

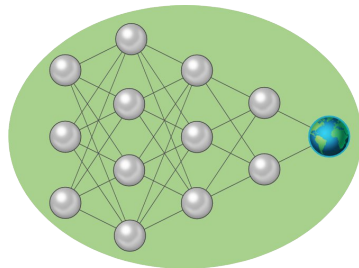
universität freiburg

# Know Your Footprint! — Webpage and Plans

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University of Freiburg

PEARLS Days 2026, Freiburg

Tuesday, 22<sup>nd</sup> September 2026



## PEARLS

Precision in Energy-aware AI Research  
for Low-carbon Solutions

With funding from the:



Federal Ministry  
of Research, Technology  
and Space



- First publication on the relation between atmospheric CO<sub>2</sub> and ground temperature ► S. Arrhenius, 1896
  - Increase in CO<sub>2</sub> levels by factor of 2 → temperature increase of  $\approx 6^{\circ}\text{C}$
  - Surprising accuracy already 130 year ago
  - Confirmed and refined since then in a multitude of studies → 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. |
| Europe 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               |
| 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](https://treaties.un.org/doc/Treaties/2016/02/20160215%2006-03%20PM/Ch_XXVII-7-d.pdf)

- Temperature targets set to 1.5°C (2.0°C) above pre-industrial levels (1850–1900)  
⇒ Translates to global carbon budget\* of 400 GtCO<sub>2</sub> (1150 GtCO<sub>2</sub>)
- Naively assuming equal yearly emissions from 2020–2050 for a static population of 8 billion people:

$$\begin{aligned} \text{Annual per person carbon budget} &= \frac{400 \times 10^9 \text{ tCO}_2}{30 \text{ years} \times 8 \times 10^9 \text{ people}} & \left( \frac{1150 \times 10^9 \text{ tCO}_2}{30 \text{ years} \times 8 \times 10^9 \text{ people}} \right) \\ &= 1.7 \text{ tCO}_2 & (4.8 \text{ tCO}_2) \end{aligned}$$

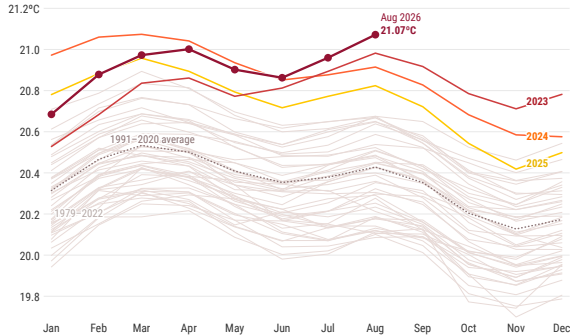
\*Carbon budget defined from the beginning of 2020 until global carbon neutrality is achieved



- ▶ Data from Copernicus Satellite → daily sea surface temperature since 1979
  - Strongest anomalies observed in January 2024 →  $1.65^{\circ}\text{C}$  above 1991–2020 average

## Monthly sea surface temperature for $60^{\circ}\text{S}$ – $60^{\circ}\text{N}$

Data: ERA5 • Credit: C3S/ECMWF



- ▶ August 2026 hottest month ever  
⇒  $1.65^{\circ}\text{C}$  above 1850–1900 average

Already reached and surpassing  
the ideal target of  $1.5^{\circ}\text{C}$   
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!

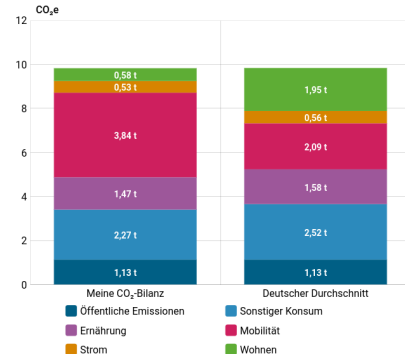


- ▶ HEP has significant CO<sub>2</sub> emissions  
⇒ Seen in recent environmental reports
- ▶ But how large per-researcher? ⇒ **Know your footprint!**
  - Estimate professional CO<sub>2</sub> footprint per researcher  
⇒ Allows comparison with private and target footprints  
⇒ Strong focus on the German scenario
  - Identify dominant sources of emissions
  - Devise strategies to address biggest sources first

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



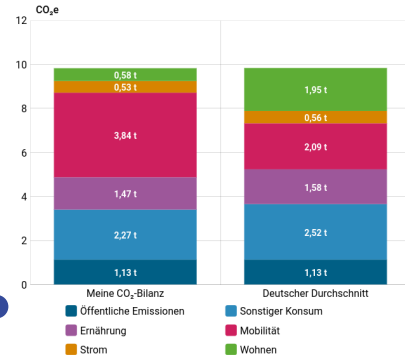
- ▶ Know your footprint (Kyf) calculator → tool to estimate carbon emissions for researchers
    - Private emissions in Germany: ▶ Carbon Calculator by German Federal Environment Ministry (UBA)\*
    - Professional emissions in HEP and related fields → split into 4 categories:
      - ⇒ Experiment
      - ⇒ Institute
      - ⇒ Computing
      - ⇒ Travel
- Each category configurable for an individual, i.e. for your individual research situation
  - Investigate the impact of each category



\*Permission duly granted by UBA



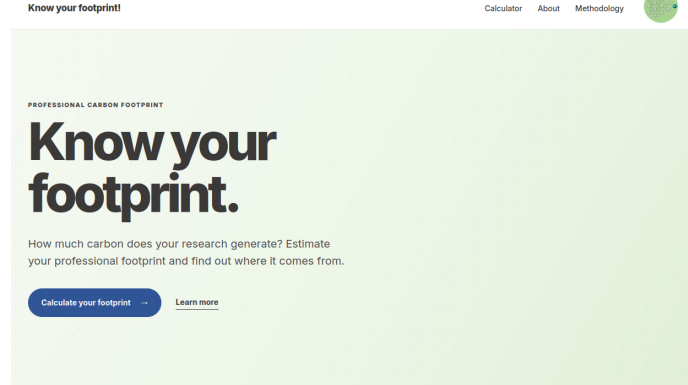
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      - ⇒ Computing
      - ⇒ Travel
- Each category configurable for an individual, i.e. for your individual research situation
  - Investigate the impact of each category
- ▶ The Kyf calculator was the inception of the PEARLS project
  - ▶ Paper discussing the basis of Kyf calculator: ▶ [npj Clim. Action 4 \(2025\) 28](#)
  - ▶ Know your footprint calculator is currently down
    - ⇒ Access to previous survey tool lost



\*Permission duly granted by UBA



- ▶ Migrating the Kyf calculator to a dedicated webpage
  - Freedom for customisability
  - Avoids issues with managing rights
  - Long-term stability
- ▶ Bought webhosting package and domains from [manitu](#)
  - Dedicated servers in Germany
  - Respect data privacy regulations
  - Strong focus on sustainability and ecological responsibility
- ▶ Webpage under development:
  - ▶ [www.know-your-footprint.com](http://www.know-your-footprint.com)
    - Additional TLDs (.de and .eu), which redirect to main webpage  
⇒ Avoid future conflicts





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YOUR RESEARCH FOOTPRINT

## Measure what matters.

The calculator estimates the CO<sub>2</sub>-equivalent emissions associated with your professional research activities.

01

### Experiments

Large research infrastructures, collaborations and experimental projects.

02

### Institutions

The resources and energy associated with your university or research centre.

03

### Computing

Simulation, data analysis and, where applicable, data storage.

04

### Travel

Professional journeys to conferences, meetings, workshops and other destinations.

READY TO START?

Get your footprint in a few minutes.

Start the calculator →



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WHY THIS CALCULATOR?

## Research has a footprint too.

Scientific research depends on energy-intensive infrastructures, computing resources, institutions and travel. Knowing the scale and sources of your professional footprint is a first step towards understanding where reductions can be made.

**Know your footprint** is designed for researchers in high-energy physics and related fields, with a methodology that can be adapted to other research communities.

[Explore the methodology --](#)

TRANSPARENT BY DESIGN

## Understand the estimate.

The calculator is based on the published *Know your footprint* study. Its estimates and assumptions are documented so that users can understand what contributes to their result.

[Read the paper](#)



## ► Possible choices offered:

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

| Benchmark Experiment | Footprint [tCO <sub>2</sub> e] |
|----------------------|--------------------------------|
| 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 footprint)/(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<br>Institute | Footprint<br>[tCO <sub>2</sub> e] |
|------------------------|-----------------------------------|
| Research Centre        | 16.65                             |
| University             | 1.54 (1.00)                       |

► Estimate annual per-researcher footprint:

- (Total annual institute footprint)/(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 <sub>2</sub> e] |
|--------------------|-------------------|---------------------------------|
| 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



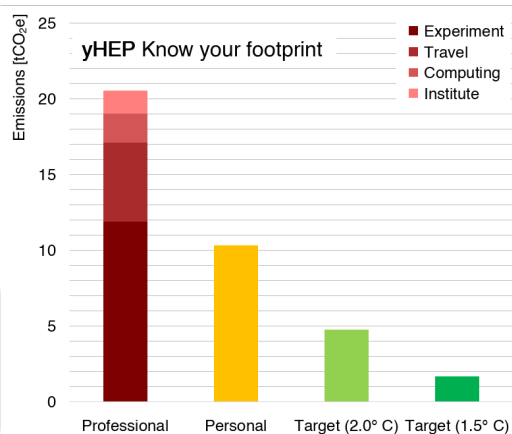
- ▶ Only considering business travel  
⇒ Private travel included in private footprint
- ▶ International research environment  
⇒ Travel important for personal connections
  - Most notably missed during COVID-19 pandemic
- ▶ But travel leads to CO<sub>2</sub> emissions  
⇒ Need to reconsider which trips are essential
  - Avoid air travel if possible
  - More flexibility in business trips (combination, etc.)
- ▶ Possibility for detailed calculations for business trips in Kyf calculator
- ▶ Alternatively, also possible to configure with benchmark trips

| Benchmark Trip                    | Footprint<br>[tCO <sub>2</sub> e] |
|-----------------------------------|-----------------------------------|
| Train within Europe (1 week)      | 0.111                             |
| Flight within Europe (1 week)     | 0.711                             |
| Transcontinental flight (2 weeks) | 4.267                             |



- ▶ 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!





- ▶ Climate crisis progressing and intensifying each year
  - Relation between atmospheric CO<sub>2</sub> and ground temperature known since  $\approx 130$  years
  - However, targeted action still missing today!
- ▶ HEP and related fields contribute to global emissions
  - Estimate per-researcher emissions → Know your footprint
  - Four categories: Experiment, Institute, Computing, Travel
- ▶ Migrate calculator to its own dedicated webpage
  - Currently v1.0 under development
  - Plans for future
    - ⇒ Updated calculations with newer environmental reports
    - ⇒ Inclusion of more options to cover a wider audience

⇒ Know your footprint to know where to start!

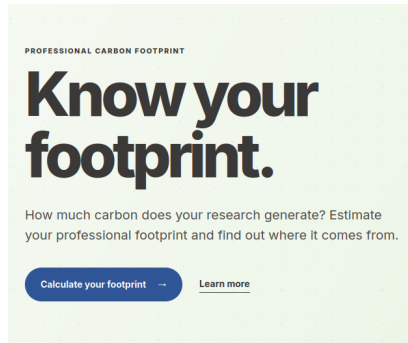
⇒ Every gram of CO<sub>2</sub> not emitted counts!



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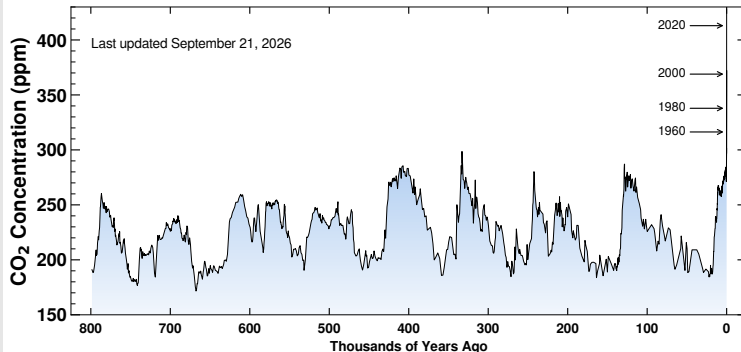


Stay tuned for v1.0 of the Kyf calculator on its dedicated webpage

**Backup**



- ▶ 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



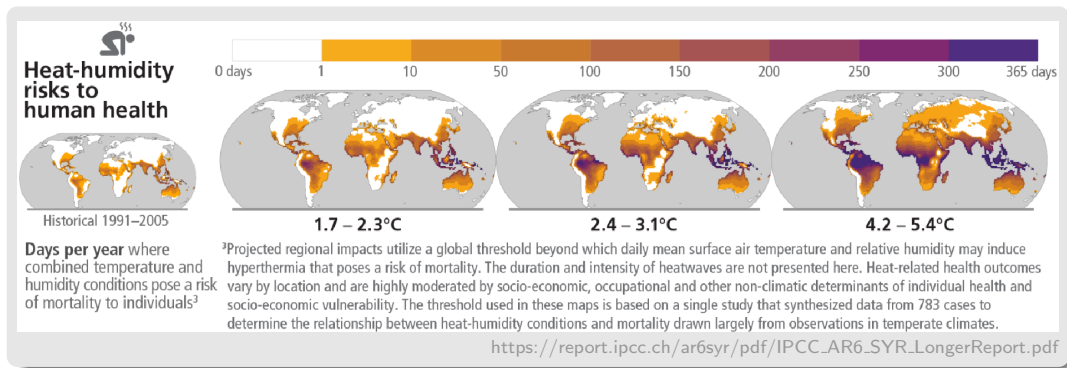
Latest reading: 426.00 ppm

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

<https://keelingcurve.ucsd.edu/>



- Projections for impact of climate change on natural and human systems:
  - With  $> 2^{\circ}\text{C}$  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*

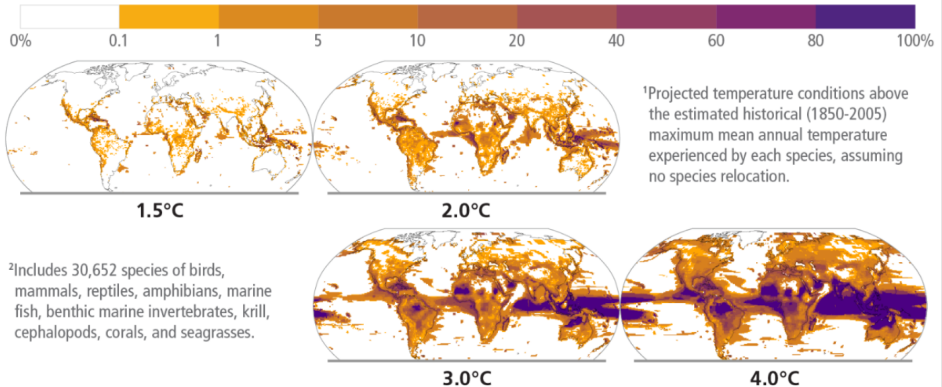


\*Hyperthermia: Failure of heat-regulating mechanisms of the body due to extreme external heat



## Risk of species losses

Percentage of animal species and seagrasses exposed to potentially dangerous temperature conditions<sup>1, 2</sup>

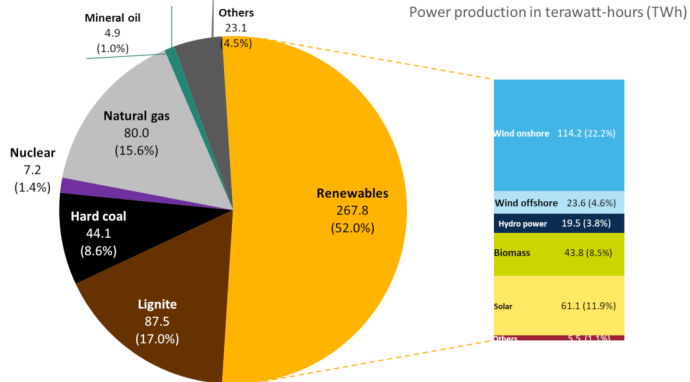


[https://report.ipcc.ch/ar6syr/pdf/IPCC\\_AR6\\_SYR\\_LongerReport.pdf](https://report.ipcc.ch/ar6syr/pdf/IPCC_AR6_SYR_LongerReport.pdf)



## Share of energy sources in gross German power production in 2023. Data: AGEB 2024.

CLEAN  
ENERGY  
WIRE



Note: Government renewables targets are in relation to total power consumption (525.5 TWh in 2023), not production. Renewables share in gross German power consumption 2023: 51.8%.

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## 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    |

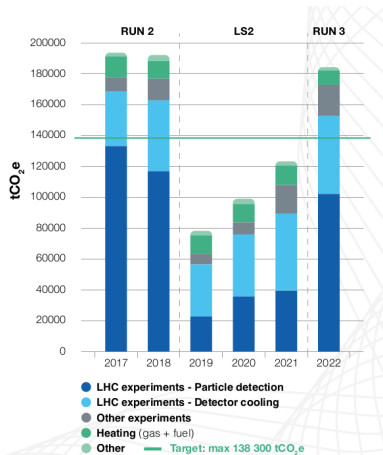
## Scope 2

|          | 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 |

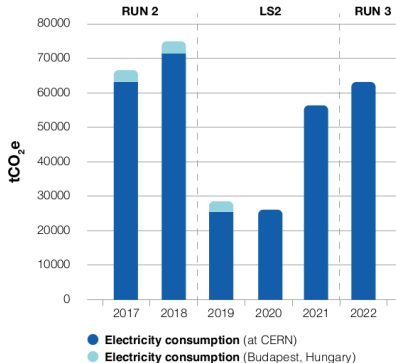
|       | Experiment | Members   | Mean | Emissions                |
|-------|------------|-----------|------|--------------------------|
| Small | ALICE      | 1968 [23] | 1684 | 8.76 tCO <sub>2</sub> e  |
|       | LHCb       | 1400 [24] |      |                          |
| Large | CMS        | 6288 [25] | 6144 | 11.91 tCO <sub>2</sub> e |
|       | ATLAS      | 6000 [26] |      |                          |

► Overall =  $\frac{4 \times \text{Run} + 3 \times \text{SD}}{7}$



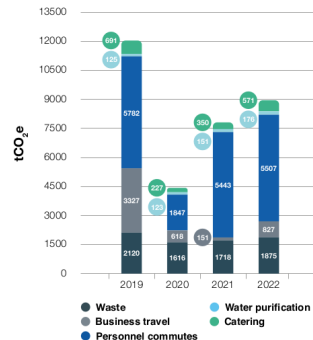
## CERN SCOPE 1 EMISSIONS FOR 2017–2022 BY CATEGORY

"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.

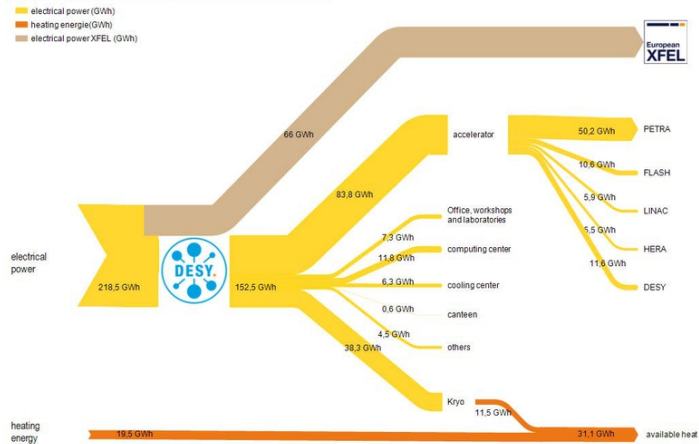


## CERN'S SCOPE 3 EMISSIONS 2019–2022 (EXCLUDING PROCUREMENT)

"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.



## Energy consumption DESY 2021



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



| 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   |

►  $\text{Corrected} = \text{Total} - T - C - W$

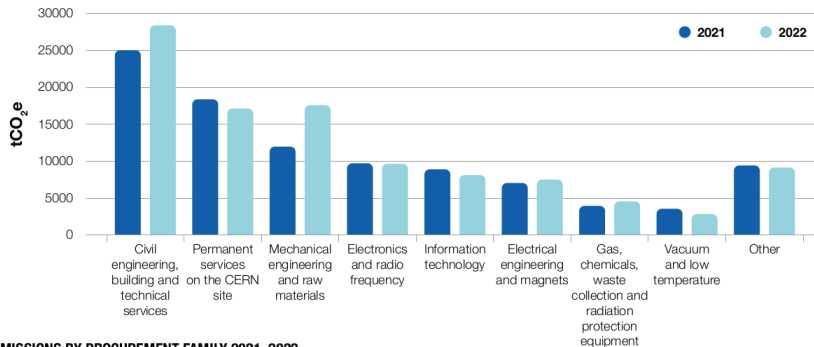


| Category        | Emissions [tCO <sub>2</sub> e ] |
|-----------------|---------------------------------|
| Electricity     | 2431 (19 224)                   |
| Heating/Cooling | 13 584                          |
| Water           | 14                              |
| Waste           | 577                             |
| Procurement     | 14 486                          |
| Total           | 31 092 (47 885)                 |

University of Freiburg

| Category                   | Emissions [tCO <sub>2</sub> e ] |
|----------------------------|---------------------------------|
| 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.



| Source of Emission       | Emission Factor |                           |
|--------------------------|-----------------|---------------------------|
| Long-distance Buses      | 0.031           | kgCO <sub>2</sub> e/km    |
| Long-distance Trains     | 0.031           | kgCO <sub>2</sub> e/km    |
| Personal Car             | 0.17            | kgCO <sub>2</sub> e/km    |
| Flights within Europe    | 130             | kgCO <sub>2</sub> e/h     |
| Transcontinental Flights | 170             | kgCO <sub>2</sub> e/h     |
| Hotel room               | 12              | kgCO <sub>2</sub> e/night |
| Event venue              | 0.19            | kgCO <sub>2</sub> e/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