WLCG Environmental Sustainability

D. Giordano (CERN/IT-LCG)

Workshop sul Calcolo nell'I.N.F.N.

27/05/2025

Aim of This Contribution

- Review the WLCG community **initiatives** to reduce the **computing** environmental impact
  - Involve LHC experiments and WLCG computing sites
  - To measure, monitor and reduce the environmental footprint of large-scale scientific computing

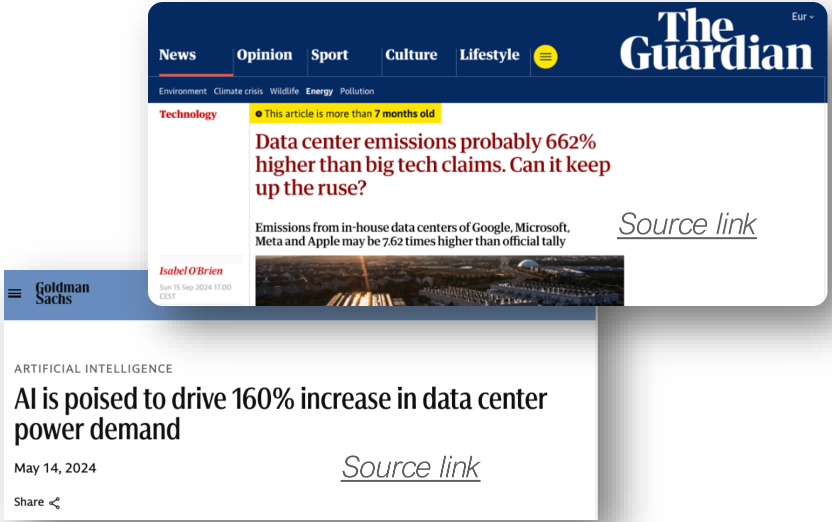
- Report based on recent community-wide workshops
  - WLCG Workshops, HEPiX Workshop, CHEP, Sustainable HEP, ATLAS publication

- All credits go to the contributions' authors
  - Apologies for omissions due to necessary selection

Environmental Sustainability in Computing

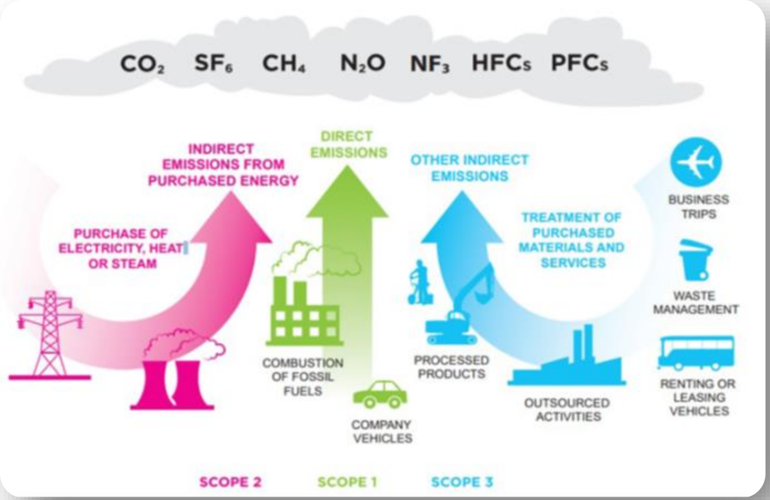
Data centres in 2024 accounted for 1.5% of global electricity consumption (International Energy Agency)

- US (45%), China (25%), Europe (15%)
- Rise of AI creates ever bigger demand
  - Questioned the reliability of current measurements



The 3 Scopes of Greenhouse Gas Protocol

- Greenhouse Gas (GHG) Protocol Corporate
  - Launched in 1998, to develop internationally accepted greenhouse gas (GHG) accounting and reporting
  - Scope 1: Direct emissions
    - including refrigerants, chemicals, and gasses
  - Scope 2: Indirect emissions from purchased electricity
  - Scope 3: Other indirect emissions

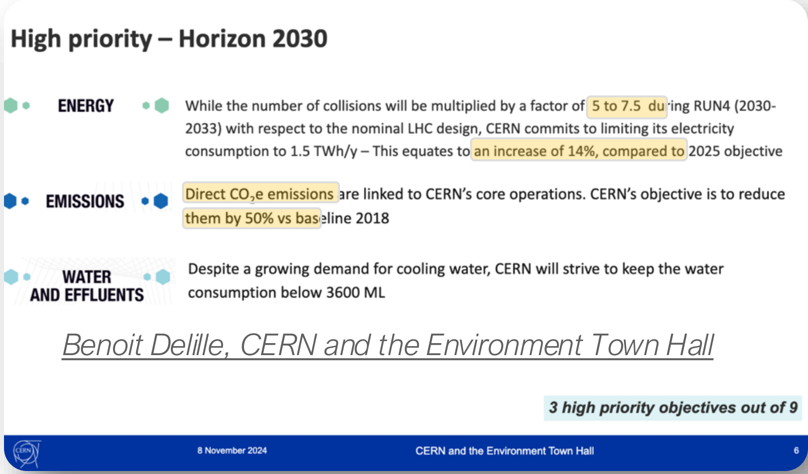


Wikimedia Carbon Accounting Scopes (CC)

- Computing is concerned by
  - Scope 2: Operation of data centres
  - Scope 3: Embedded carbon for acquired hardware and building

Sustainability Beyond Energy Consumption

- CERN biennial environment reports
  – ISO 50001 Certified since Feb 2023



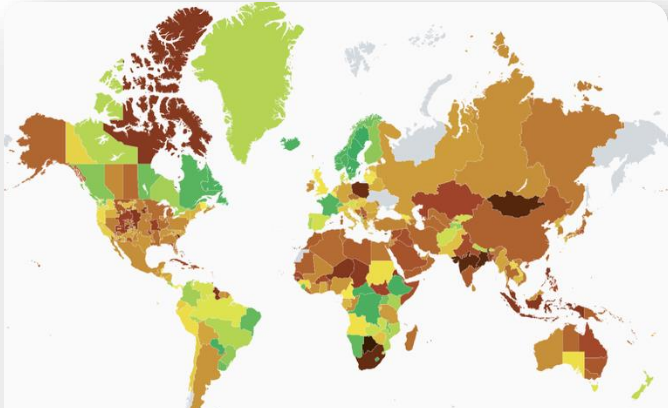
- High Priority objectives **for Horizon 2030**
  – Reducing CO_2e emissions by **50%**
    - Mostly (**78%**) from fluorinated gases for detectors and cooling
  – Improve efficiency of electrical power usage
    - Reminder: main source nuclear power plants in France

  – **CERN Data Centres: ~5%** of CERN's energy consumption and < 2.2% of CERN's CO_2e
    - Averaged over periods w/ LHC on/off

WLCG Computing is x5 CERN Computing

- WLCG: over 170 sites in 42 countries
  - 4/5 of the computing power outside CERN
  - Carbon emissions per kWh at WLCG sites are generally higher than in France
  - Average Data Centre PUE ~1.45

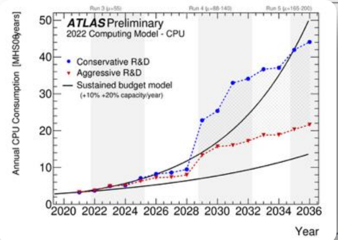
- Environmental impact of computing is also strictly connected to financial savings



https://app.electricitymaps.com

Preliminary Assessment

- WLCG energy needs for the HL-LHC program
  - Ignore site-specific cases, extrapolate CERN experience
  - Focuses on the energy needs for CPUs
  - Based on ATLAS and CMS computing needs
- Assessment:
  - Pessimistic: **x2** higher than in Run-2
  - Optimistic: **10%** higher than in Run-2



EPJ Web of Conferences **295**, 04001 (2024) https://doi.org/10.1051/epjconf/202429504001
CHEP 2023

Presented at CHEP 2023

A holistic study of the WLCG energy needs for the LHC scientific program

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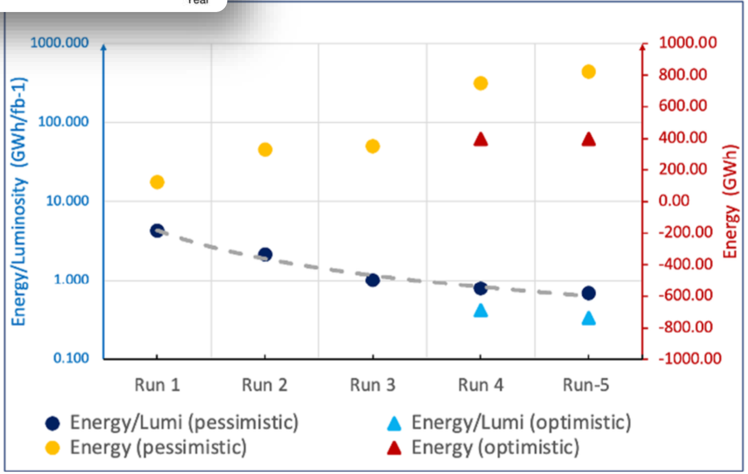
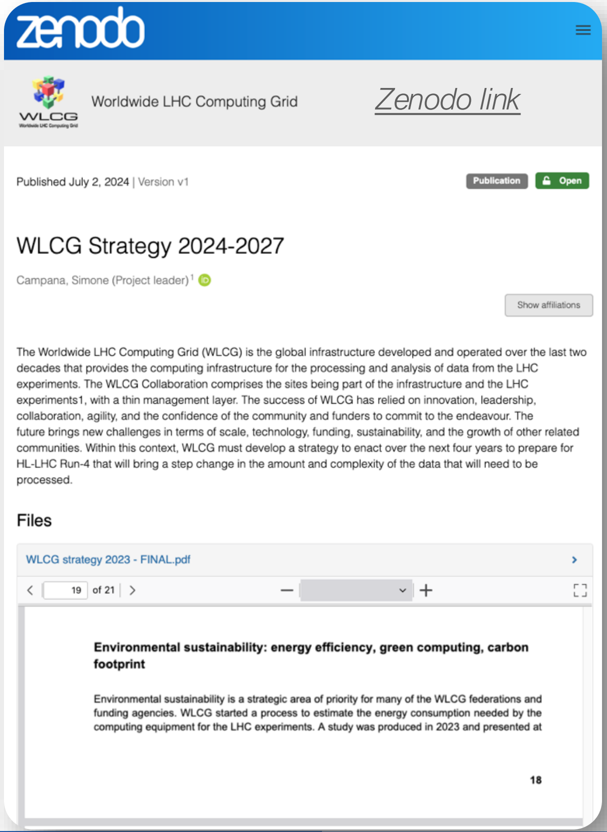


Figure 4. The "Energy" markers show the estimated average CPU energy needs in WLCG for the ATLAS and CMS experiments. The two scenarios, "optimistic" and "pessimistic" highlight the potential impact of the current R&D program. The scale those markers refer to is the one on the right Y-axis of the plot. The "Energy/Lumi" markers show the ratio between the energy needs as above and the integrated luminosity expected for a given run. The scale those markers refer to is the one on the left Y-axis.

WLCG Environmental Sustainability

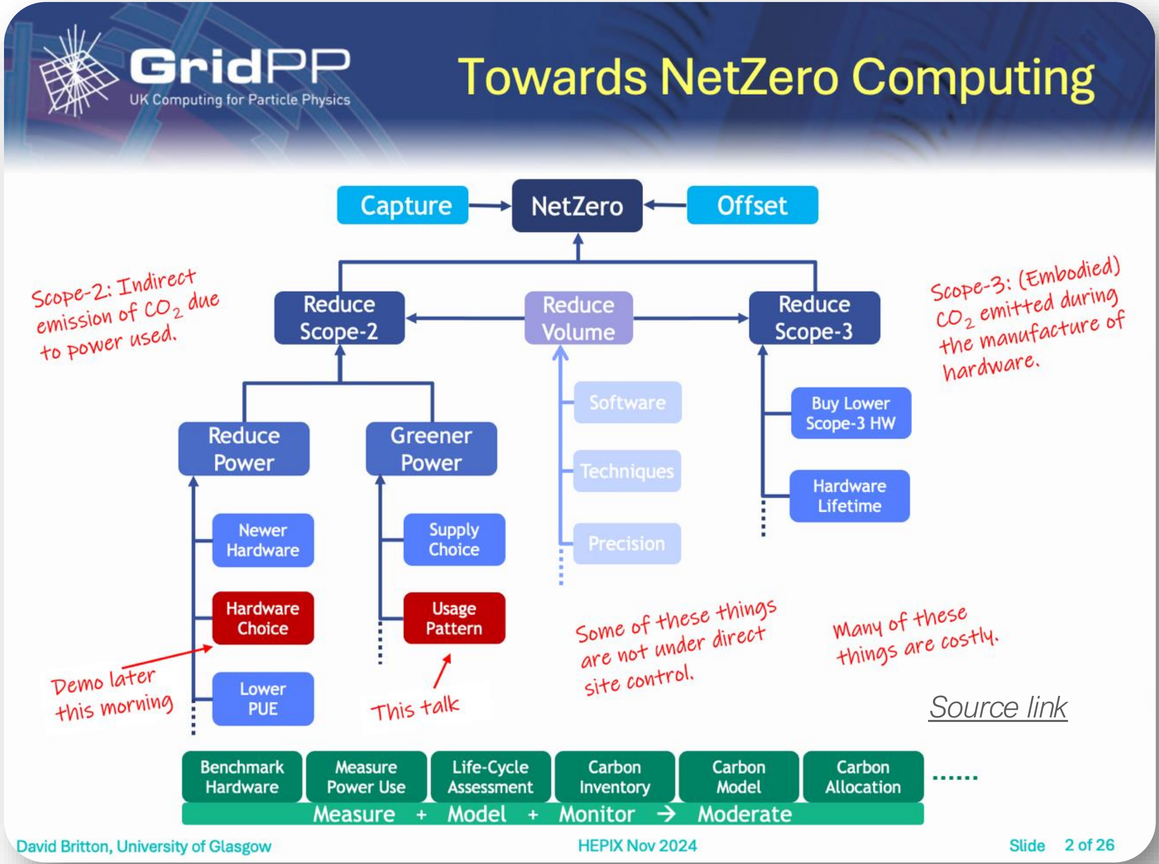
- Environmental sustainability is one of the **11 strategic area** identified for the future of WLCG
  - [ENV-1] WLCG to agree **on metrics** and provide a framework to collect information related to **energy efficiency.**
  - [ENV-2] WLCG to facilitate the use of more **energy-efficient hardware** where possible, depending on the readiness of the experiment software and the common libraries.
  - [ENV-3] WLCG to develop and promote a sustainability plan **to improve energy efficiency** and **reduce carbon footprint**, **covering software, computing models, facilities**, and hardware technology and lifecycle.



Areas of Work

Set of coherent actions needed involving

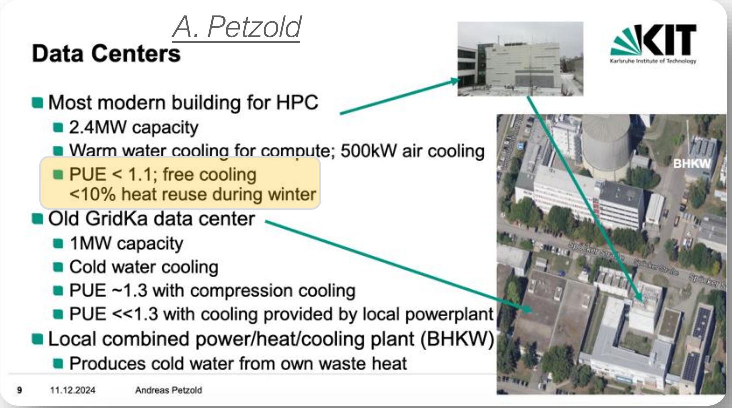
- Data Centres conception / renovation
- Hardware lifecycle
- Electricity usage patterns
- Improve computing practices
- Software Development



Data Centres, Hardware, Monitoring, …

The Quest for Low PUE

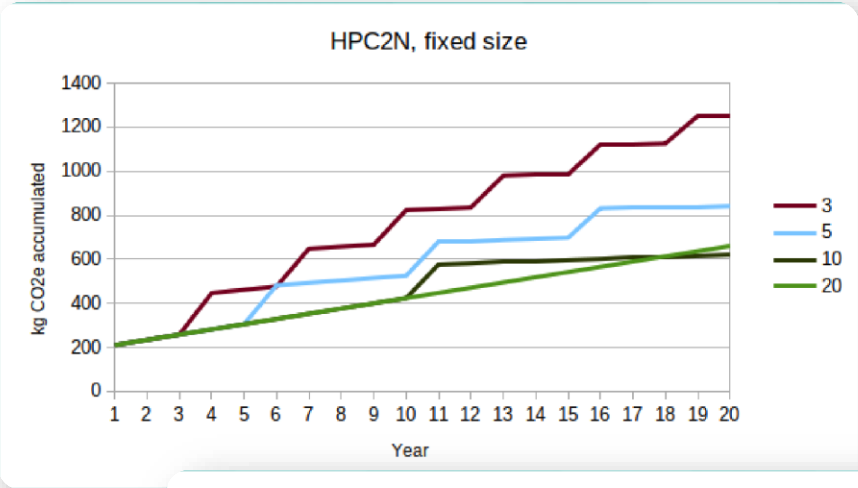
- New DCs , modernization of cooling systems offer better PUEs
  - Leverage new technologies, less energy needed for cooling
    - Warmer air, warm water, adiabatic air cooling, lake water cooling (CSCS), server water cooling, …
  - Heat reuse during winter
- Examples of PUEs
  - KIT (< 1.1), CSCS (~ 1.2), CERN (^{new}DC~1.17 vs ^{old}DC~1.5), ALICE container farm (winter: 1.05, summer: 1.16), LHCb container farm (~1.06)
- New efficient DCs can mitigate emissions in regions with high CO_2e/kWh
  - In few years amortise the cost of building embedded carbon

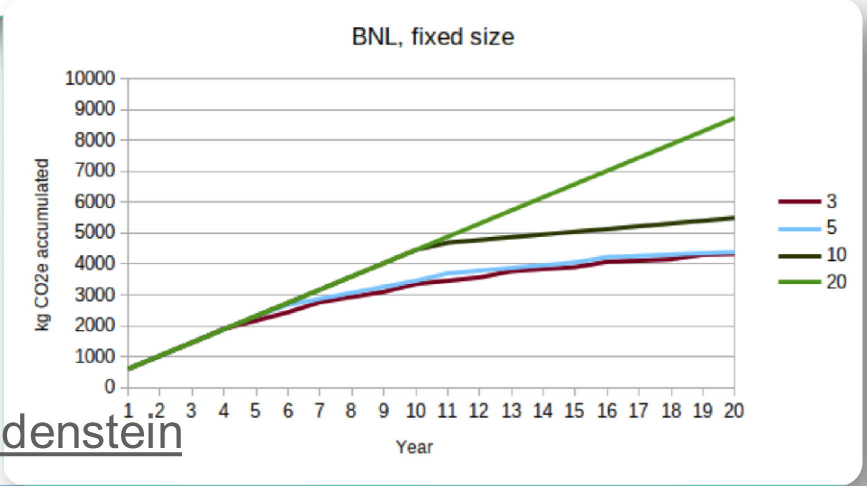


Hardware Lifecycle

- Embedded CO_2 is also significant
  - Extend lifetime, donate, recycle (send back to vendors)

- A model for computing the total lifecycle emissions for compute nodes
  - Simulates different replacement scenarios
  - Parameters: Real-world data from
    - data centers
    - electricity CO_2e/kWh,
    - vendor server information





M. Wadenstein

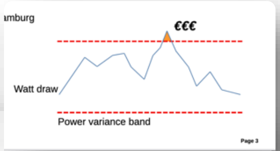
Adapting to Energy Price Variability

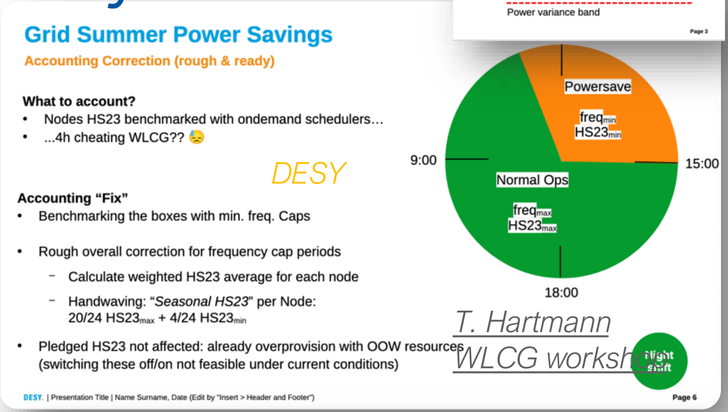
Modulating usage according to external factors like peak electricity costs

- Often correlated with higher CO_2 emissions

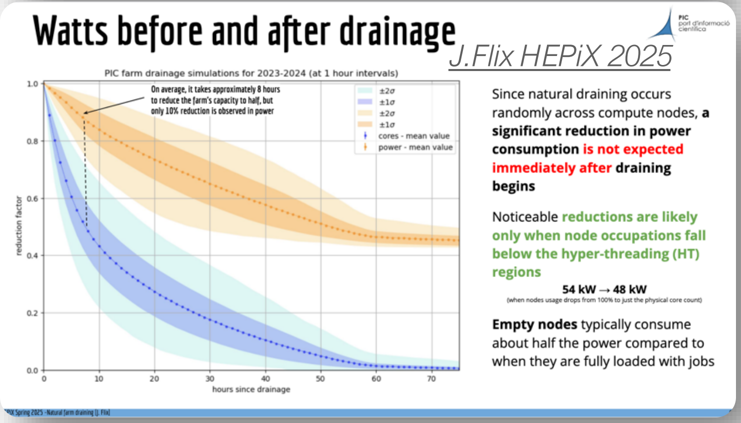
- DESY to reduce the clock frequency at peak hours
  - Governor from **Performance** to **Powersave**
  - **Open question**: *how to account for less performance delivered?*

- PIC to drain servers
  - Without **preemptible** jobs or proper queues' settings drainage can be very long
  - Software **checkpoint** needed to avoid waste of processing





T. Hartmann WLCG workshop

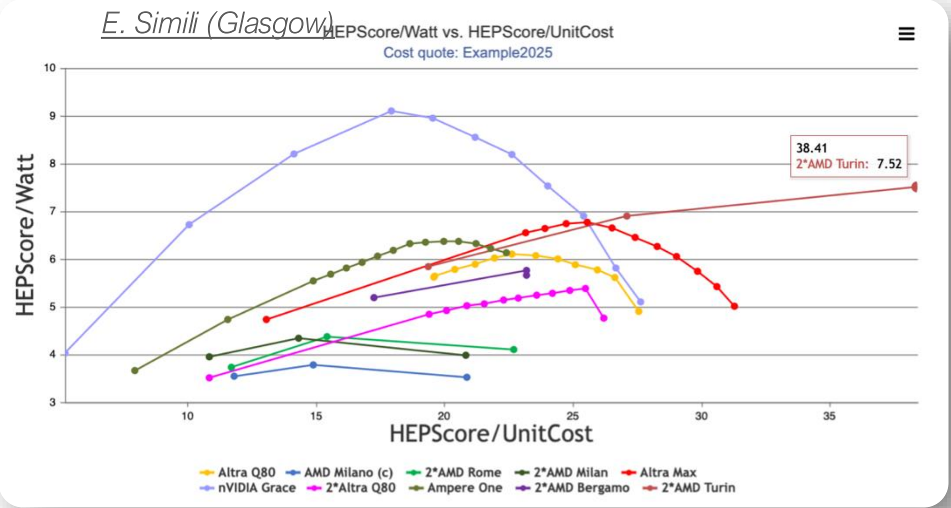


J.Flix HEPiX 2025

Hardware Selection: CPUs

https://www.ppe.gla.ac.uk/smartpro/plots.php

E. Simili (Glasgow)



- For CPUs <=> ARM vs x86 CPU
  - GridPP has pioneered detailed study of energy and performance of different CPU models & arch.
- Enabling factors:
  - Code porting on ARM by experiments
  - Support for ARM in HEPScore23
- Recent ARM and AMD CPUs are competing for the significative improvements in energy efficiency and comparable HS23
  - Frequency tuning can change the figures of merit
- Need a collaborative effort to collect more data

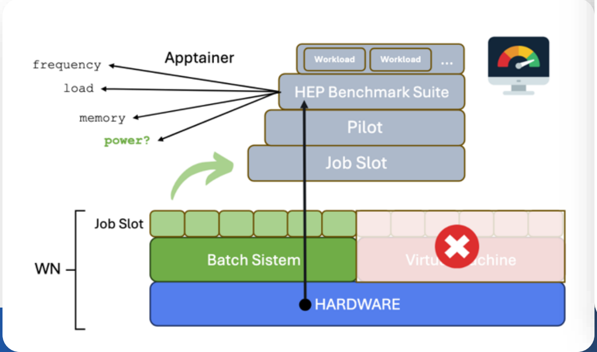
Data Collection: Goals and Approaches

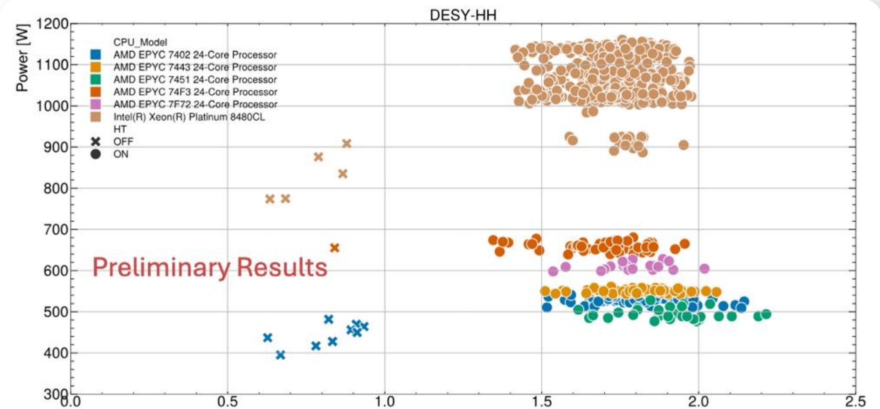
- Centrally collect and publish data on energy use, PUE, and CO_2 (where possible)
  - Include **the storage and network** contribution, a widely understudied area
  - *The goal is not to penalize sites lacking immediate sustainability options, but to* ***track and encourage progress*** *(link)*
- Two approaches being consideration
  - Site-provided average estimates
    - Useful for **baseline assessments**, but not suitable for detailed optimization
  - Automated collection of **job-level measurements**
    - Enables higher resolution data, forming the basis for **accurate projections** and digital twin modelling

Dynamic Power Accounting

- End-to-end proof of concept at ScotGrid Glasgow
  - Use **IPMI power usage**, cores/job, duration to attribute energy consumption to individual VOs

- HEPiX Benchmarking WG
  - Instantaneous power consumption readings available on worker nodes and read by grid jobs
    - Pilot: 4 sites (AGLT2, DESY, Glasgow, Fribourg)
  - Future: pilot jobs should send data to **central monitoring** and accounting





Natalia Szczepanek, D.G. (CERN)

Experiments:
Computing Policies
Software Improvements

Experiments: Computing Policies

- Track and report job carbon footprint
  - Increase awareness for user jobs
  - Measure cost of production campaigns
  - Measure the **waste from failed or inefficient jobs**

- Data storage strategies affect differently carbon footprint
  - Embedded carbon of SSD > HDD > Tape
  - **Reduce** data on disk (“data carousel” from tape); archive unused data; **reproduction** “on-demand”
  - Plan background tasks during low carbon intensity time periods

Awareness

R. Walker (LMU Munich)

- Users and production coords see gCO2 per job/task/campaign
  - shows component from failed jobs
- Estimate based on:
  - configurable per site cpu core power
    - should include PUE, e.g. cooling
    - mostly left at default 10W/core (highish)
  - time dependant gCO2/kWh of regional electricity
    - 2 years of hourly data in OpenSearch
    - ignore local renewables, e.g. PV on roof
- Report global average of running jobs
  - users should not force jobs to clean sites

PanDA

Summary of TaskID: 42140307

Detail	Value
Created	2024-11-21 00:21:50
Ended	2024-11-21 01:13:41.620986
Final Status	done

Total Number of Inputs

Category	Count
Succeeded	1
Failed	0
Cancelled	0
Total	1

Error Dialog: None

Datasets

In	[]
Out	['user. johndoe .prunroottest1_foo.root/']
Log	['user. johndoe .prunroottest1.log/']

Parameters

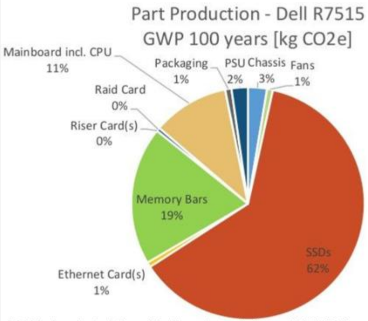
Command	prun --exec="root -b -q HistTest.C" --nJobs=1 --outputs=foo.root --outDS=user. johndoe .prunr cmtConfig=x86_64-el9-gcc13-opt

Estimated Carbon Footprint for the Task

Category	gCO2
Succeeded	0.06 gCO2
Failed	0 gCO2
Cancelled	0 gCO2
Total	**0.06 gCO2**

More details on estimation: https://panda-wms.readthedocs.io/en/latest/advanced/carbon_footprint.html

Embedded Carbon: SSDs dirty secret



M.Wadenstein https://indico.desy.de/event/48727/

- 5yr emissions factor 2 higher for SSD
  - 10yr assumes replacement of both
  - SSD now has 10yr lifetime
  - electricity 430g/kWh is high
- Hybrid WNs an option?
  - small SSD for random io
  - large HDD for volume

Table 1: Emissions of SSD and HDD.

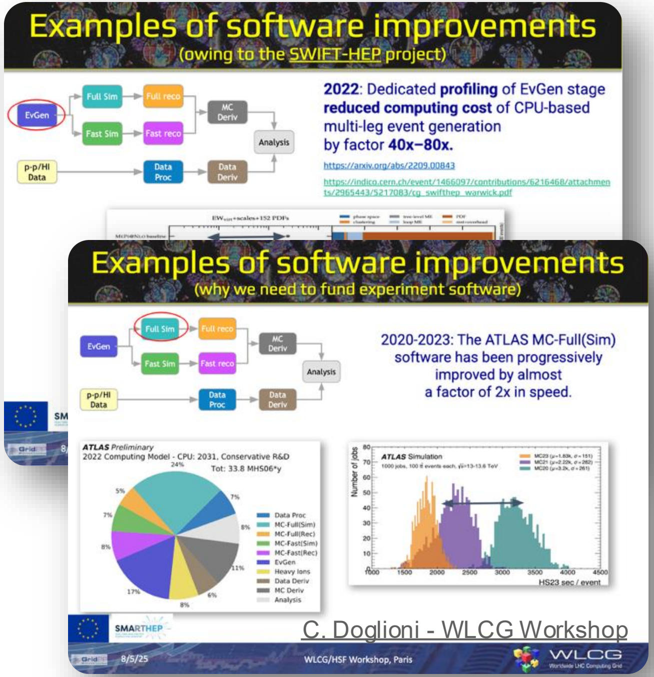
Storage	Energy (KWh)		OPEX CO2e (Kg)		CAPEX CO2e (Kg)		Total CO2e (Kg)	
Exp. Life	5yr	10yr	5yr	10yr	5yr	10yr	5yr	10yr
HDD (1TB)	183.9	367.9	79.6	159	20	40	99.6	199
SSD (1TB)	56.9	113.8	24.6	49.2	160	320	184	369.2

Experiment: Software Improvements

- This is the area with the highest potential for improvement — measured in factors, not just percentages.
  - The same pressure driving HL-LHC computing optimization applies here.
  - Focus first on the largest CPU consumers: (event generation, simulation, reconstruction)

- Two lines of action: improving software on CPU, porting to GPU (next slide)

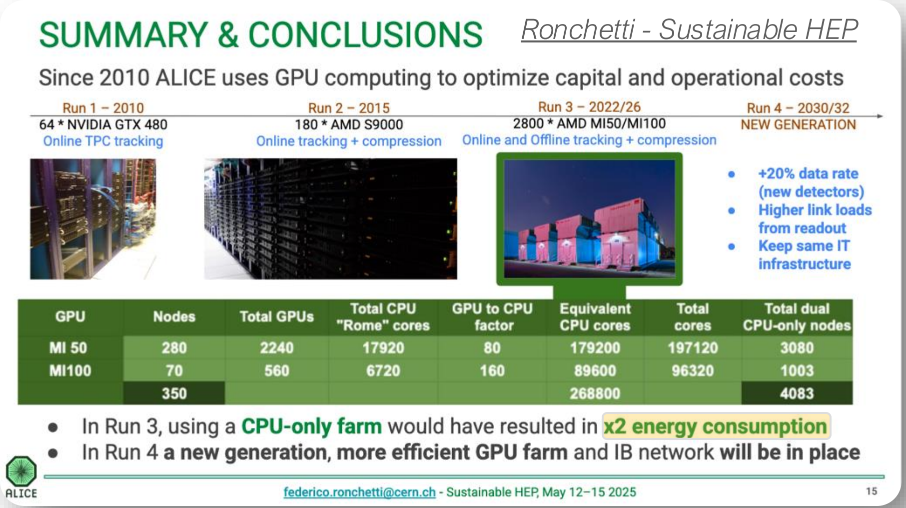
- Some examples of speedup improvements:
  - MadGraph: between $\times 3$ and $\times 70$
  - Generators: LHAPDF and SHERPA $\times 10$
  - ATLAS MC Full Simulation: $\times 2$



C. Doglioni - WLCG Workshop

GPUs: Increase Throughput and Efficiency

Significant gain in throughput and energy efficiency across multiple initiatives



SUMMARY & CONCLUSIONS

Ronchetti - Sustainable HEP

Since 2010 ALICE uses GPU computing to optimize capital and operational costs

Run 1 – 2010: 64 * NVIDIA GTX 480, Online TPC tracking

Run 2 – 2015: 180 * AMD S9000, Online tracking + compression

Run 3 – 2022/26: 2800 * AMD MI50/MI100, Online and Offline tracking + compression

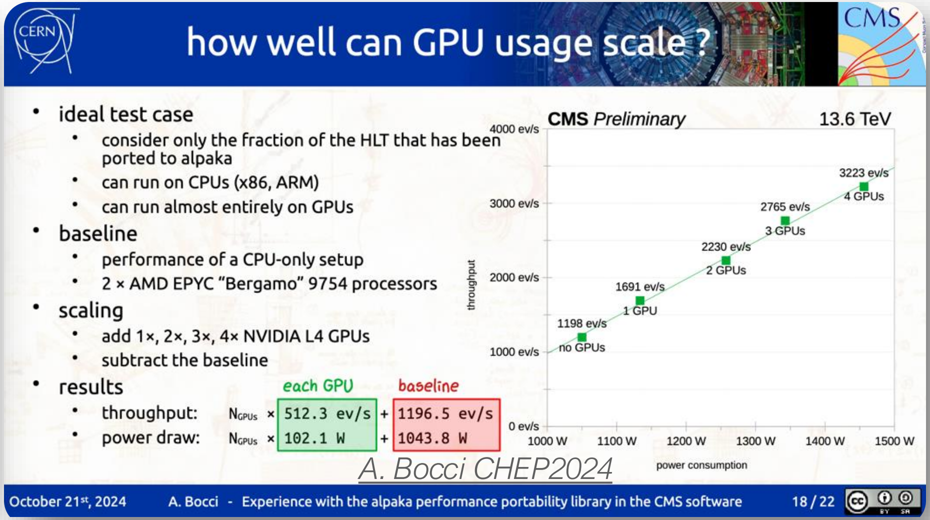
Run 4 – 2030/32: NEW GENERATION

- +20% data rate (new detectors)
- Higher link loads from readout
- Keep same IT infrastructure

GPU	Nodes	Total GPUs	Total CPU "Rome" cores	GPU to CPU factor	Equivalent CPU cores	Total cores	Total dual CPU-only nodes
MI 50	280	2240	17920	80	179200	197120	3080
MI100	70	560	6720	160	89600	96320	1003
	350				268800		4083

- In Run 3, using a **CPU-only farm** would have resulted in **x2 energy consumption**
- In Run 4 **a new generation, more efficient GPU farm** and IB network **will be in place**

ALICE federico.ronchetti@cern.ch - Sustainable HEP, May 12–15 2025 15



how well can GPU usage scale ?

- ideal test case
  - consider only the fraction of the HLT that has been ported to alpaka
  - can run on CPUs (x86, ARM)
  - can run almost entirely on GPUs
- baseline
  - performance of a CPU-only setup
  - 2 × AMD EPYC "Bergamo" 9754 processors
- scaling
  - add 1×, 2×, 3×, 4× NVIDIA L4 GPUs
  - subtract the baseline
- results

		each GPU		baseline
throughput:	N_{GPUs} ×	512.3 ev/s	+	1196.5 ev/s
power draw:	N_{GPUs} ×	102.1 W	+	1043.8 W

A. Bocci CHEP2024

October 21st, 2024 A. Bocci - Experience with the alpaka performance portability library in the CMS software 18 / 22

- ALICE EPN:
  More than **2000 64-core servers** would be needed for non-GPU online processing

- CMS HLT:
  GPU beneficial for all indicators

GPU Adoption is Not a Free Lunch

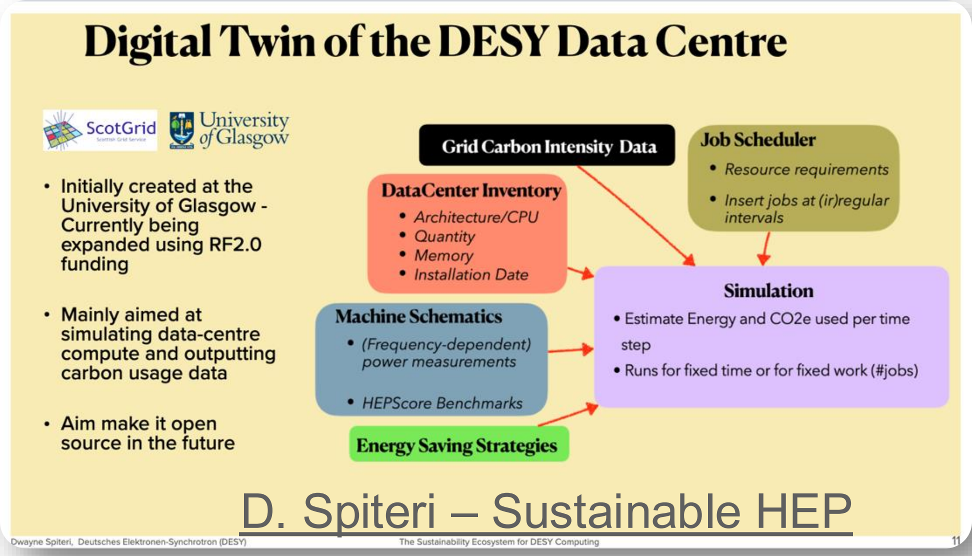
- Higher performance and energy efficiency is achievable with heterogeneous hardware
  - But optimization and tuning are complex
  - **Significant effort is needed** for developing, porting, optimizing algorithms
  - Define a **common metric** to translates the SW improvements into energy & carbon impact
    - Energy use and CO_2 emissions per processed (or simulated) physics workload

- Facilitating the Adoption of Heterogeneous Architectures
  - Sites should support by **providing the platforms needed** (development, integration and validation)
  - Monitor the market trend evolution (GPU FP32/64 vs lower precision)
  - **Training developers** is crucial

Other Initiatives: RF2.0

- Interesting work in the context of Research Facility 2.0 (RF2.0)
  - A Horizon Europe funded project
  - Introduce novel solutions for sustainable and energy efficient research infrastructures (accelerators, data centres, etc)

- **Digital Twin**: simulate strategies of job scheduling, HW config., energy consumption to evaluate their effectiveness
- Requires realistic input data
  - Performance/Power per HW conf.
  - Job modelling
  - Energy strategies

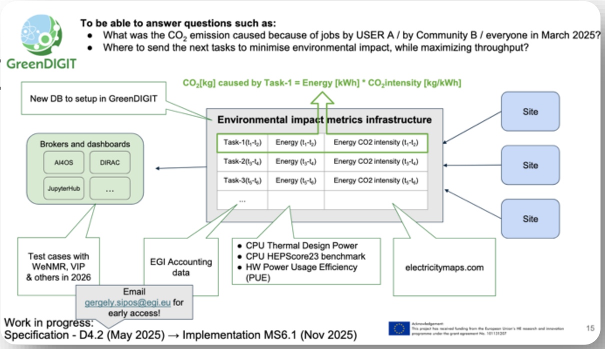


D. Spiteri – Sustainable HEP

Other initiatives: GreenDIGIT, UMRI

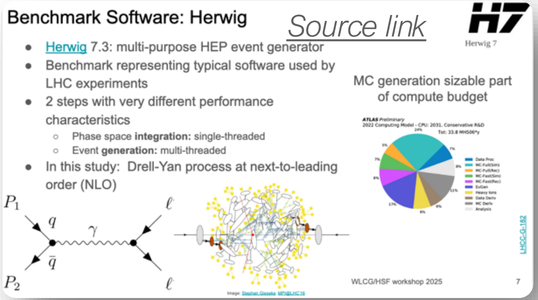
- GreenDIGIT
  Reduce environmental impact of European Research Infrastructures
    - Among the participants: EGI; CNR (coordinates the SoBigData RI for social mining and Big Data)
  - Education and support initiatives
  - Supply technical tools for both providers and researchers

Source link



- University of Manchester Research Institute (UMRI) Pump-Prime scheme
  - Benchmark HW, SW profiling, lifecycle assessment

Source link



Conclusions

- The HEP/WLCG community **is highly aware** of the critical importance of environmental sustainability
  - **Multiple initiatives** are underway, addressing:
    data centres, hardware, monitoring, and software development

- In the current wave of urgency and momentum, there is also a risk of **duplication**
  - Maximizing the impact of ongoing efforts is essential

- WLCG will set up a Sustainability Forum
  - Provide information, opportunities, and incentives to help collaborators
  - Express interest by email lcg.office@cern.ch

CERN