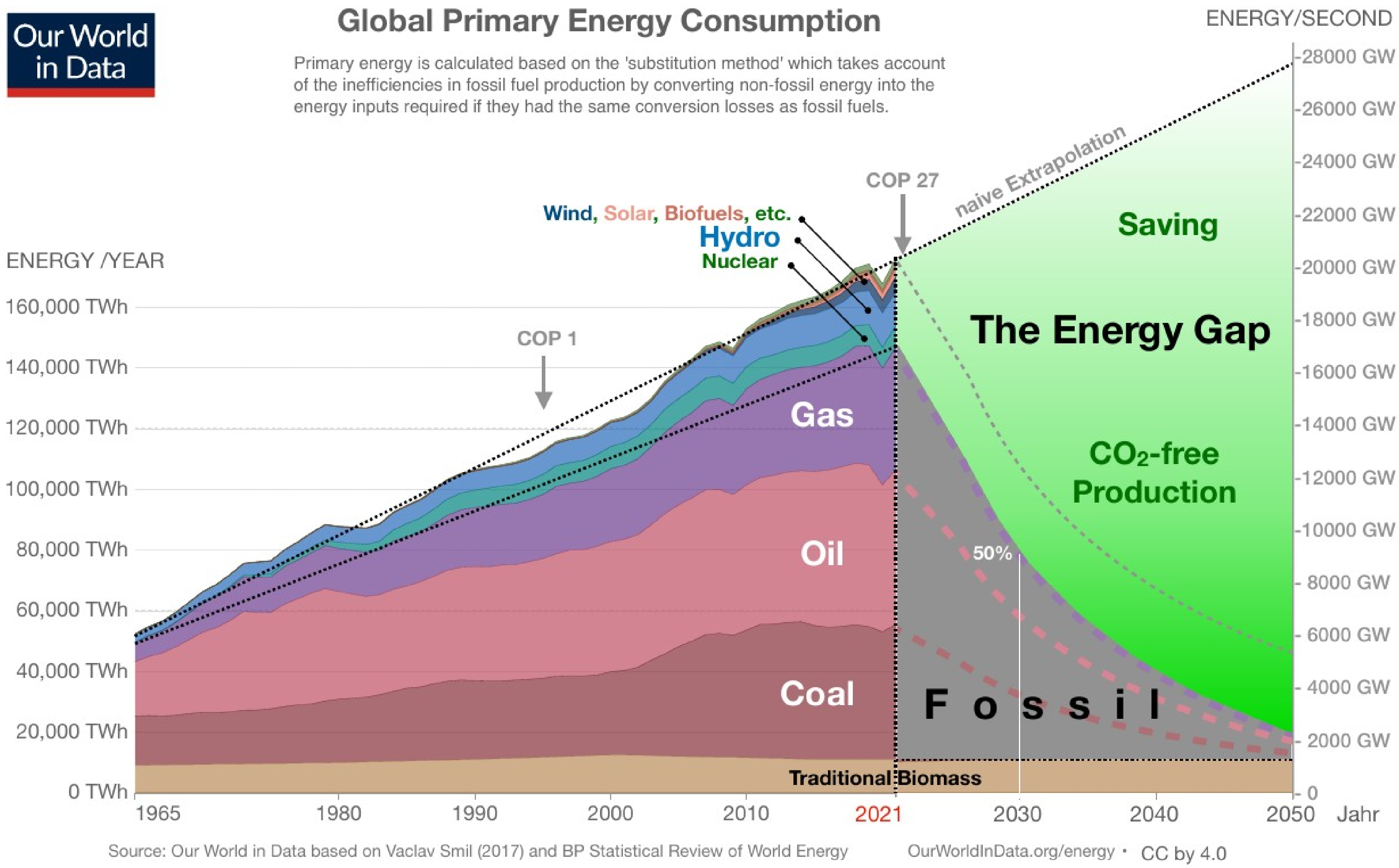
Why? Climate change in a nutshell

- 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



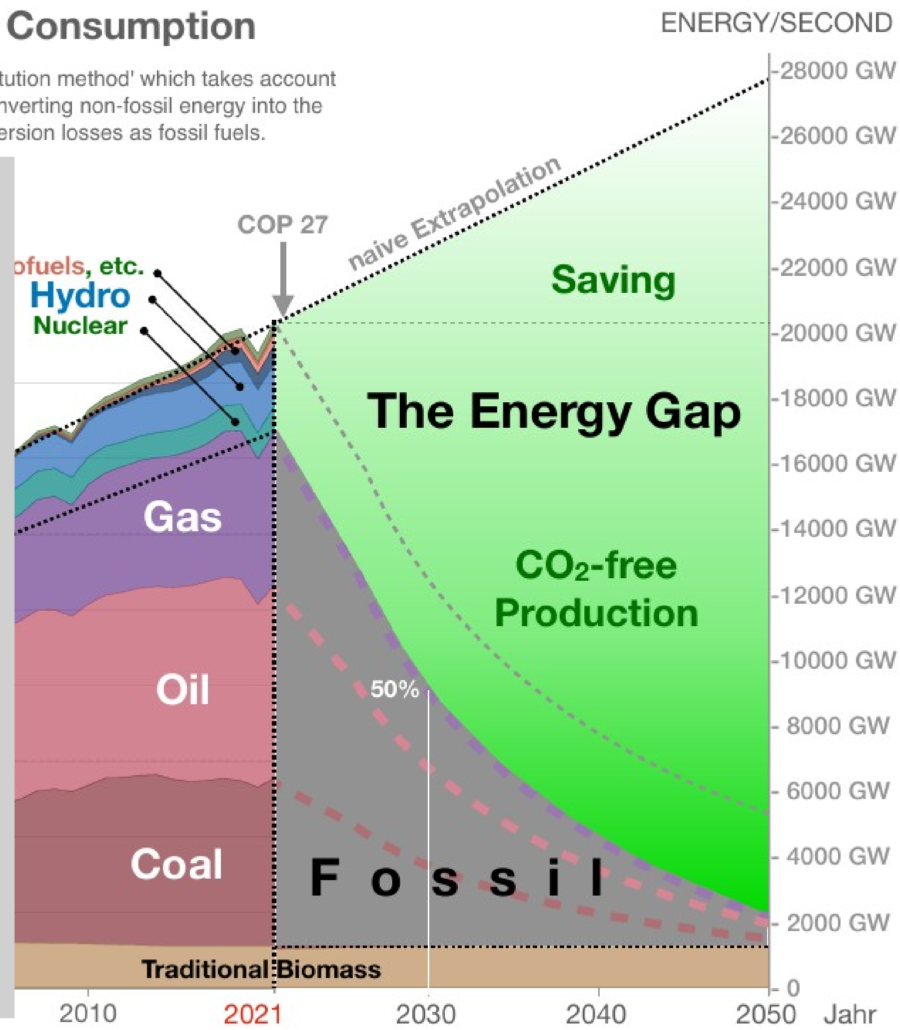
The energy gap

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



Source: Our World in Data based on Vaclav Smil (2017) and BP Statistical Review of World Energy OurWorldInData.org/energy • CC by 4.0

Why does sustainability matter

- **Legal:** e.g. German scientists self-committed to be CO_2e neutral by 2035 & many countries demand to reach the Paris agreement
- **Funding:** will (likely) be tied to sustainability in the future
  → "A detailed plan for the minimisation of environmental impact and for the saving and re-use of energy should be part of the approval process for any major project." (European Strategy for HEP 2020, Ch. 7, Paragraph A; example: LHCb phase-II upgrade TDR)
- **Outreach:** we may want to tell the world in the future how sustainable we are and how we got there
- **Society:**
  we have extraordinary many smart minds around
  we can help pioneering ideas and be a role model for society and companies
  who if not scientist will start paving the way?

Sustainability for future colliders

[…] I think the there has been growing awareness over the past years on the importance of sustainability and minimizing the impact of our research infrastructure on the environment.

I think it's very important that our field becomes again a model: […] we're model of worldwide collaboration we're model of technological development I think it would be good if you could also become a model of sustainable research and show that research can be done in a sustainable way.

[…] We should ramp up those efforts and it's clear that a future collider whichever this collider will be must be of course carbon neutral. This is a very difficult thing [...] to have an impact on the environment which is absolutely acceptable by Society otherwise this will be a show showstopper.

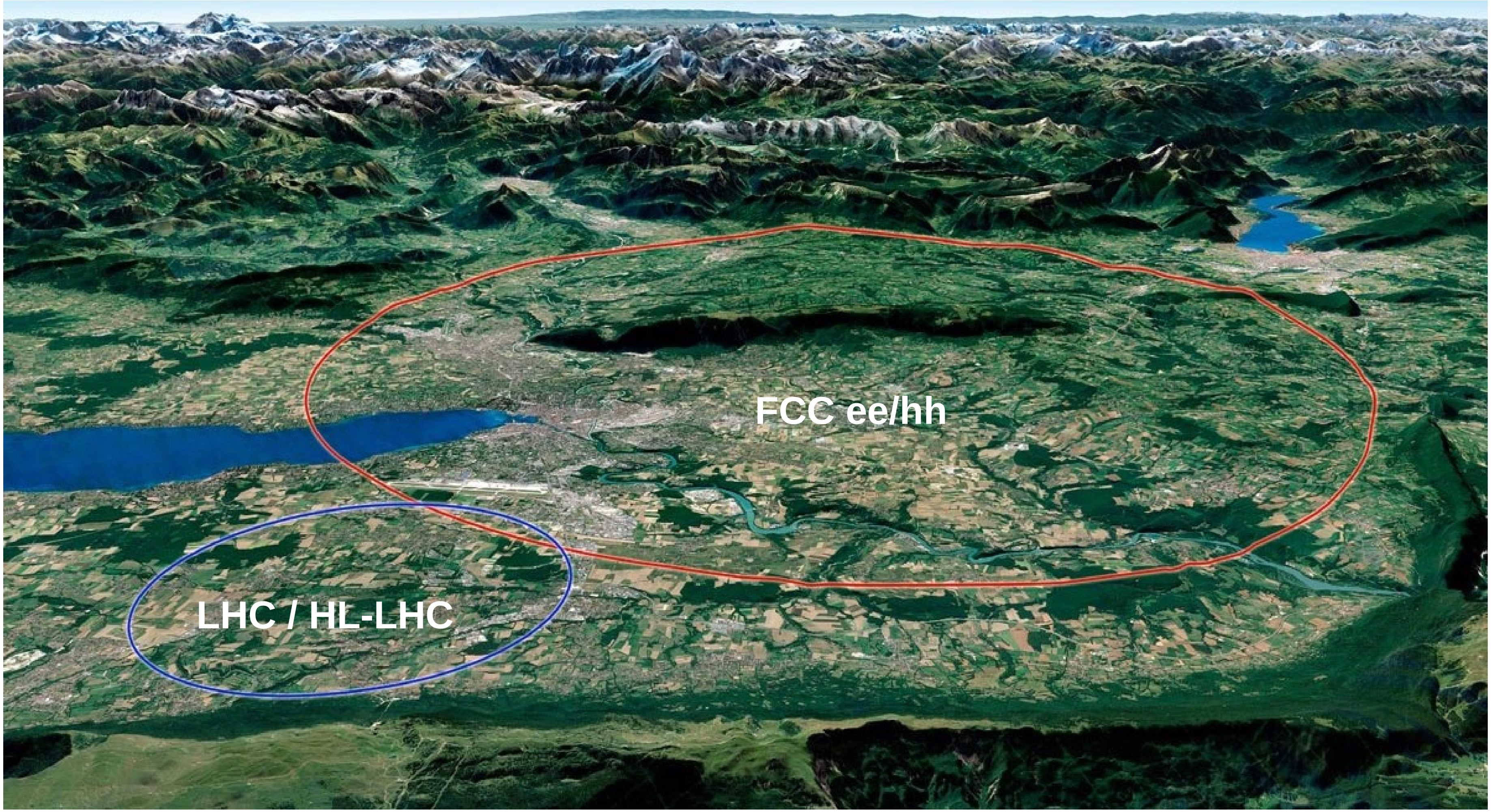
(Fabiola Gianotti)

Panel discussion on Future Colliders

Panelists:
Fabiola Gianotti (CERN), Lia Merminga (FNAL), Yifang Wang (IHEP), and Shoji Asai (KEK)

https://www.youtube.com/watch?v=IE3DY0dQo_I&t=5793s

The FCC

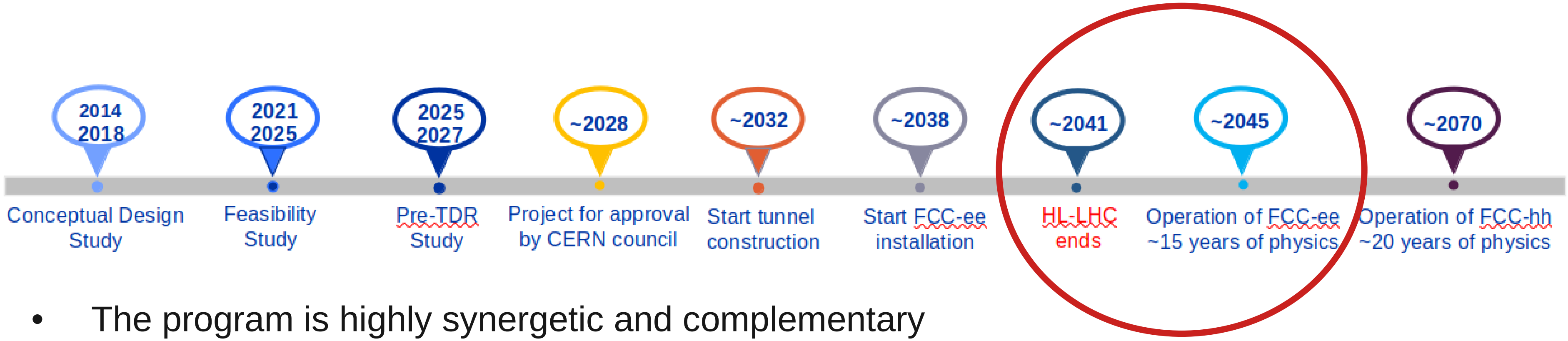


Slides taken from:
Future facilities and advances in accelerator technologies
Rende Steerenberg (CERN)

The FCC

Maximising physics opportunities:

- Stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as a Higgs factory, electroweak & top factory at highest luminosities
- Stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, proton-proton with options



- The program is highly synergetic and complementary enhancing the physics potential of both colliders
- Common civil engineering and technical infrastructures, building on and reusing CERN's existing infrastructure
- FCC integrated project allows the development of a significant new facility at CERN, within **a few years of the completion of the HL-LHC physics programme**

Slides taken from:
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The FCC

Layout chosen:

- One out of ~100 initial variants, based on geology and surface constraints, environment, infrastructure

Baseline:

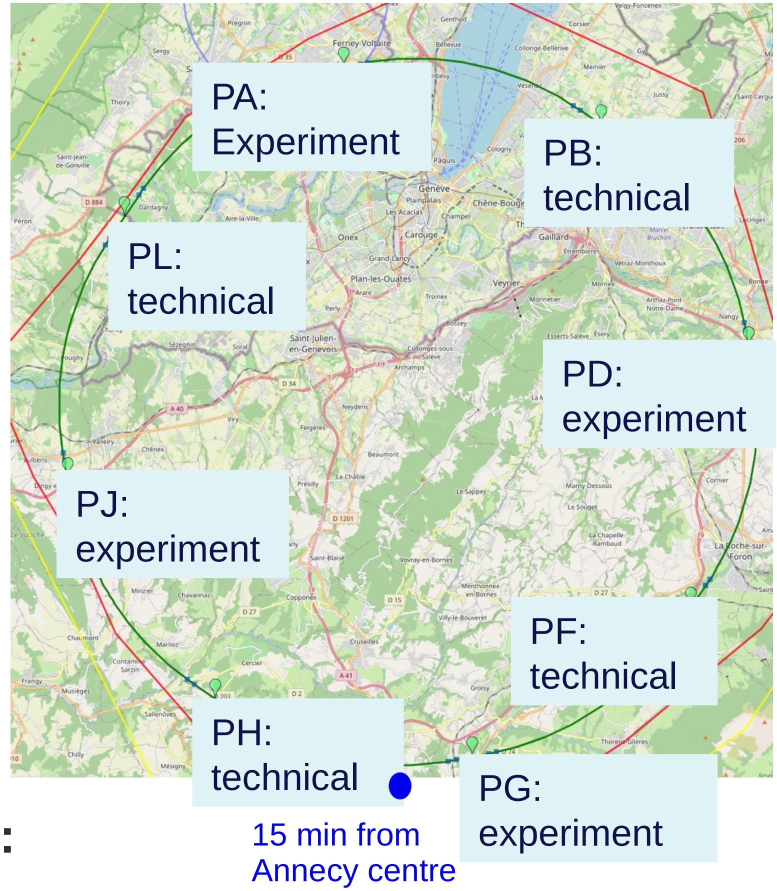
- 90.7 km ring
- 8 surface points
- 4-fold super-periodicity
- 4 interaction points for experiments

Integration with regional services:

- Connections with highway network
- Electrical connection concept developed with the French electricity grid operator

Sustainability is an integral part of the study:

- Commitment to environmental protection
- Heat recuperation, reduced water consumption, etc….



Summary of layout constraints and opportunities -- https://zenodo.org/records/13773120

Slides taken from:
Future facilities and advances in accelerator technologies
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The FCC: Technological challenge

Significant global efforts have been made in developing RF technology delivering high accelerating gradients and high Q factors. However, this has not been the focus at CERN for several years.

- LEP ran with 288 cavities
- LHC has only 16 cavities
- FCC in ttbar mode plus the full energy booster require >1000 cavities

In Higgs mode, the RF systems represents 40% of the total FCC energy consumption

Motivates building of a new superconducting RF facility at CERN

R&D on thin film coated and bulk superconducting cavities and on higher temperature superconducting cavity materials

Prototyping and pre-series for FCC-ee

R&D on the process to maximise throughput, reproducibility and minimise resources

Goal:

Limit the operational cost of new large projects

Reduce capital investment in SRF systems

Start operation mid-2029

Environmental impact of the FCC: An overview

- General overview over footprint
  → see in-depth talk by Veronique Boisvert

- **Main drivers:**
  → Civil infrastructure construction
  → Dipoles ~7% of construction
  → Travel ~25% of construction

- Computing, gases omitted
  (difficult to project,
  gases will be discontinued)

- Important to note:
  → number of full LCA and estimated numbers of e.g.CCC for other colliders agree within 10%
  → robust estimation!

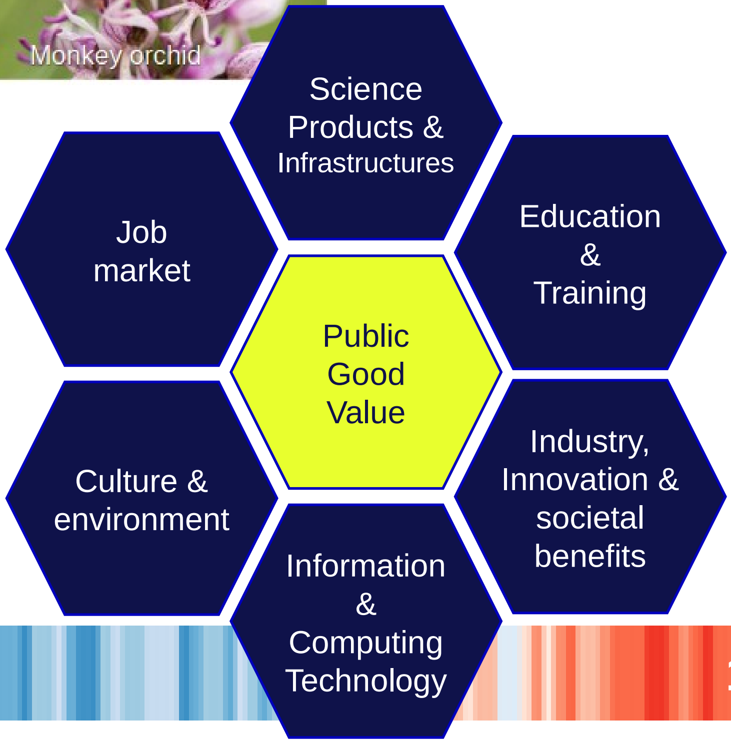
  Some contributions (potentially) missing:
  extra buildings (campus on the other "pole" of the ring, up to 2500 people)

Table 1 Carbon emissions from civil construction for future colliders.

Collider	Emissions (Mt CO_2e)	Notes (see text for more complete information)
ILC (Japan) 250 GeV, 500 GeV	0.266	From ARUP report (29).
CEPC (China) 91.2 - 360 GeV	1.138	From CEPC presentation (30) which uses the factors of 7.0 kt CO_2e/km, 30% for the auxiliary buildings and 25% for A4-A5 contributions.
FCC-ee (CERN) 88 - 365 GeV	1.056	From FCC presentation (31), the deduced emissions per length of the main tunnel is 7.2 kt CO_2e/km.
CLIC (CERN) 380 GeV Drive Beam	0.127	From ARUP report (29).
CCC (USA) 250 GeV, 550 GeV	0.146	From CCC paper (32).
Muon Collider (USA) 10 TeV	0.378	Using 27 km for the sum of the accelerator and collider rings (23) and using factors of 7.0 kt CO_2e/km, 60% for the auxiliary buildings and 25% for A4-A5 contributions.
FCC-hh (CERN) 100 TeV	0.245	Re-using the FCC-ee tunnel, using factors of 7.2 kt CO_2e/km, 10% for the auxiliary buildings and 25% for A4-A5 contributions.
SPPC (China) 100 TeV	0.263	Re-using the CEPC tunnel, using factors of 7.0 kt CO_2e/km, 10% for the auxiliary buildings and 25% for A4-A5 contributions.
LEP3 (CERN) 240 GeV	0.061	Re-using LHC tunnel, using factors of 6.0 kt CO_2e/km, 10% for the auxiliary buildings and 25% for A4-A5 contributions.
HE-LHC (CERN) 27 TeV	0.061	Re-using LHC tunnel, using factors of 6.0 kt CO_2e/km, 10% for the auxiliary buildings and 25% for A4-A5 contributions.

FCC sustainability studies

- Sustainability features prominently in the FCC planning:
  - Status and progress of environment analysis and report
  - The OpenSky Lab for innovating excavation materials re-use
  - Waste heat supply opportunities
- Generally treated together with socioeconomic cost-benefit studies
  - For the region
  - For CERN member states and contractors in those

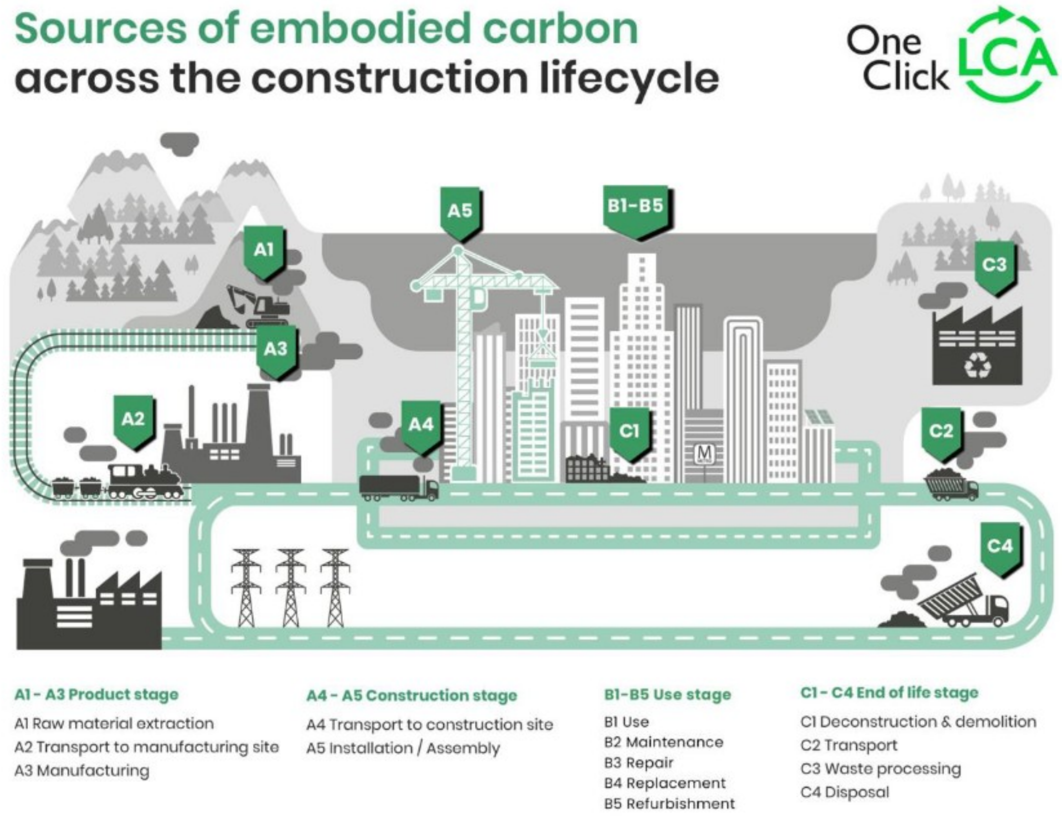


Lifecycle assessment (LCA) of FCC

- Study conducted by consultancy WSP

Use of OneClick LCA Tool

- ➢ Access to *environmental declaration products* from manufacturers
- ➢ Access to local *(KBOB)* and international database *(INIES)*
- ➢ Provide calculations for the EN17472

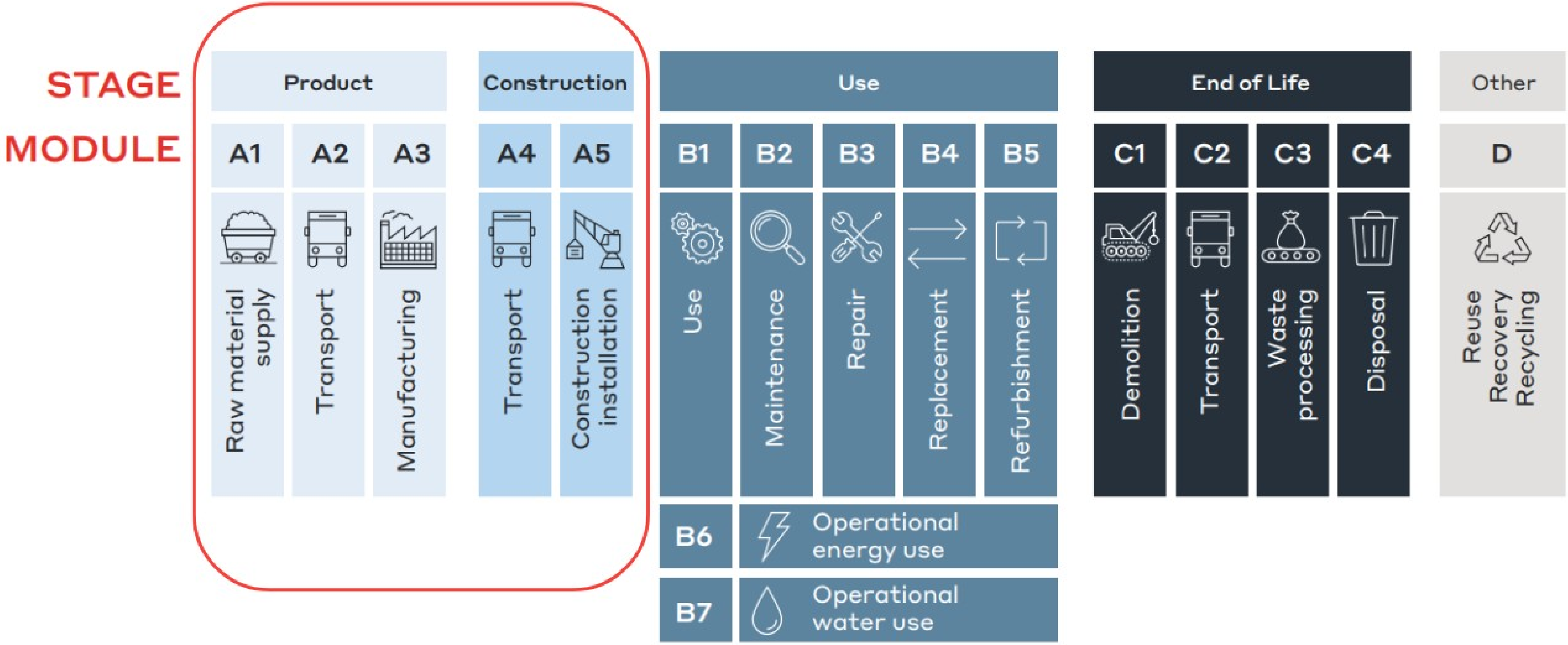


LCA is a methodology for assessing environmental impacts associated with all the stages of the life cycle of a commercial product, process, or service. Follow ISO standards, i.e. is a standardized procedure → comparable results. Training course at CERN: https://lms.cern.ch/ekp/servlet/ekp?PX=N&TEACHREVIEW=N&CID=EKP000044552&TX=FORMAT1&LANGUAGE_TAG=en&DECORATEPAGE=N

Assessment of FCC civil construction

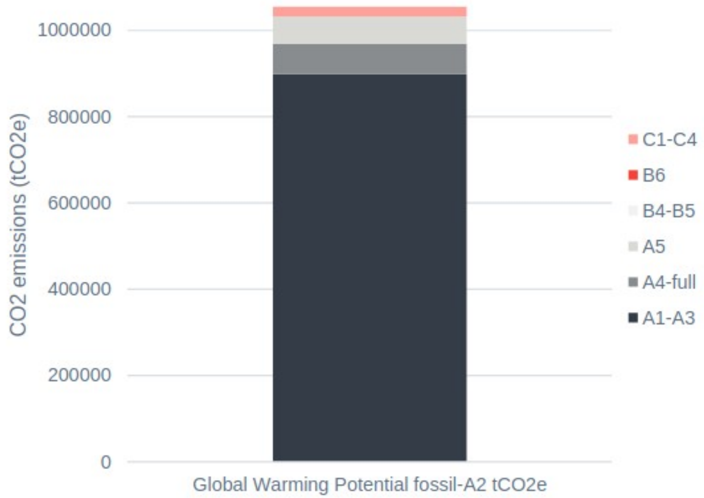
- So far concentration on construction part of FCC
(→ largest and earliest footprint with least amount of time/potential of technological developments)

- Split into subsurface/underground and surface experimental and technical sites

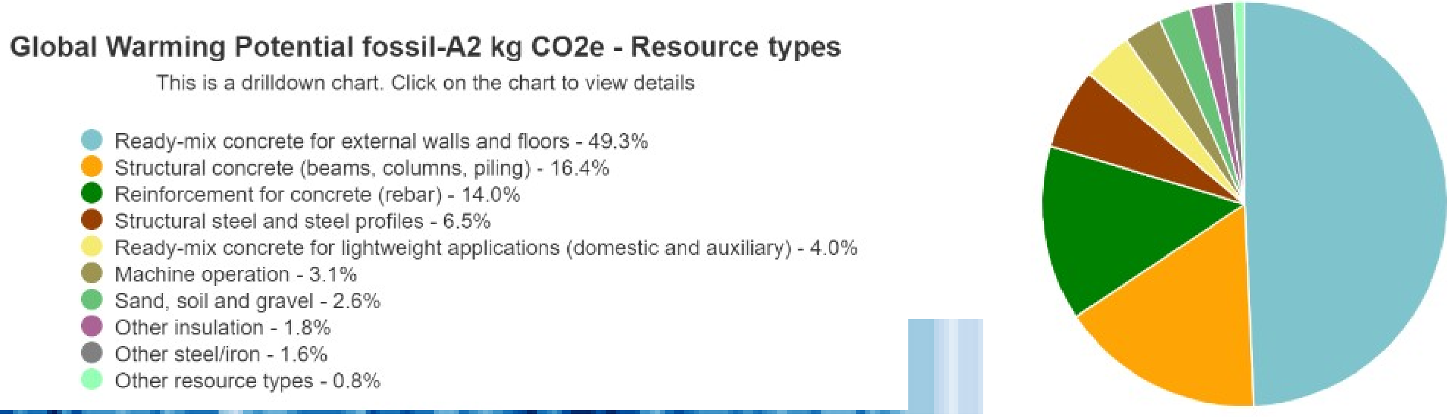


Subsurface LCA

Stage	Global Warming Potential fossil-A2 tCO2e	Global Warming Potential, LULUC tCO2e
A1-A3	898 670	338
A4-full	70 294	2
A5	62 485	91
B4-B5	1	0
B6	280	0
C1-C4	23 251	7
D	-303 632	-141



- Largest impact through building/construction (stages A1-A3)
- Largest resources / material component is cement (even clearer for surface)



Optimization of carbon footprint

- Reduction through replacement of standard materials with recycled cement content
- Here: detailed list for surface

Benchmark	Emission CO2	Optimised	Emission CO2	Reduction
Steel sheets, generic, 0% recycled content, S235, S275 and S355	3.91 kgCO2e/kg	Steel sheets, generic, 100% recycled content, S235, S275 and S355	0.87 kgCO2e/kg	77%
Steel fibre for concrete reinforcement, 0% recycled content (One Click LCA)	2.09 kgCO2e/kg	Steel fibre for concrete reinforcement, 100% recycled content (One Click LCA)	0.51 kgCO2e/kg	75%
Reinforcement steel (rebar), generic, 60% recycled content (only virgin materials), A615	1.41 kgCO2e/kg	Reinforcement steel (rebar), generic, 100% recycled content, A615	0.42 kgCO2e/kg	70%
Ready-mix concrete, normal strength, generic, C35/45 (5000/6500 PSI) with CEM I, 0% recycled binders (340 kg/m3; 21.2 lbs/ft3 total cement)	327.02 kgCO2e/m³	Ready-mix concrete, normal strength, generic, C35/45 (5000/6500 PSI) with CEM III/A, 60% GGBS content (340 kg/m³; 21.2 lbs/ft³ total cement)	170.36 kgCO2e/m³	48%
Ready-mix concrete, low-strength, generic, C12/15 (1700/2200 PSI), 0% recycled binders in cement (220 kg/m3 / 13.73 lbs/ft3)	217.91 kgCO2e/m³	Ready-mix concrete, low-strength, generic, C12/15 (1700/2200 PSI), 40% recycled binders in cement (220 kg/m³ / 13.73 lbs/ft³)	149.41 kgCO2e/m³	31%
Ready-mix concrete, normal-strength, generic, C40/50 (5800/7300 PSI), 0% recycled binders in cement	384 kgCO2e/m³	Ready-mix concrete, normal-strength, generic, C40/50 (5800/7300 PSI) with CEM III/B, 75% GGBS content in cement	173.00 kgCO2e/m³	39%

Benchmark		Optimised
1 056 391 tCO2(eq)		505 005 tCO2(eq)
Reduction		52%

Optimization of carbon footprint

- Overall reduction – Impressive, but still large footprint
- Reduction equivalent to the annual energy use in buildings for Geneva

Impact CO2	Initial	Optimised	Reduction
Subsurface	1 056 391 tCO2(eq)	505 005 tCO2(eq)	52%
Technical site x4	54 800 tCO2(eq)	17 600 tCO2(eq)	68%
Experimental site x4	114 800 tCO2(eq)	31 200 tCO2(eq)	73%
Total	1 170 800 tCO2(eq)	553 805 tCO2(eq)	55%

Side note:

- Increases impact of accelerator to 14%
  Travel to 50%*

*Assume 5000 members, 25% regional (~London, 4x/yr), 25% remote (~Chicago, 2x/year)

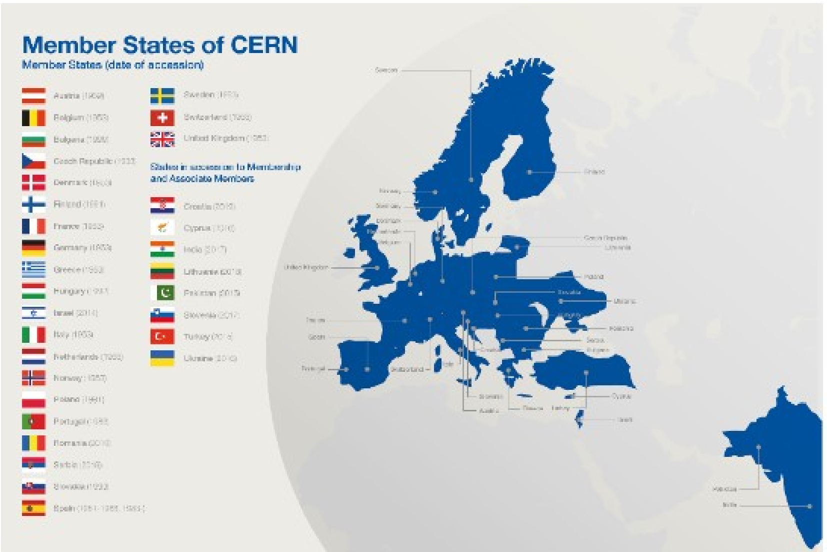
Further improvements

- Reuse of excavated materials
- Reduce thickness/strength of cement/steel
- Optimize locations of site
- Optimize transport flows
- Electric vehicles
- Collaboration with local steel/cement produces to improve footprint of materials

Concrete: is there hope?

- **The cement Industry in Europe is trying to move towards a more sustainable future.**
- **In 2024 a new plant in Norway will start producing cement with low CO2 emissions**
- **We don't know which quantities they can produce, how much it will cost, and how fast competitors will react.**
- **6 more plants in Europe are on the way to be completed.**
- **By 2030, we might have a decent probability to purchasing low CO2 cement**
  - At what price?

The wrong message?



GHG emissions corresponds to **1 kg CO2 / person** of all member states of CERN

Paris climate objective is **2000 kg CO2 / person / yr** by 2050

This is the ~same as the Men’s Euro 2024 football tournament (per EU citizen)

Health is ~500 times larger, but probably not what one would want to cut

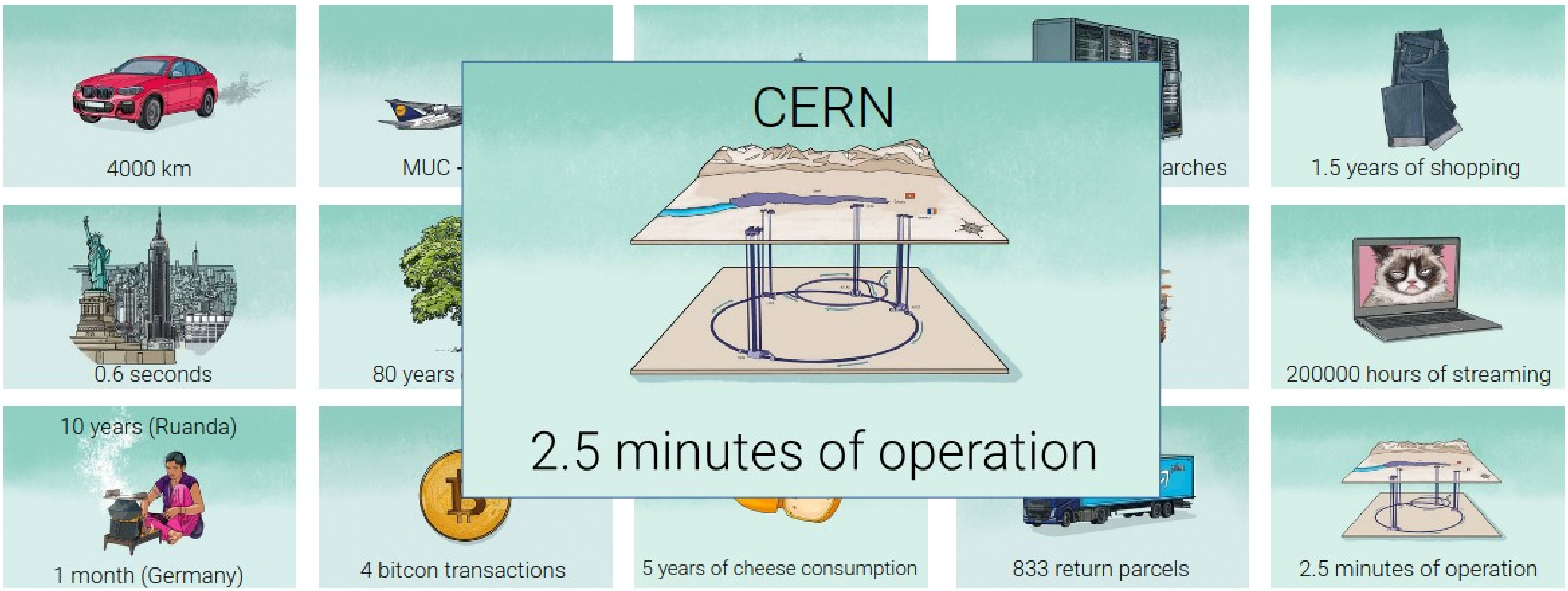
Why does sustainability matter

How much is 1 ton of CO_2 ?

Sueddeutsche Zeitung: "Was ist eine Tonne CO2"?
https://www.sueddeutsche.de/projekte/artikel/wissen/kohlendioxid-e412457/

- 1 tCO2 ~ 500 m³ at atmospheric pressure
- 0.03 – 0.04 % of our air is CO2
- 1 tCO_2 fills 1.25 million m³ of ambient air

Süddeutsche Zeitung

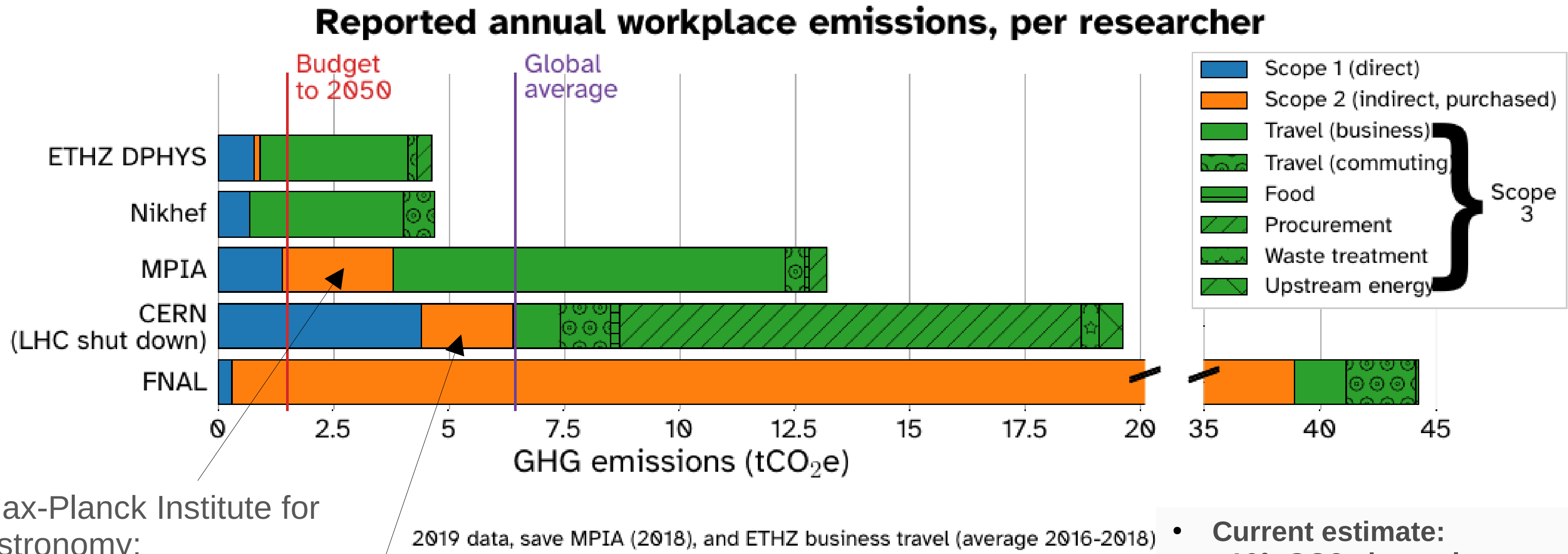


The Carbon Footprint of ATLAS D. Britzger – ATLAS Sustainability Forum 8

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
(see backup)



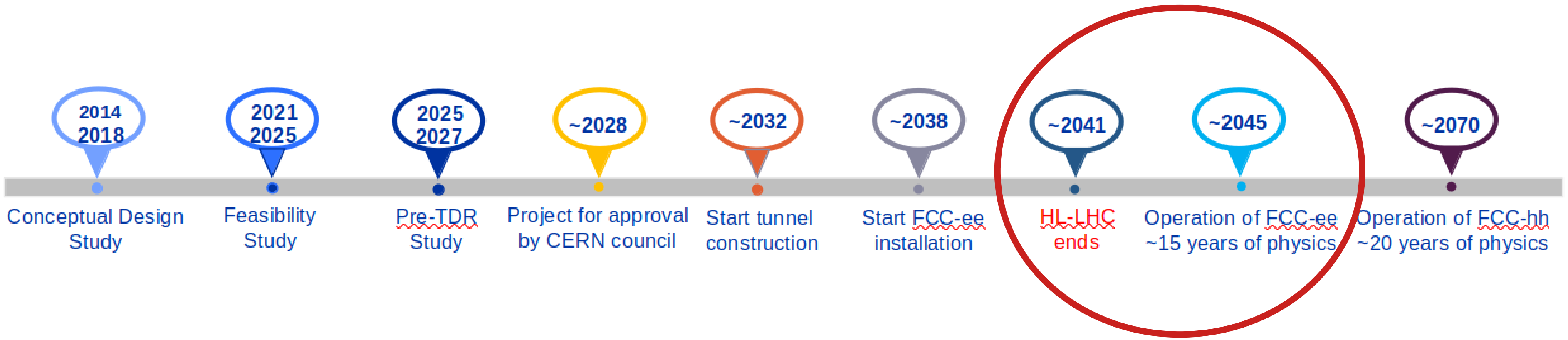
Max-Planck Institute for Astronomy:
88% of electricity is computing

CERN:
1/3 is data centre in Hungary

- **Current estimate:**
  >10^6 tCO2e in total
  → ~1000 tCO2e / paper
  → 0.3 tCO2e / paper / author
- **Compare to e.g. astronomy with**
  → 0-200 tCO2e / paper,
  → 0-20 tCO2e / paper / author
  arXiv:2201.08748

Some remarks

- FCC is (together with CEPC) most impactful future project (in terms of carbon footprint) and are competing on which collider will be built
- Project approval planned for within this ESUPP period → 2028
- Potential start of construction: Within 8 years (just after having missed Paris targets?)
- General objective/goal for FCC is preservation of expertise (and jobs) in the field
- Current gap between HL-LHC and FCC-ee very small (4 years)
- Challenge: Most carbon intensive phase is at the start of the project



Some conclusions

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

- Lifecycle assessment for most of the large future projects and sustainability considerations are taken seriously within the planning

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

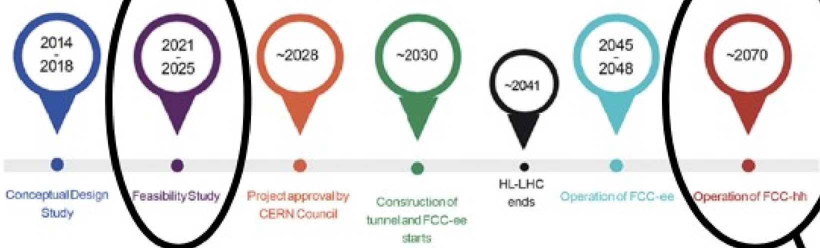
  → If we take Paris as the desired goal

- FCC carbon footprint is not small… (though comparing is certainly not easy → what would be a reasonable benchmark?)

- Does the current time scale make sense?

No particle physics on a dead planet

FCC timeline

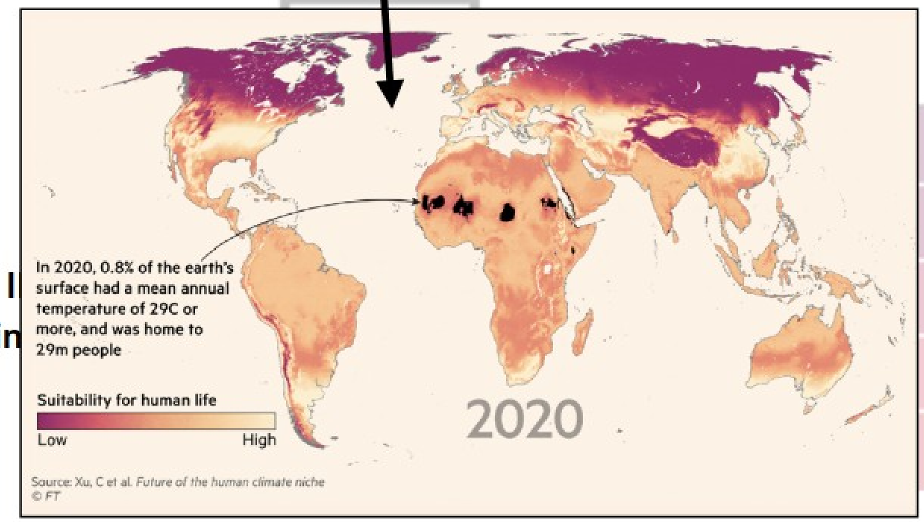


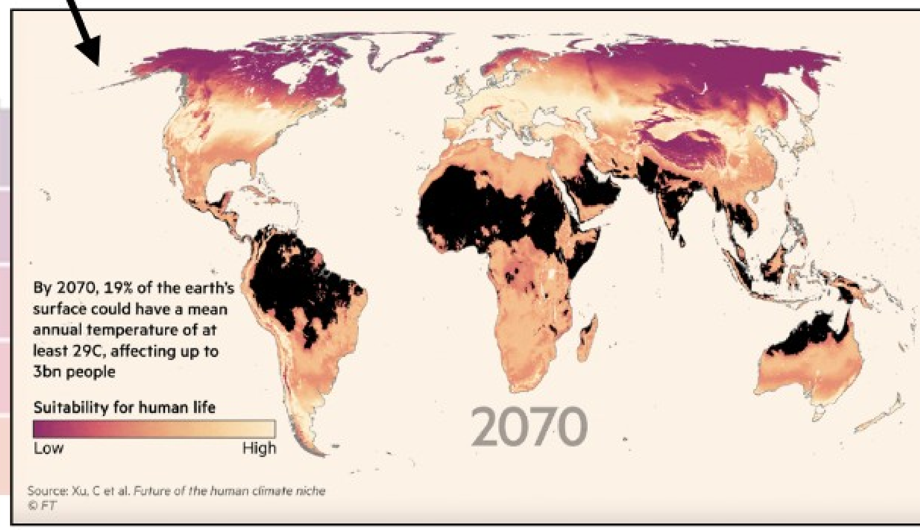
CERN Courier:

ACCELERATORS | MEETING REPORT

Towards a century of trailblazing physics

1 September 2023



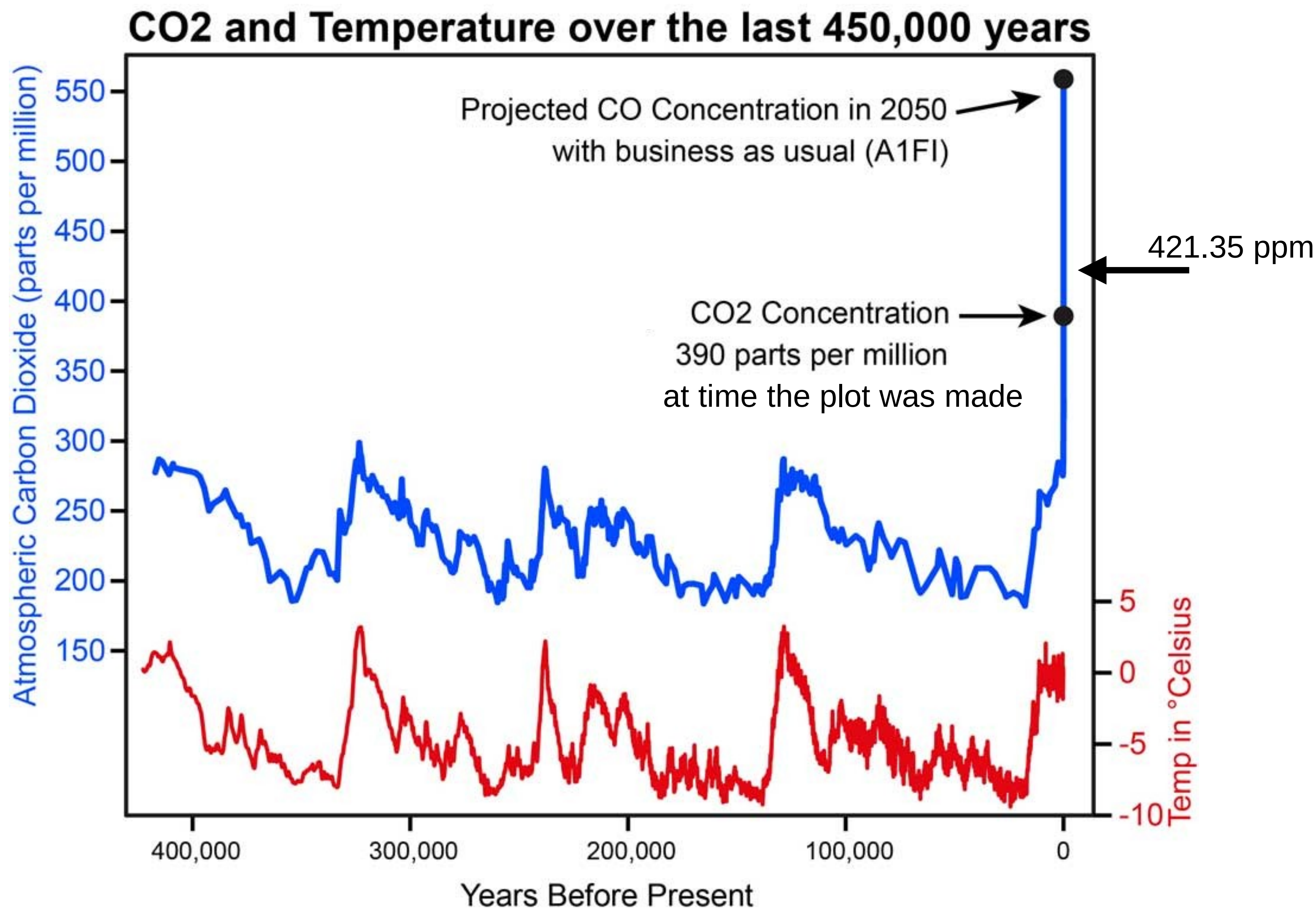


FT article: https://www.ft.com/content/072b5c87-7330-459b-a947-be6767a1099d

Based on this paper: https://www.pnas.org/doi/10.1073/pnas.1910114117

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

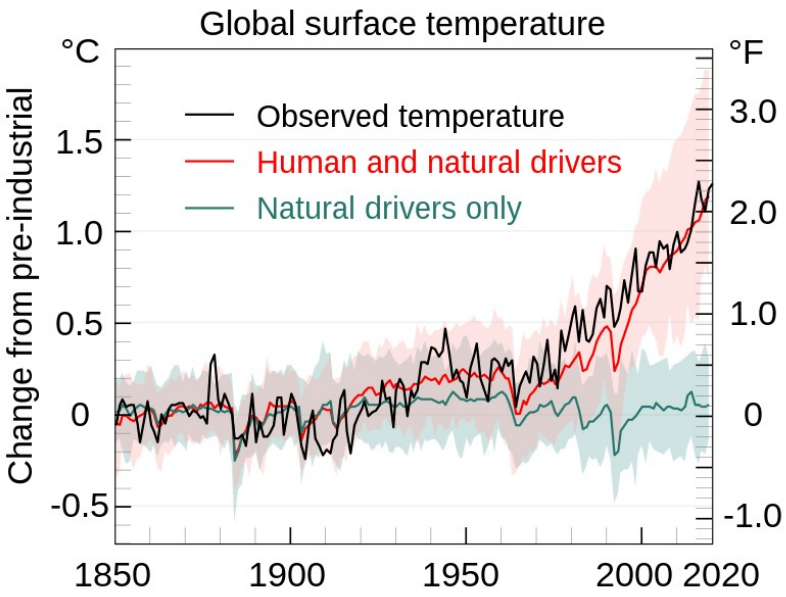
- Whilst not all of these extreme weather events are caused by climate change, their occurrence will get more and more frequent

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

https://en.wikipedia.org/wiki/Attribution_of_recent_climate_change

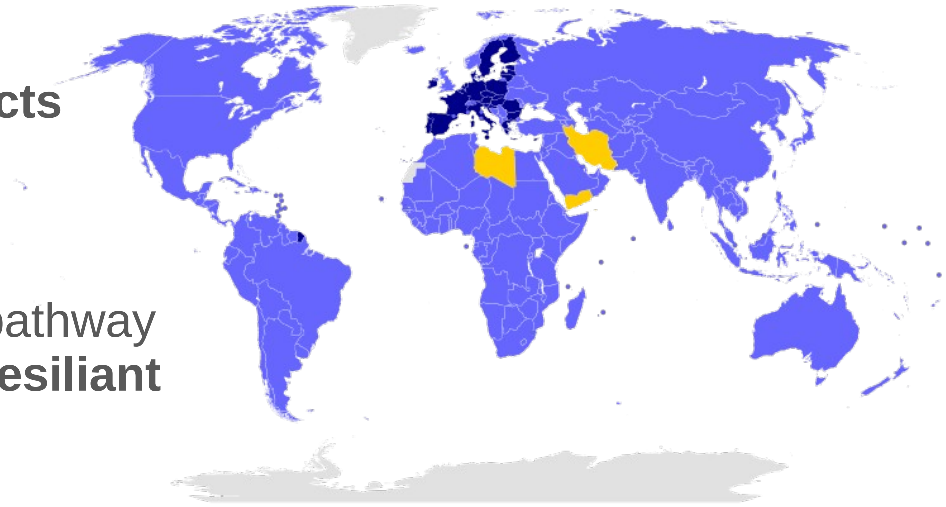
Political consequences

- **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?

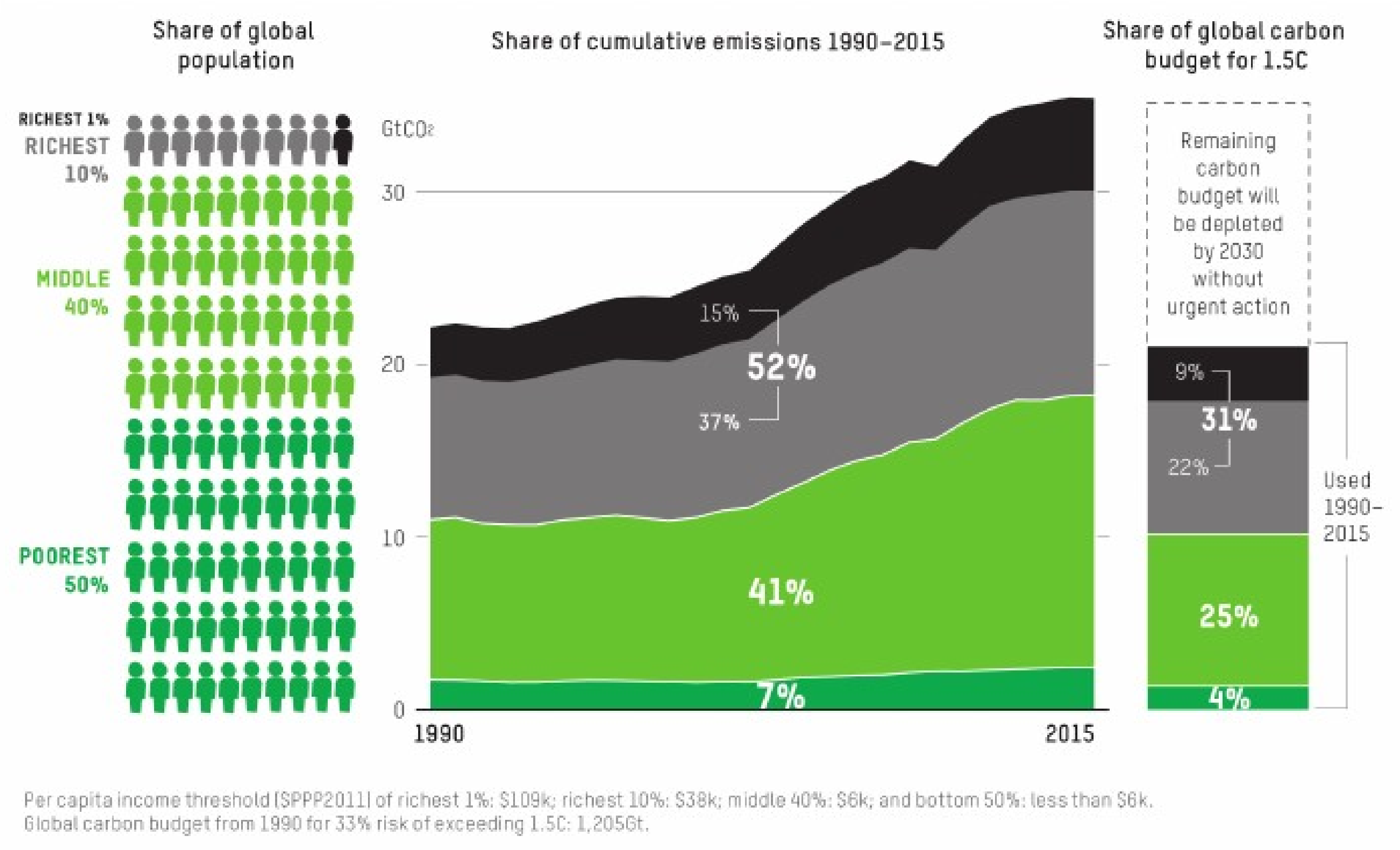


Figure 1.2: Share of cumulative emissions from 1990 to 2015 and use of the global carbon budget for 1.5°C linked to consumption by different global income groups. Figure reproduced from Ref. [9] with the permission of Oxfam.[a]

What are Scope 1, 2 and 3 carbon emissions?

The three scopes are a way of categorising the different types of greenhouse gas emissions created by a company, its suppliers and its customers.

Scope 1
Direct emissions

Direct emissions that are owned or controlled by a company.

Emissions from sources that an organisation owns or controls directly.

Example
From burning fuel in the company's fleet of vehicles (if they're not electrically powered).

Scope 2
Indirect emissions

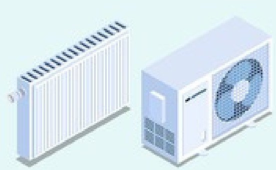
Scope 3
Indirect emissions

Indirect emissions that are a consequence of a company's activities but occur from sources not owned or controlled by it.

Scope 2

Emissions a company causes indirectly that come from where the energy it purchases and uses is produced.

Example
The emissions caused by the generation of electricity that's used in the company's buildings.

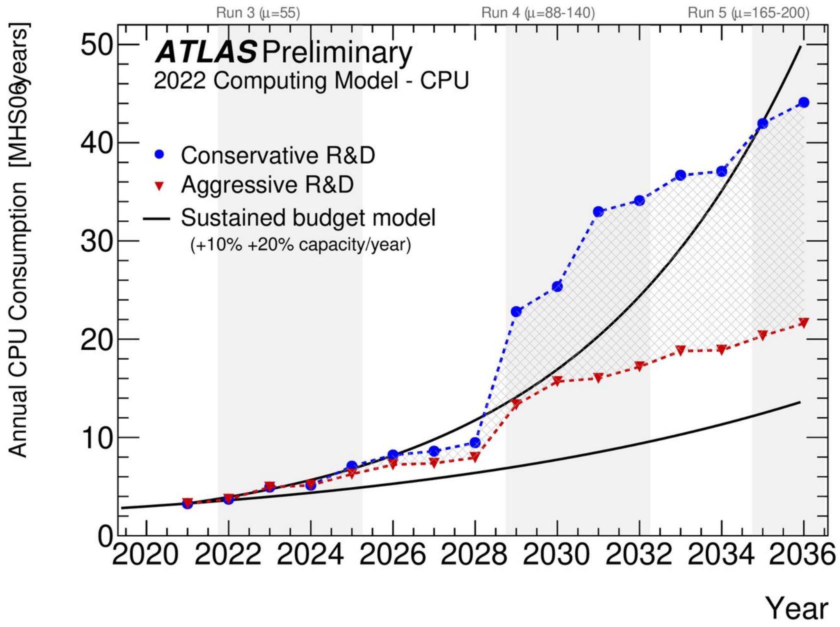


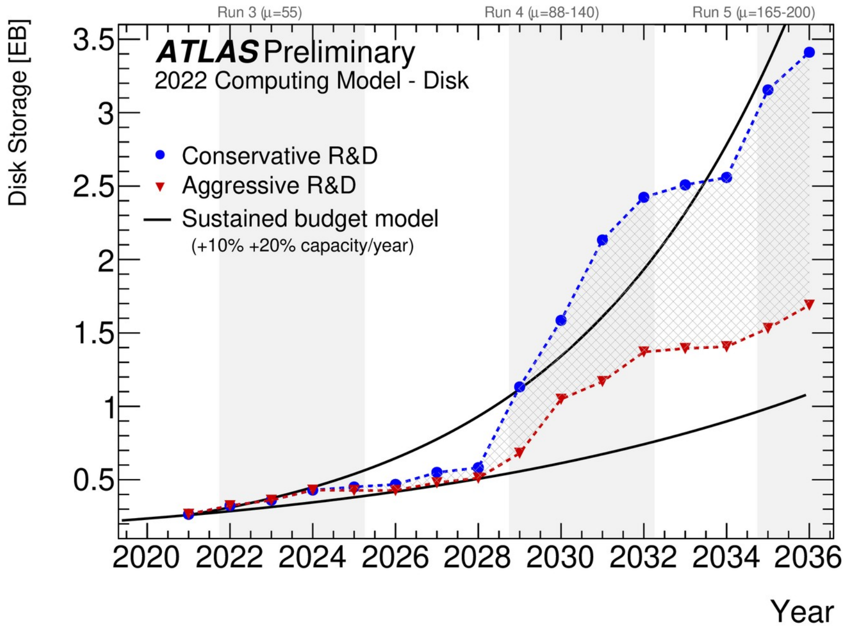
Scope 3

All emissions not covered in scope 1 or 2, created by a company's value chain.

Example
When the company buys, uses and disposes of products from suppliers.

Computing





→ **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.