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Know Your Footprint!
- A yHEP Initiative

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- First publication on the relation between atmospheric CO_2 and ground temperature ▸ S. Arrhenius, **1896**
  - Increase in CO_2 levels by factor of 2 $\rightarrow$ temperature increase of $\approx 6^{\circ}\mathrm{C}$
  - Surprising accuracy already 128 year ago
  - Confirmed and refined since then in a multitude of studies $\rightarrow$ e.g. ▸ Nobel Prize 2021

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

Latitude.	Carbonic Acid=0·67.					Carbonic Acid=1·5.					Carbonic Acid=2·0.					Carbonic Acid=2·5.					Carbonic Acid=3·0.				
	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.
70																									
	−2·9	−3·0	−3·4	−3·1	−3·1	3·3	3·4	3·8	3·6	3·52	6·0	6·1	6·0	6·1	6·05	7·9	8·0	7·9	8·0	7·95	9·1	9·3	9·4	9·4	9·3
Europe 60																									
	−3·0	−3·2	−3·4	−3·3	−3·22	3·4	3·7	3·6	3·8	3·62	6·1	6·1	5·8	6·1	6·02	8·0	8·0	7·6	7·9	7·87	9·3	9·5	8·9	9·5	9·3
50																									
	−3·2	−3·3	−3·3	−3·4	−3·3	3·7	3·8	3·4	3·7	3·65	6·1	6·1	5·5	6·0	5·92	8·0	7·9	7·0	7·9	7·7	9·5	9·4	8·6	9·2	9·17
40																									
	−3·4	−3·4	−3·2	−3·3	−3·32	3·7	3·6	3·3	3·5	3·52	6·0	5·8	5·4	5·6	5·7	7·9	7·6	6·9	7·3	7·42	9·3	9·0	8·2	8·8	8·82
30																									

- Excerpt from the Paris Agreement 2015

> (a) Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;
>
> https://treaties.un.org/doc/Treaties/2016/02/20160215%2006-03%20PM/Ch_XXVII-7-d.pdf

- Temperature targets set to $1.5^{\circ}\mathrm{C}$ $(2.0^{\circ}\mathrm{C})$ above pre-industrial levels (1850–1900)
  $\Rightarrow$ Translates to global carbon budget* of $400\,\mathrm{GtCO_2}$ $(1150\,\mathrm{GtCO_2})$
- Naively assuming equal yearly emissions from 2020–2050 for a static population of 8 billion people:

$$\text{Annual per person carbon budget} = \frac{400 \times 10^9\,\mathrm{tCO_2}}{30\,\text{years} \times 8 \times 10^9\,\text{people}} \quad \left(\frac{1150 \times 10^9\,\mathrm{tCO_2}}{30\,\text{years} \times 8 \times 10^9\,\text{people}}\right)$$

$$= 1.7\,\mathrm{tCO_2} \quad (4.8\,\mathrm{tCO_2})$$

*Carbon budget defined from the beginning of 2020 until global carbon neutrality is achieved

Trends in Ground Temperature

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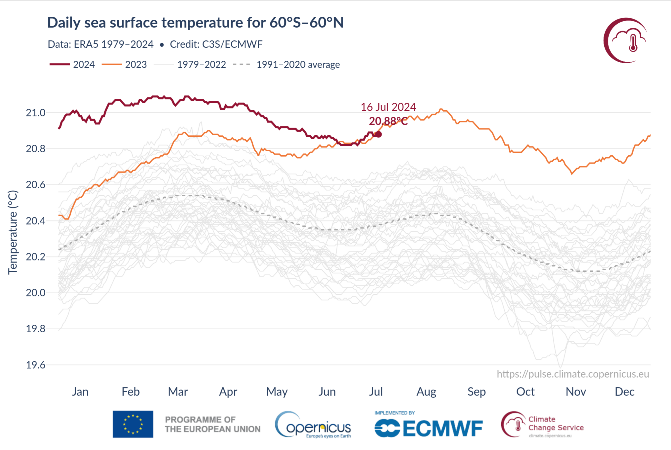
- Data from Copernicus Satellite $\rightarrow$ daily sea surface temperature since 1979
  - Strongest anomaly observed in January 2024 $\Rightarrow$ March 2024 hottest month



- Comparing last 12 months with 1850–1900 average $\Rightarrow$ Global average $1.64^\circ\mathrm{C}$ higher

Already reached and surpassing the ideal target of $1.5^\circ\mathrm{C}$ set by Paris climate agreement 2015!

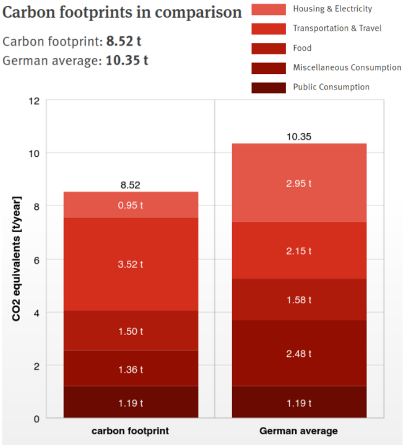
https://climate.copernicus.eu/surface-air-temperature-june-2024

In order to mitigate climate change, *ALL* areas of society need to contribute towards reducing emissions
⇒ This includes HEP!

- HEP has significant CO_2 emissions
  ⇒ Seen in recent environmental reports
- But how large per-researcher? ⇒ **Know your footprint!**
  - Estimate professional CO_2 footprint per researcher
    ⇒ Allows comparison with private and target footprints
    ⇒ Strong focus on the German scenario
  - Identify dominant sources of emissions
  - Devise strategies to address biggest sources first

Steps to solve a problem: Acknowledge → **Identify** → Strategise → Implement

- Know your footprint (Kyf) calculator → tool to estimate carbon emissions for researchers
  - Private emissions in Germany: Carbon Calculator by German Federal Environment Ministry (UBA)*
  - Professional emissions in HEP and related fields → split into 4 categories:
    - ⇒ Experiment
    - ⇒ Institute
    - ⇒ Computing
    - ⇒ Travel



- Each category configurable for an individual, i.e. for your individual research situation
- Investigate the impact of each category

- Know your footprint calculator now live: Kyf calculator
- Paper discussing the basis of Kyf calculator available online on arXiv: arXiv:2403.03308

*Permission duly granted by UBA

Experiment, Collaboration or Project

- Possible choices offered:
  - Large LHC experiment
  - Small LHC experiment
    } CERN environmental report(s) and LHCb technical design report
  - Small HEP experiment* → DESY electricity consumption
  - Astrophysics experiment → ESO annual report

Benchmark Experiment	Footprint [tCO_2e]
Large LHC	11.91
Small LHC	8.76
Small HEP	16.68 (1.40)
Astrophysics	0.88

- Estimate annual per-researcher footprint:
  - (Total annual experiment footrint)/(Total experiment members)
  - Experiment member → collaboration members or users (and operators) as per applicability
  - Do not consider indirect benefits to society → too vague and diffuses responsibility
  - We researchers designing, building and operating detectors, and analysing data must take responsibility

*Choice between green (100 % photovoltaic) and conventional (German mix 2023) electricity

- Possible choices offered:
  - Research centre → CERN environmental report(s)
  - University* → University of Freiburg environmental report (Cross check with Leibniz University Hannover)

Benchmark Institute	**Footprint** [tCO_2e]
Research Centre	16.65
University	1.54 (1.00)

- Estimate annual per-researcher footprint:
  - (Total annual institute footrint)/(Effective number of institute members)
  - One year outside COVID-19 pandemic considered representative
    ⇒ 2019 for University of Freiburg, 2022 for CERN
  - University of Freiburg preferred over Leibniz University Hannover as default university footprint:
    - ⇒ Procurement information omitted by Leibniz University Hannover
    - ⇒ Decent agreement in overlapping categories

*Choice between green (100 % photovoltaic) and conventional (German mix 2023) electricity

- Focus on high-performance computing (HPC)
  - Specify researcher's individual computing workload in core hours
  - Distinguish between CPU and GPU → based on computational task
    - ⇒ Several possibilities to tune configuration
    - ⇒ Assume optimal core utilisation
- Potential to add footprint for large external data storage resources
- Personal computers, small institute clusters, etc.
  ⇒ Assumed to be covered by personal or institute electricity and procurement
- Benchmark scenarios provided for user-friendliness

$$\text{Footprint} = f_{\text{PUE}} \cdot f_{\text{overh}} \cdot n_{\text{WPC}} \cdot f_{\text{conv}},$$

$$n_{\text{WPC}} = p_{\text{CPU-core}} \cdot l_{\text{core-h,CPU}} + p_{\text{GPU}} \cdot l_{\text{h,GPU}}$$

$$p_{\text{CPU-core}} = 7.25\,\text{W}, \quad p_{\text{GPU}} = 250\,\text{W}$$

$$f_{\text{conv}} = 416\,\text{gCO}_2\text{e/kWh} \quad (35\,\text{gCO}_2\text{e/kWh})$$

Benchmark Scenario	Usage per month	Footprint* [tCO_2e]
Low	4000 CPU core-h	0.25
Medium	30 000 CPU core-h	1.91
High	2500 GPU h	5.48
Very high	8000 GPU h	17.52

*Here using conventional (German mix 2023) electricity

Business Travel

- Only considering business travel
  ⇒ Private travel included in private footprint
- International research environment
  ⇒ Travel important for personal connections
  - Most notably missed during COVID-19 pandemic
- But travel leads to CO_2 emissions
  ⇒ Need to reconsider which trips are essential
  - Avoid air travel if possible
  - More flexibility in business trips (combination, etc.)

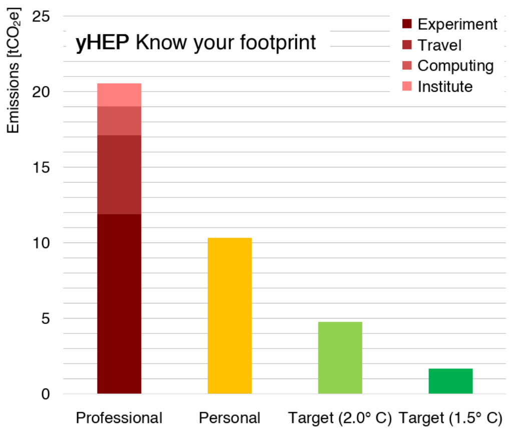
Benchmark Trip	**Footprint** [tCO_2e]
Train within Europe (1 week)	0.111
Flight within Europe (1 week)	0.711
Transcontinental flight (2 weeks)	4.267

- Possibility for detailed calculations for business trips in Kyf calculator
- Alternatively, also possible to configure with benchmark trips

Benchmark Researcher

- Doctoral researcher as a benchmark case:
  - Working on a large LHC experiment
  - Employed by a university (conventional electricity)
  - Medium computing level (conventional electricity)
  - Annual travel:
    - ⇒ Two 1-week trips by train in Germany
    - ⇒ One 1-week flight travel in Europe
    - ⇒ One 2-week transcontinental travel

- Professional footprint double of private footprint
- Both far above the targets set in Paris agreement
- HEP researchers urgently need to address this
  ⇒ Become part of the solution to the climate crisis!



Summary

- Climate crisis progressing and intensifying each year
  - Relation between atmospheric CO_2 and ground temperature known since ≈ 130 years
  - However, targeted action still missing today!
- HEP and related fields contribute to global emissions
  - Estimate per-researcher emissions $\rightarrow$ Know your footprint
  - Four categories: Experiment, Institute, Computing, Travel
  - Evaluation of benchmark researcher:
    $\Rightarrow$ Total footprint ≈ 6 (≈ 18) times larger than what is needed for the 2.0°C (1.5°C) target

$\Rightarrow$ Know your footprint to know where to start!

$\Rightarrow$ Every gram of CO_2 not emitted counts!

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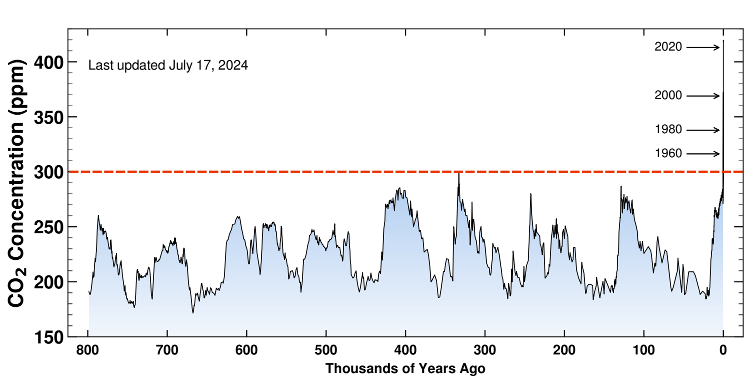
$\Rightarrow$ Every gram of CO_2 not emitted counts!

Please consider submitting your results $\Rightarrow$ provides us better statistics to understand trends

Backup

Trends in Atmospheric CO_2 Concentration

- Keeling curve using measurements since 1958 at Mauna Loa Observatory
  - Combined with data from ice cores over last 800k years
    ⇒ Composition of air trapped in ice from Antarctica

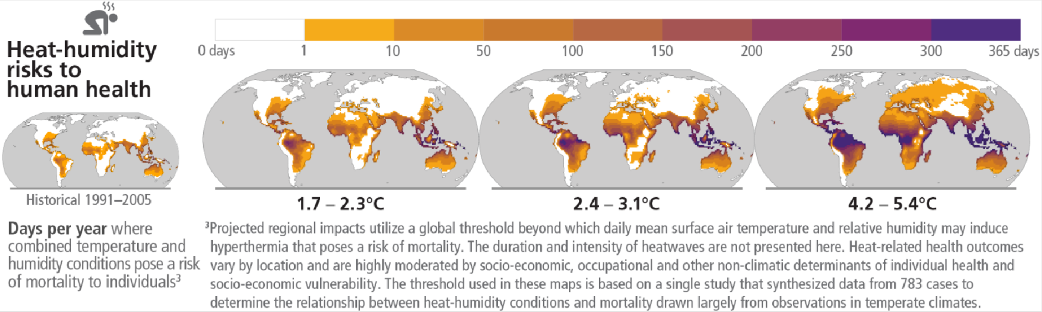


https://keelingcurve.ucsd.edu/

Latest reading: $425.62\,\mathrm{ppm}$

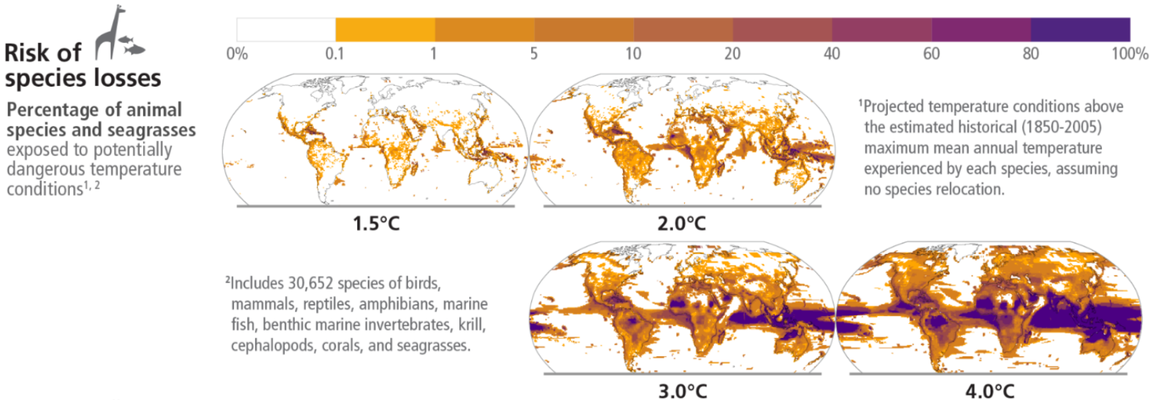
- Currently $40\,\%$ higher than the maximum in past 800k years
- Extremely significant deviation from the observed variation

- Projections for impact of climate change on natural and human systems:
  - With $> 2^\circ\mathrm{C}$ rise in temperature, risks posed in regions around the equator:
    - ⇒ Risk of losing $100\,\%$ of animal species
    - ⇒ Risk of Hyperthermia* due to heat-humidity conditions *throughout the year*



https://report.ipcc.ch/ar6syr/pdf/IPCC_AR6_SYR_LongerReport.pdf

*Hyperthermia: Failure of heat-regulating mechanisms of the body due to extreme external heat



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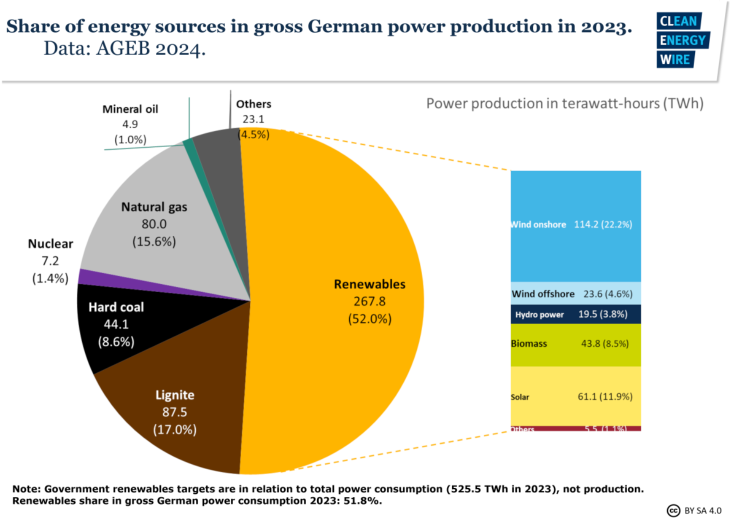
German Conventional Electricity Mix



Scope 1

	Year	Total	Corrected
Run	2017	193 600	168 293
	2018	192 100	162 718
	2022	184 173	152 444
	Mean	-	161 151
Shutdown	2019	78 169	56 446
	2020	98 997	75 958
	2021	123 174	89 547
	Mean	-	73 984

Scope 2

	Year	Total	Corrected
Run	2017	66 667	63 333
	2018	74 884	71 140
	2022	63 161	60 003
	Mean	-	64 825
Shutdown	2019	28 527	27 101
	2020	26 202	24 891
	2021	56 382	53 563
	Mean	-	35 185

	Phase	Scope 1	Scope 2	Total
Small	Run	2244	16 206	18 450
	SD	1030	8796	9826
	Overall	-	-	14 754
Large	Run	78 332	16 206	94 538
	SD	35 962	8796	44 758
	Overall	-	-	73 204

	Experiment	Members	Mean	Emissions
Small	ALICE	1968 [23]	1684	8.76 tCO_2e
	LHCb	1400 [24]		
Large	CMS	6288 [25]	6144	11.91 tCO_2e
	ATLAS	6000 [26]		

- $\text{Overall} = \dfrac{4 \times \text{Run} + 3 \times \text{SD}}{7}$

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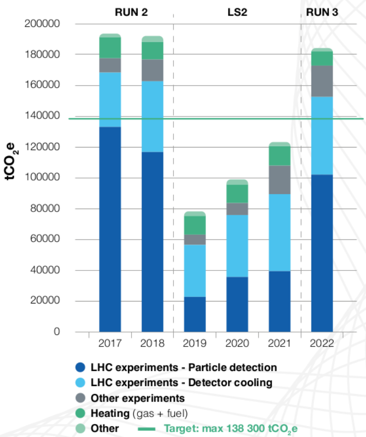
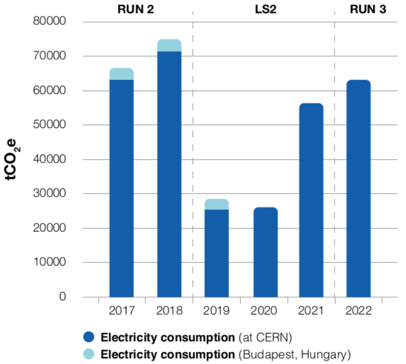
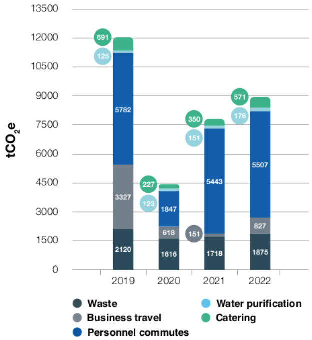


CERN SCOPE 1 EMISSIONS FOR 2017–2022 BY CATEGORY
"Other" includes air conditioning, electrical insulation, emergency generators and the fuel consumption of the CERN vehicle fleet.



CERN SCOPE 2 EMISSIONS FOR 2017–2022
Emission calculations for electricity follow a location-based methodology, with average yearly emission factors taken from ADEME Base Empreinte©. From 2017 to 2019, CERN operated a data centre at the Wigner Centre in Budapest, Hungary, for which the emissions are also shown. The location-based emission factors used for Hungary were taken from Bilan Carbone® V8.4.



CERN'S SCOPE 3 EMISSIONS 2019–2022 (EXCLUDING PROCUREMENT)
"Waste" includes the waste that is sent through the different elimination pathways, as well as the water that is sent to wastewater treatment plants. For emissions related to business travel and personnel commutes, only personnel on CERN's payroll are included. The calculation methodology is aligned with the GHG protocol; the emission factors were retrieved from the Ecoinvent database, and the impact method used was IPCC 2021 GWP100 V1.01. All data from previous reporting years has been recalculated for this report. Emissions arising from procurement are not included and are reported separately.

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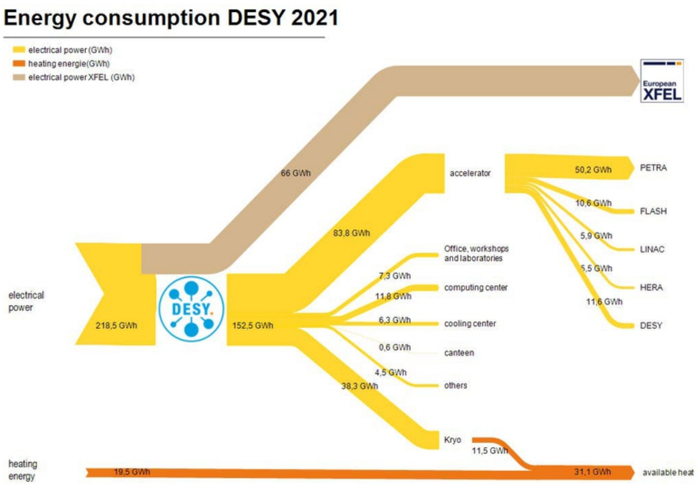

- Excluded: XFEL, offices, workshops, labs, canteen, computing centre and others

Experiments: ESO

Category	Emission
Energy (E)	8599
Purchase (P)	5924
Freight (F)	2675
Travel (T)	191
Commuting (C)	1083
Capital Goods (CG)	2166
Waste (W)	127
Total	20 764
Corrected	19 363

- Corrected = Total − T − C − W

Category	Emissions [tCO_2e]
Electricity	2431 (19 224)
Heating/Cooling	13 584
Water	14
Waste	577
Procurement	14 486
Total	31 092 (47 885)

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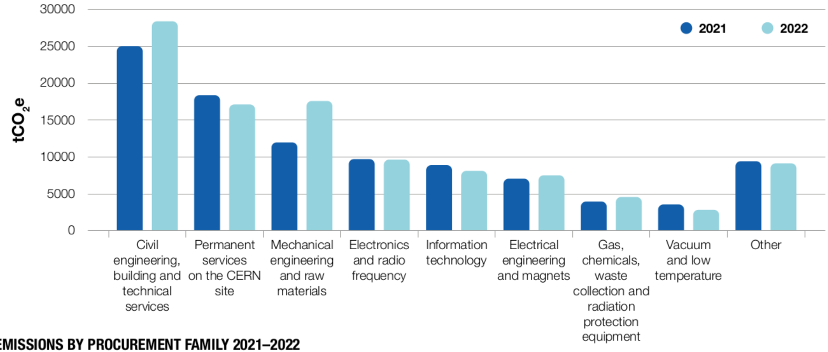
Category	Emissions [tCO_2e]
Electricity	3158
Heating (gas+fuel) + Other	11 250
Water purification	176
Waste	1875
Procurement	104 974
Total	121 433
Total without Procurement	16 459

CERN (Research Centre)



EMISSIONS BY PROCUREMENT FAMILY 2021–2022

"Other" includes: office supplies, furniture, transport, handling and vehicles; centralised expenses and codes for internal use; particle and photon detectors; health, safety and environment; optics and photonics.

Business Travel

Source of Emission	Emission Factor	
Long-distance Buses	0.031	$kgCO_2e/km$
Long-distance Trains	0.031	$kgCO_2e/km$
Personal Car	0.17	$kgCO_2e/km$
Flights within Europe	130	$kgCO_2e/h$
Transcontinental Flights	170	$kgCO_2e/h$
Hotel room	12	$kgCO_2e/night$
Event venue	0.19	$kgCO_2e/day$

- Long-distance buses and trains have equal impact by chance:
  - TTW for Buses much higher than for trains
  - Compensated by WTT for trains (German conventional mix) and infrastructure