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Know your footprint – Evaluation of the professional carbon footprint for individual researchers in high energy physics and related fields

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With the ever-increasing requirement for sustainability in the modern age, it is crucial to understand the environmental impact of High Energy Physics (HEP) and related fields, especially considering the field's high resource consumption. The *Know your footprint* initiative attempts to quantify the carbon footprints associated with four categories: Experiment, corresponding to the large infrastructure within HEP collaborations; Institute, accounting for the emissions from research institutes and universities; Computing, covering the resource consumption for data analysis and running simulations; and Travel, accommodating business trips for conferences, workshops, and meetings. A survey for self-evaluation was devised based on these studies, enabling colleagues to estimate their professional footprint. The *Know your footprint* campaign aims to raise awareness, identify the dominant contributing factors to the HEP-related footprint, and motivate the community to move towards more sustainable research practices. These proceedings summarise the above-mentioned efforts.

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1. Introduction

The relationship between atmospheric CO_2 and ground temperature was first studied in 1896 [1], i.e. more than 100 years ago. Nowadays, the effects of abnormally high CO_2 concentrations in the atmosphere can be observed all over the planet in the form of climate change.

In order to mitigate climate change, the Paris agreement of 2015 [2] set a target to restrict the increase in global average temperature above pre-industrial (1850–1900) levels to "well below 2.0°C" and aimed to pursue efforts to limit it to 1.5°C. This translates to a global carbon budget of 1150 $GtCO_2e$ (400 $GtCO_2e$) for a target of 2.0°C (1.5°C). This global carbon budget is defined from the beginning of 2020 until global carbon neutrality is achieved. Naively assuming equal yearly emissions from 2020–2050 for a static population of 8 billion people, this results in an annual per person carbon budget of 4.8 tCO_2e (1.7 tCO_2e) for a target of 2.0°C (1.5°C).

Following data from the Copernicus satellite, which monitors daily sea surface temperature since 1979, current trends show that March 2024 was globally the hottest month, while January 2024 showed the strongest anomaly on comparing with the 1991–2020 average [3]. Additionally, the global average temperature from July 2023–June 2024 was observed to be 1.64°C higher than the global average for 1850–1900 [4], which has already surpassed the ideal target of 1.5°C set by the Paris agreement of 2015.

In view of these trends, there is a dire need for dedicated action towards the reduction of carbon footprint from *all* sectors of society. This includes high energy physics (HEP), which has significant CO_2 emissions as seen in recent environmental reports, e.g. from CERN [5–7]. The *Know your footprint* (Kyf) campaign [8, 9] by the *young High Energy Physicists* (yHEP) association [10] targets to estimate the professional footprint for individual researches in HEP and related fields. This will facilitate the identification of the most dominant sources of carbon emissions at an individual level and allow researchers to devise strategies to address them.

2. *Know your footprint* (Kyf) calculator

The Kyf calculator [9] is an online tool that allows researchers in HEP and related fields, in or associated to Germany, to estimate their individual carbon emissions. For the estimation of the private footprint, it refers to the *Carbon Calculator* by the German Federal Environment Agency (*Umweltbundesamt* – UBA) [11–13]. For the professional emissions, the tool targets four distinct categories: *Experiments*, *Institutes*, *Computing* and *Travel*. All four categories are customisable for an individual researcher's situation and provides benchmark scenarios to make the tool user-friendly. The basis of the calculations, along with all sources and assumptions used for the Kyf calculator, are described in Ref. [8] and are summarised in the following sections.

2.1 Experiment, collaboration or project footprint

The *experimental* footprint accounts for the emissions from research infrastructures, which plays an important role in experimental HEP, where large experiments are currently driving the research. The Kyf calculator provides four benchmark scenarios for this category: *Large LHC experiment*, *Small LHC experiment*, *Small HEP experiment* and *Astrophysics experiment*.

The large (small) LHC experiments refer to the ATLAS and CMS (ALICE and LHCb) experiments. Their total footprint is estimated using the environmental reports from CERN [5–7] and the technical design report from the LHCb collaboration for the phase-II upgrade [14]. The benchmark scenario for small HEP experiment uses the DESY electricity consumption replicated in Figure 1 of Ref. [8]. The Kyf calculator provides a choice between green (100% photovoltaic) and conventional (German mix 2023) electricity for this case. The last benchmark scenario for an astrophysics experiment is based on the 2022 annual report of the European Southern Observatory (ESO) [15].

In order to estimate the annual per-researcher footprint, the total annual footprint for the experiments are divided among their respective collaboration members or users as per applicability. Any indirect benefit to the society is not considered, since the definitions of the benefits and the beneficiaries in this case are too vague and lead to diffusion of responsibility. The researchers designing, building and operating detectors, and analysing the data must take the responsibility for the associated carbon emissions.

The estimation results in an annual per-researcher footprint of 11.91 tCO_2e (8.76 tCO_2e) for large (small) LHC experiments. A small HEP experiment results in an annual per-researcher carbon footprint of 16.68 tCO_2e (1.40 tCO_2e) assuming conventional (green) electricity. A researcher affiliated to ESO would bear an annual footprint of 0.88 tCO_2e.

2.2 Institute footprint

Institutes within universities and research centres form an integral part of a researcher's workplace, while also contributing to their environmental footprint. The Kyf calculator offers two benchmark scenarios to the users: *University*, based on the environmental report by the University of Freiburg for 2019–2020 [16], and *Research centre*, based on the environmental report of CERN for 2021–2022 [7].

In order to obtain a representative number, a year outside the COVID-19 pandemic was chosen for both benchmark scenarios. This corresponds to 2019 for the University of Freiburg and 2022 for CERN. For the *University* scenario, the Kyf calculator allows the user to choose between the conventional and green electricity. The environmental report from the Leibniz University Hannover for 2017–2019 [17] was employed to validate the footprint for universities. Decent agreement between both universities for the overlapping categories was obtained, however, due to the lack of information on procurement by the Leibniz University Hannover, University of Freiburg was chosen as the default case for the *University* scenario. Procurement is included in the institute footprint of CERN, although it contains contributions that rather belong to the experimental footprint of future machines. The currently available information is, however, too coarse for a detailed split up, increasing the footprint of CERN as a research institute.

The annual per-researcher institute footprint is estimated by dividing the total annual footprint among the effective number of institute members. This results in a value of 1.54 tCO_2e (1.00 tCO_2e) for universities using conventional (green) electricity and 16.65 tCO_2e for research centres.

2.3 Computing footprint

Research in HEP and related fields strongly relies on the use of high-performance computing (HPC) clusters for running simulations and analysing huge volumes of data. The Kyf calculator allows researchers to specify their individual computing workload in CPU core hours ($l_{\text{core-h,CPU}}$) and GPU hours ($l_{\text{h,GPU}}$). The annual workload power consumption (WPC) is calculated as

$$n_{\text{WPC}} = p_{\text{CPU-core}} \cdot l_{\text{core-h,CPU}} + p_{\text{GPU}} \cdot l_{\text{h,GPU}}, \tag{1}$$

with $p_{\text{CPU-core}} = 7.25\,\text{W}$ and $p_{\text{GPU}} = 250\,\text{W}$ as the power consumptions of a CPU core and a GPU, respectively. The annual computing footprint of a researcher is then given by

$$\text{Footprint} = f_{\text{PUE}} \cdot f_{\text{overh}} \cdot n_{\text{WPC}} \cdot f_{\text{conv}}, \tag{2}$$

with $f_{\text{PUE}} = 1.5$ as the power usage effectiveness of the HPC, $f_{\text{overh}} = 1.17$ as an overhead factor accounting for idle times of the HPC, and $f_{\text{conv}} = 416\,\text{gCO}_2\text{e/kWh}$ ($35\,\text{gCO}_2\text{e/kWh}$) as the conversion factor for conventional (green) electricity.

The working conditions of the HPC can be customised in the Kyf calculator by changing the default values of f_{PUE} and f_{overh}. Additionally, there is a possibility to add footprints for large external data storage resources. To allow for user-friendliness, four benchmark scenarios are defined and are described in Table 1. It should be noted that this category only caters to emissions from the usage of HPCs. Usage of personal computers and small institute clusters are assumed to be covered by the personal or institute footprint.

Benchmark	**Monthly usage**	**Footprint** [tCO_2e]
Low	4000 CPU core-h	0.25 (0.02)
Medium	30000 CPU core-h	1.91 (0.16)
High	2500 GPU h	5.48 (0.46)
Very high	8000 GPU h	17.52 (1.47)

Table 1: Benchmark scenarios defined in the Kyf calculator for computing. The annual footprint is calculated using the default values for the HPC working conditions and assuming conventional (green) electricity.

2.4 Business travel footprint

By virtue of large worldwide collaborations, HEP and related fields have an intrinsically international research environment. This makes business travel a inherent part of the field to strengthen personal connections, which was notably missed during the COVID-19 pandemic. However, travelling results in emissions, making it essential for researchers to critically review their travelling habits. While personal travel is considered in personal footprints, business trips fall under professional footprint of a researcher. The Kyf calculator facilitates detailed calculations for business travels by allowing to enter the total distance travelled by various modes of transport, nights spent in hotels, and the duration event venues were in use. Alternatively, users may configure their total annual business travel footprint using three benchmark trips provided in the Kyf calculator.

The first benchmark trip considers a one-week long event within Europe with train as the mode of transportation, which yields a footprint of $0.111\,\text{tCO}_2\text{e}$. The second benchmark trip assumes similar conditions but with intra-European air travel as the mode of transportation, resulting in a footprint of $0.711\,\text{tCO}_2\text{e}$. The third benchmark trip pertains to a two-week long event outside Europe with a transcontinental flight as the mode of transportation, rendering a footprint of $4.267\,\text{tCO}_2\text{e}$. The users can add multiple trips to fit their individual case.

3. Professional footprint example

In order to exemplify the working of the Kyf calculator, Ref. [8] illustrates the footprint of a benchmark researcher. This researcher is assumed to be a doctoral researcher working on one of the large LHC experiments and employed by a German university using conventional electricity. The researcher is assumed to have a medium computing level, with the HPC also running on conventional electricity. Additionally, the researcher is assumed to have an annual travel of two one-week trips by train within Germany, one week-long trip in Europe by flight and one two-week transcontinental travel. This results in an annual professional footprint of 20.56 tCO_2e, which needs to be considered in addition to the personal footprint.

Figure 1 compares this illustration to the average personal footprint in Germany of 10.35 tCO_2e and the targets set by the Paris agreement. The comparison depicts that the professional footprint for this benchmark researcher is twice as large as the average personal footprint in Germany, which is far above the targets from the Paris agreement. This reiterates the urgency for HEP researchers to address this issue and become an active part of the solution to the climate crisis.

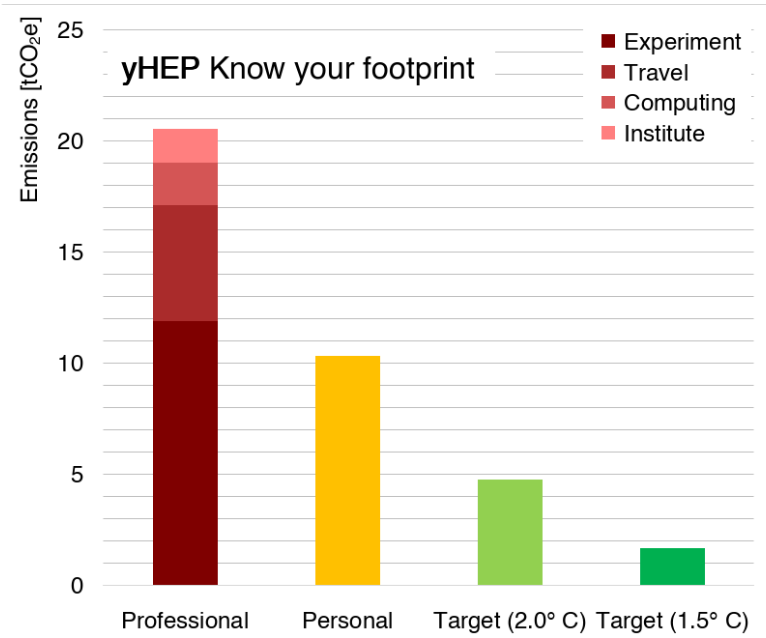

Figure 1: Professional CO_2 footprint of a benchmark doctoral researcher, working on one of the large LHC experiments, employed by a German university, with medium computing usage level and travel as discussed in the text. The yellow bar for the average personal footprint in Germany, and green bars for the remaining per person annual carbon budget of 4.8 tCO_2e (1.7 tCO_2e) for a maximum temperature increase of 2.0°C (1.5°C) are added as comparison [8].

4. Conclusions

The *Know your footprint* (Kyf) campaign aims to spread awareness about the environmental impacts of HEP and related fields to tackle the ever-intensifying climate crisis, and motivate sustainable practices both in professional and private life. The associated Kyf calculator identifies *Experiment*, *Institute*, *Computing* and *Business Travel* as the four dominant categories contributing to a researcher's professional footprint. Employing the Kyf calculator to evaluate the annual footprint of a benchmark researcher results in about 6 (18) times larger total footprint than the targets set by the Paris agreement for a maximum temperature increase of 2.0°C (1.5°C). It is therefore crucial to move towards sustainable research practices, remembering that every gram of CO_2 saved makes a difference.

References

[1] S. Arrhenius, Phil. Mag. S. 5 **41** (1896) 251.

[2] United Nations, United Nations Treaty Series **3156** (2015) 79.

[3] Copernicus Climate Change Service / ECMWF, *Climate Pulse*, accessed: 2024-08-21.

[4] Copernicus Climate Change Service / ECMWF, *Surface air temperature for June 2024*, accessed: 2024-08-21.

[5] CERN, CERN Environment Report 2017–2018 **1** (2020).

[6] CERN, CERN Environment Report 2019–2020 **2** (2021).

[7] CERN, CERN Environment Report 2021–2022 **3** (2023).

[8] V. Lang, N. K. Bhalla, S. Gurdasani, P. Niknejadi, arXiv:2403.03308 [physics.soc-ph].

[9] young High Energy Physicists Association (yHEP), *yHEP: Know your footprint (Kyf-2024)*, Kyf calculator, accessed: 2024-08-23.

[10] young High Energy Physicists Association (yHEP), *Sustainability In Science*, accessed: 2024-08-23.

[11] K. Schächtele, H. Hertle, Umweltbundesamt Förderkennzeichen: 206 42 110 (2007).

[12] S. Schunkert, J. Siewert, P. Pitz, et al., Umweltbundesamt Forschungskennzahl: 3718 16 313 0 (2022).

[13] Umweltbundesamt, *Carbon Calculator*, accessed: 2024-08-23.

[14] LHCb Collaboration, CERN-LHCC-2021-012, http://cds.cern.ch/record/2776420.

[15] European Organisation for Astronomical Research in the Southern Hemisphere, ESO Annual Report 2022 (2023).

[16] University of Freiburg, Umweltbericht 2019/2020 (2021).

[17] Leibniz University Hannover, Umweltbericht 2017–2019 (2021)