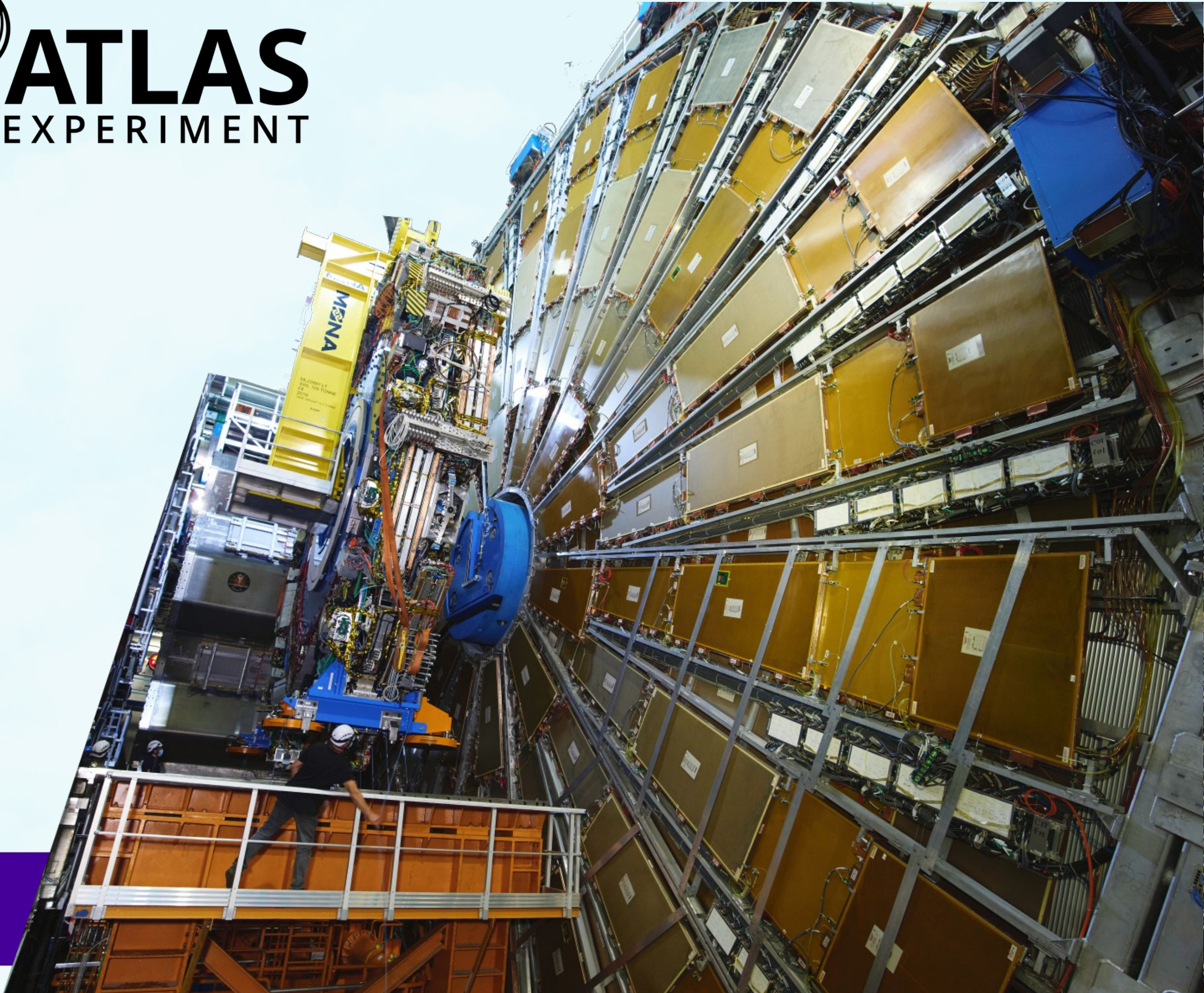
Sustainability in ATLAS



Kristin Lohwasser

30.07.2025

“The players”

ATLAS management

- Top-down
- “official” efforts
- Things that require executive decisions (e.g. exchanging gas mixtures, switching off resources)

Working groups

- Inofficial sustainability forum → exchange ideas & collect information specific to ATLAS, raise awareness
- Work carried out in e.g. Software and Computing group → direct impact

Collaboration members:

- Personal decisions
- The member universities/institutes → overlapping efforts
- Overarching initiatives: ECFA, Snowmass, Input to European Strategy Update….

Why does Sustainability matter (in ATLAS)

Collaboration: Private interest: members are interested in being more sustainable
→ e.g. former deputy spokesperson, now DESY HEP director founded a working group dedicated to evaluating/improving the sustainability in HEP

Legal: e.g. German scientists self-committed to be CO2e 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?

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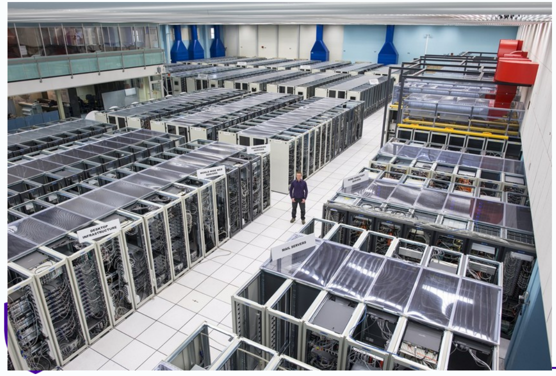
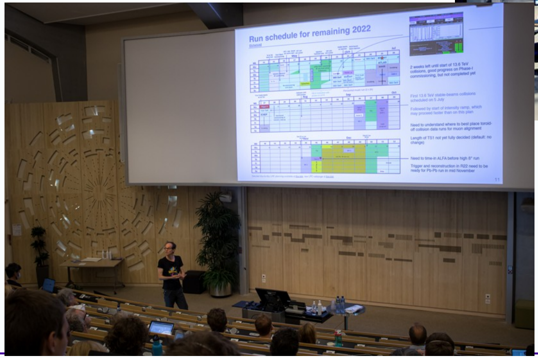
Slide by Ben Bruers,
shown in ATLAS week plenary

ATLAS footprint (the rough version)

- Construction
- Operation (LHC)
- **Operation (detector)**
- **Data analysis / computing**
- **Commuting**
- **Traveling / Conferences**
- Offices





***green = here we have the power to improve (i.e. direct influence)**

ATLAS’ emissions

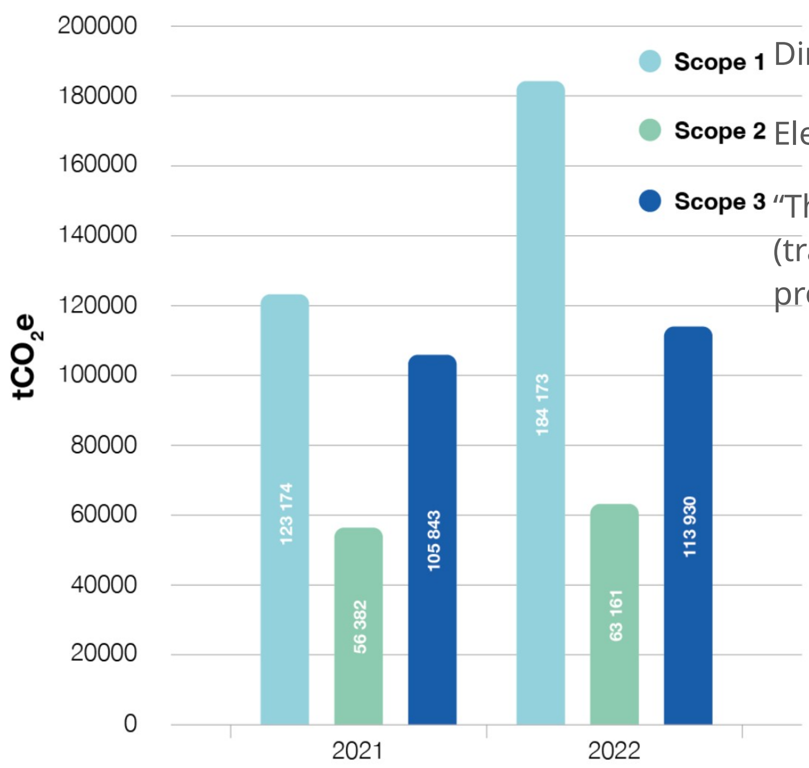
No numbers are available for ATLAS as such

- Difficult as collaboration spread across the world: CERN-based and local emissions
- CERN’s emissions can give indication of ATLAS’ emissions, but on purpose no attribution to experiments

CERN emissions dominated by gas emissions

5% of CERN’s scope 2 is computing

- CERN runs only 15% of ATLAS’ computing resources (many outside France) → computing footprint might be similar to CERN’s total



Scope 1: Direct: Gases
Scope 2: Electricity
Scope 3: “The rest” (travel, procurement)

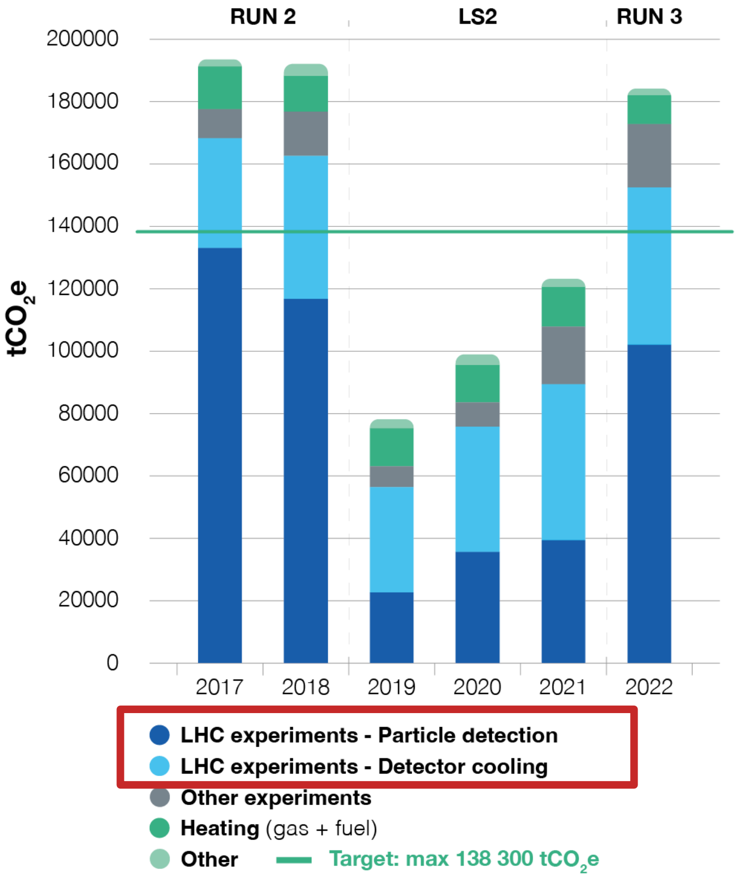
ATLAS' emissions: Gases

CERN's emissions dominated by detector and cooling gases.

Main cause are **RPC muon chambers** in ATLAS and CMS containing HFC-134a (> 90%) and SF_6 (< 1%) with a global warming potential of 1400
(due to large areas, in ATLAS' case 15m^3 but also Ship and Dune plan RPC muon chambers)

CERN's target: reduce scope 1 emissions
by **28% until the end of Run 3 (baseline: 2018).**

How?
- gas recirculation
- gas recovery
- more environmentally friendly gases



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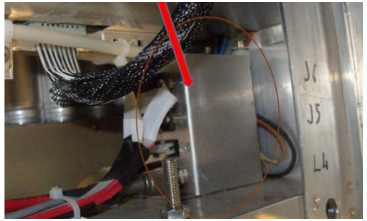
Reducing gas emissions

Leaks:
- Installation of 1100 no-return valves to minimize the leak rate due to an individual crack.
- Crack repair of inlets (either full repair or preventive measures)

→ dedicated campaigns during shutdowns though usual problem of person power (attempted to be fixed by advertisements / volunteer campaign by sustainability forum)



Replacement:
- Partial replacement of major component, R-134a, with low GWP substitute → degrade rapidly under UV exposure, creating problem of aging / degradation of chambers.

Tested in context of ECOgas@GIF++ collaboration

→ adapting mixture with 14% GWP reduction adopted in July 2023, and 25% reduction with a mixture used from 2025 on.

Recirculation:
In case of small leaks → gas can be recuperated and re-circulated

Cooling gases: Replace conventional cooling gases with CO_2 cooling for Run 4 (down to –53°C) → CERN has been developing a novel approach to detector cooling using CO_2 with new cooling systems being installed in ATLAS and CMS before Run-4

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https://cds.cern.ch/record/2910977/files/ATL-MUON-PROC-2024-014.pdf
https://indico.cern.ch/event/1291157/contributions/5900416/attachments/2900043/5085404/Presentation_ICHEP_Sinem_Simsek.pdf

ATLAS’ emissions: Computing

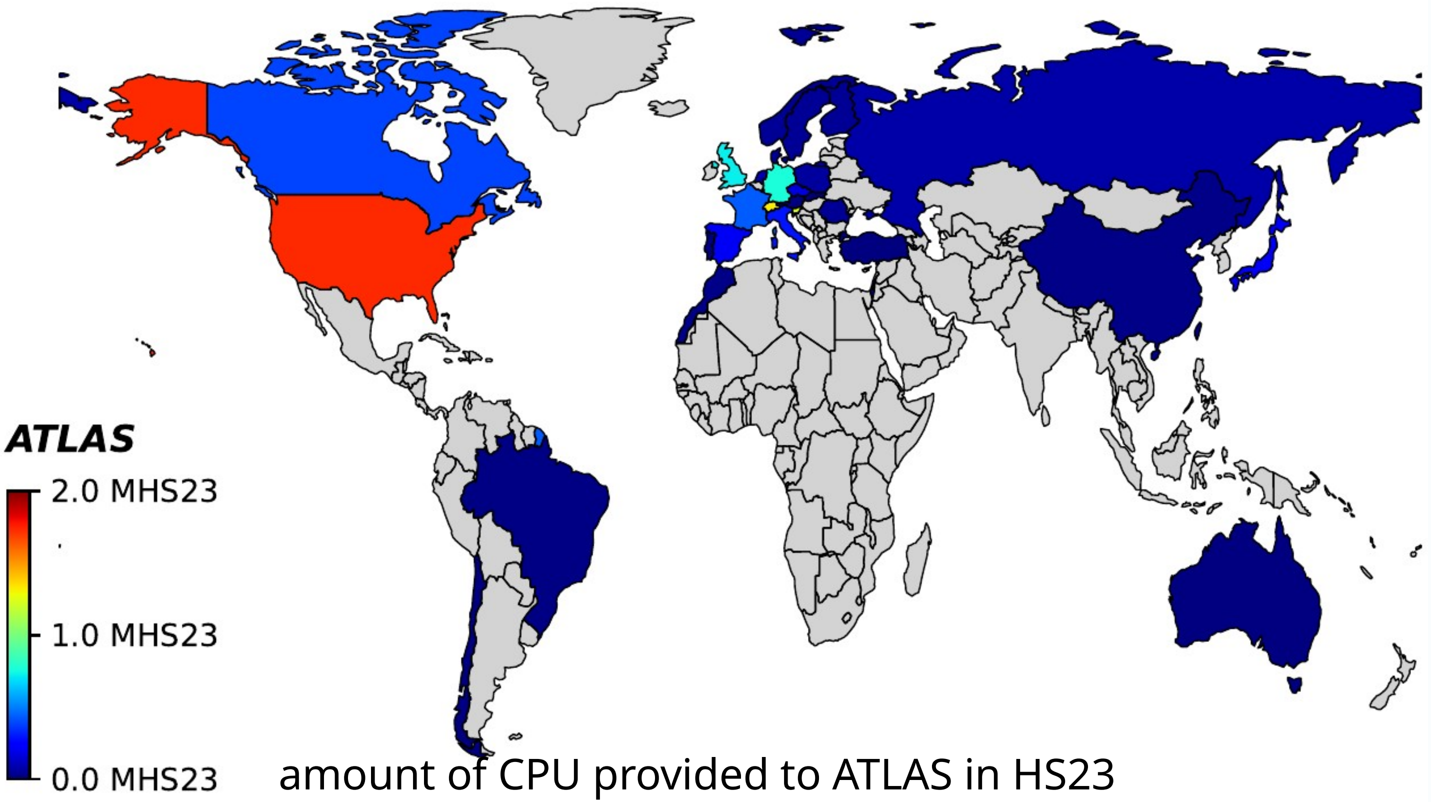
600 000–700 000 cores of compute

peaks of >1 mio cores

>10 TB of storage
→ 400 PB disk
→ 600 PB tape

100 distributed computing centers around the world

factor of 10 growth for HL-LHC



amount of CPU provided to ATLAS in HS23
(computational power based on the 2023 HEPScore)

Improve computing emissions

A first from one of the LHC experiments: A paper on

The environmental impact, carbon emissions and sustainability of computing in the ATLAS experiment

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/SOFT-2024-01/

Laying out the following basics:

Raising awareness

Experiment computing policies

ATLAS-specific site and user actions

General site actions

Sharing knowledge

Raising awareness

Reporting on Estimated Carbon footprint for user and production tasks

- Average of carbon footprint of all ATLAS jobs, using power grid carbon intensity per site (from Electricity Maps) and number of Watts per core of compute
- Appropriate as per site data is not that reliable, provides better incentive to reduce carbon footprint (instead of sending user jobs elsewhere)

Including information on failing jobs in software tutorials

Rephrasing e.g. software validation in environmental terms

Survey of computing sites (dominated by many small sites)

- More than 50% of sites do not monitor electricity usage but more than 60% of the site administrators indicated desire for advice and the sharing of best practices
-

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 .prunroottest1 --rootVer=6.32.06 --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

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Experiment computing policies

Short-term savings will be eaten up by more marginal scientific benefit
→ long-term savings can be translated into reduced forecasts / resource predictions:

e.g. reduction of 50% in time per event for MC simulations, increased speed for generators

Long term storage versus fast data reproduction: limit is <16% for data reproduction

Using automated tools to take sites offline (HammerCloud) and establishing system of scout jobs to reduce failures of full submissions

Identification of un-used data sets and follow-up by production managers

Experiment computing policies

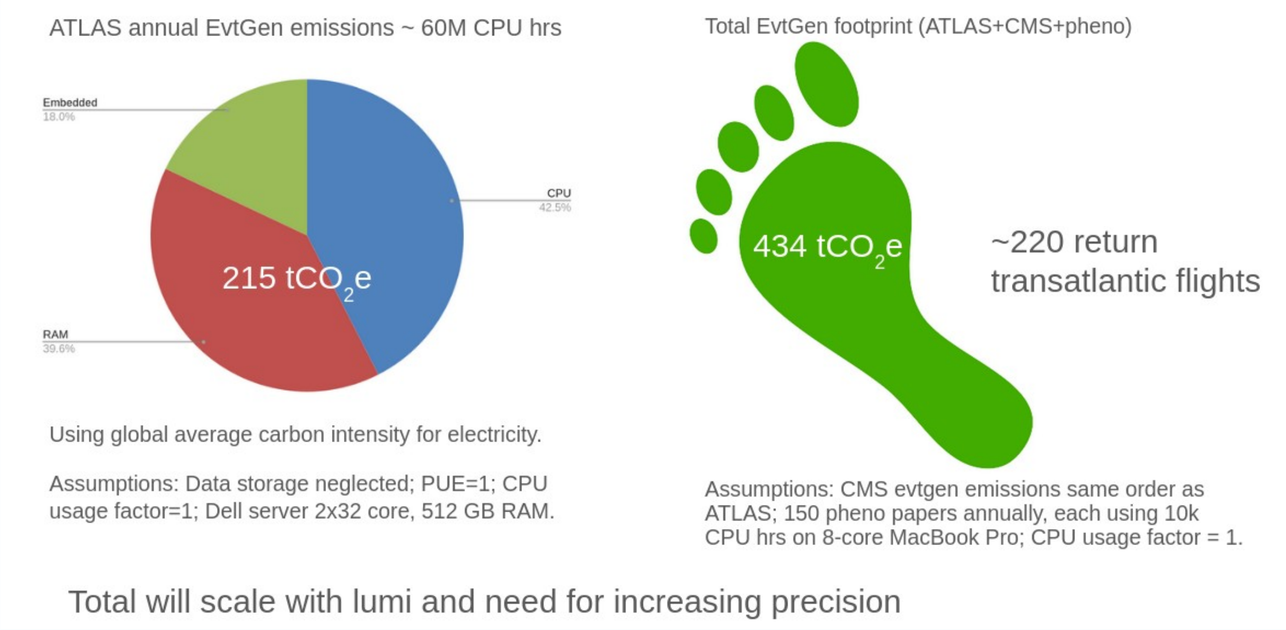
Short-term savings will be eaten up by more marginal scientific benefit
→ long-term savings can be translated into reduced forecasts / resource predictions:

- Improvement of speed: e.g. reduction of 50% in time per event for MC simulations, increased speed for generators
- Weighing long term storage versus fast data reproduction: limit is <16% for data reproduction to be more efficient
- Waste reduction: Using automated tools to take sites offline (HammerCloud) and establishing system of scout jobs to reduce failures of full submissions
- Identification of un-used data sets and follow-up by production managers
- Usage of alternative resources (e.g. trigger CPUs when detector is not running)

Experiment computing policies

- Data sharing: Atlas, CMS and phenomenologists all use the same public tools to generate the same SM backgrounds - Redundancy of effort, manpower, compute.

  → Release of open data for research: https://opendata.cern/record/160000 (HEPMC files)



SC4RC 2026 – Sustainability Conference for Responsible Research Computing
May 4th-8th, 2026 @ CERN

LHCC MC WG – subgroup on Data sharing and new workflows

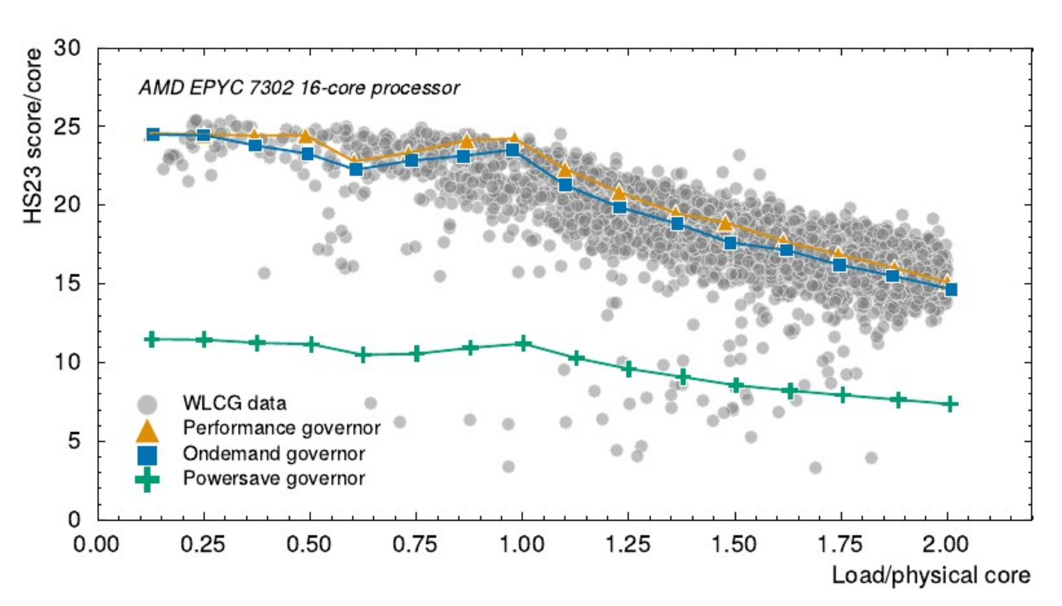
Numbers and Initiative:
Rakhi Mahbubani (RBI, HECAP+)

ATLAS-specific site and user actions

Active performance measurements on sites to understand and improve performances.

ATLAS employs the HEPScore benchmarking suite (7 standard workloads from the LHC experiments, “typical” mixture of low-level instructions, memory loads, …)

Performance measured using “q85”, the 85th-percentile
power measurement (to remove start/stop profiles)



ATLAS-specific site and user actions

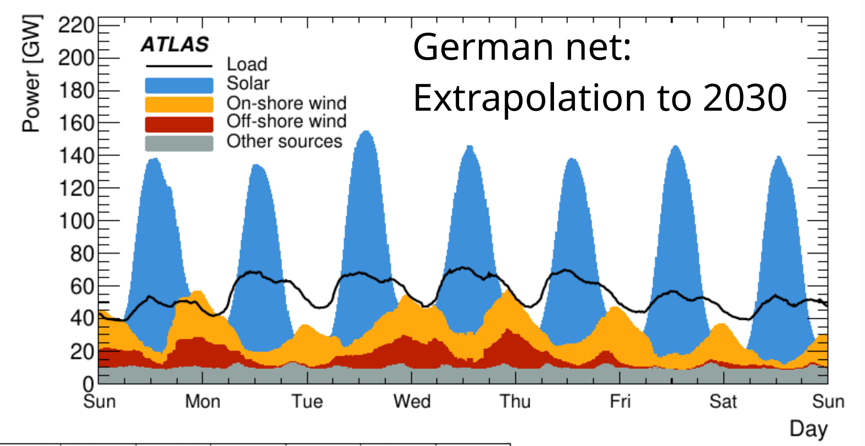
Collaboration between ATLAS site administrators and software developers to address variation in power grid availability and carbon intensity.

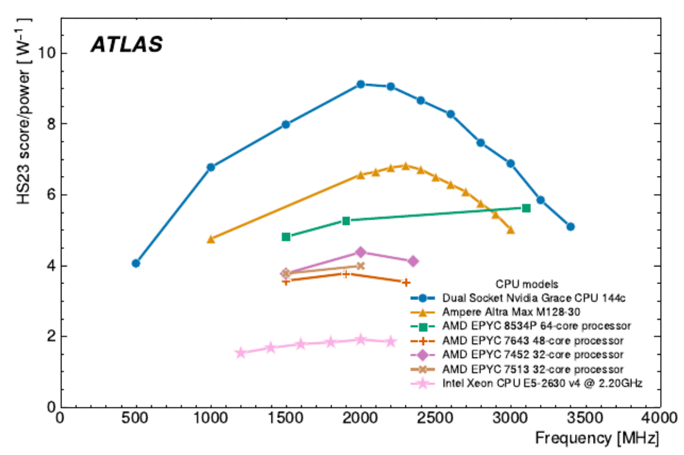
CPU scaling (→ Frequency of calculations and thus power is reduced) achieves better throughput.

Checkpointing (→ taking snapshot of the current state of a running program, storing it on disk, and later restoring the running program from that snapshot) allows to take sites offline without harm in case of low energy availability.

Several ATLAS production workloads already capable of checkpointing. Missing: functionality for communication between productions system/jobs/sites
→ non-trivial work on the list for HL-LHC preparations to improve site operations and efficiency

Consistency → design for typical usage
Latency is widely accepted (→ internal prioritization)





General site actions

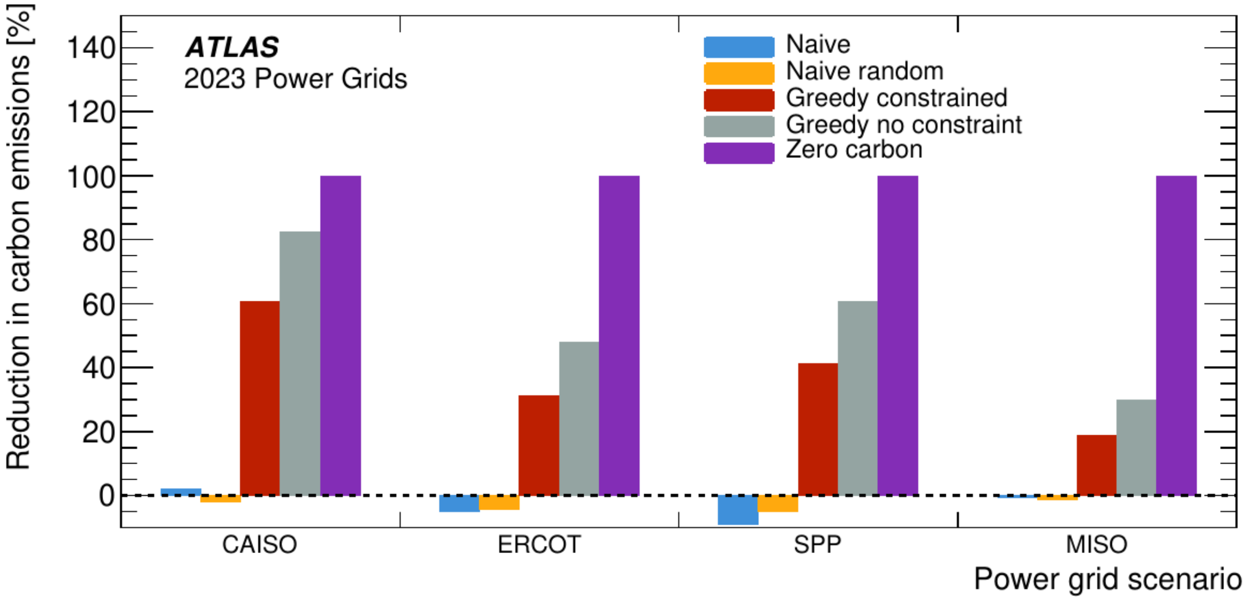
Citing the 1st ErUM workshop

Ref. [42] for a UK study). In Germany there are several ongoing efforts to understand and reduce the carbon footprint and environmental impact of computing centers (see for example Refs. [43, 44]). These

Improvement of energy consumption of storage by scheduling “cleaning tasks”:

- Constraint: At least 1 times per day
- No time constraint
- Zero carbon run during zero carbon periods

Savings of over 90% possible

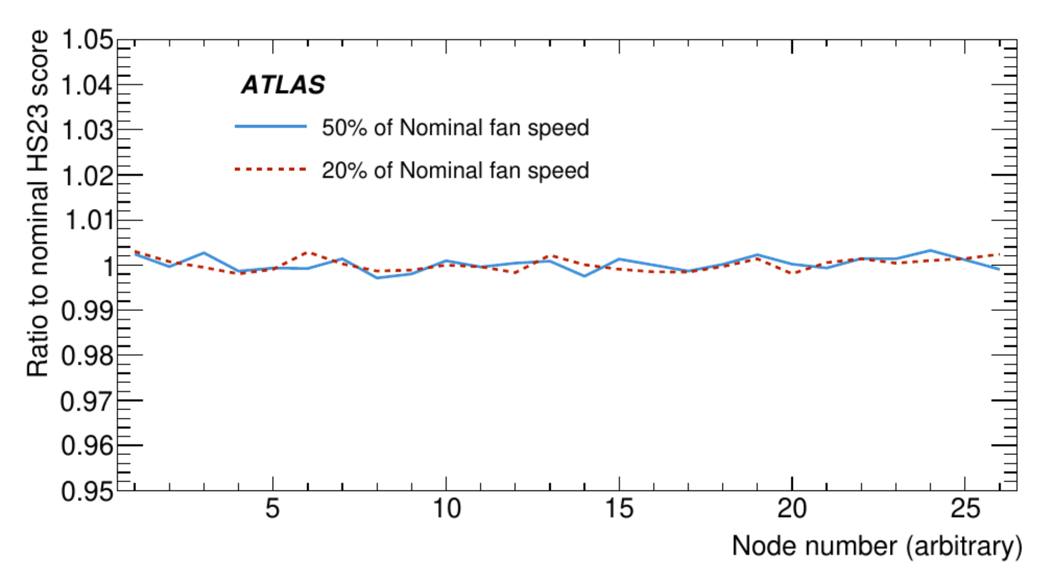


California Texas Central South Midwest& South

General site actions

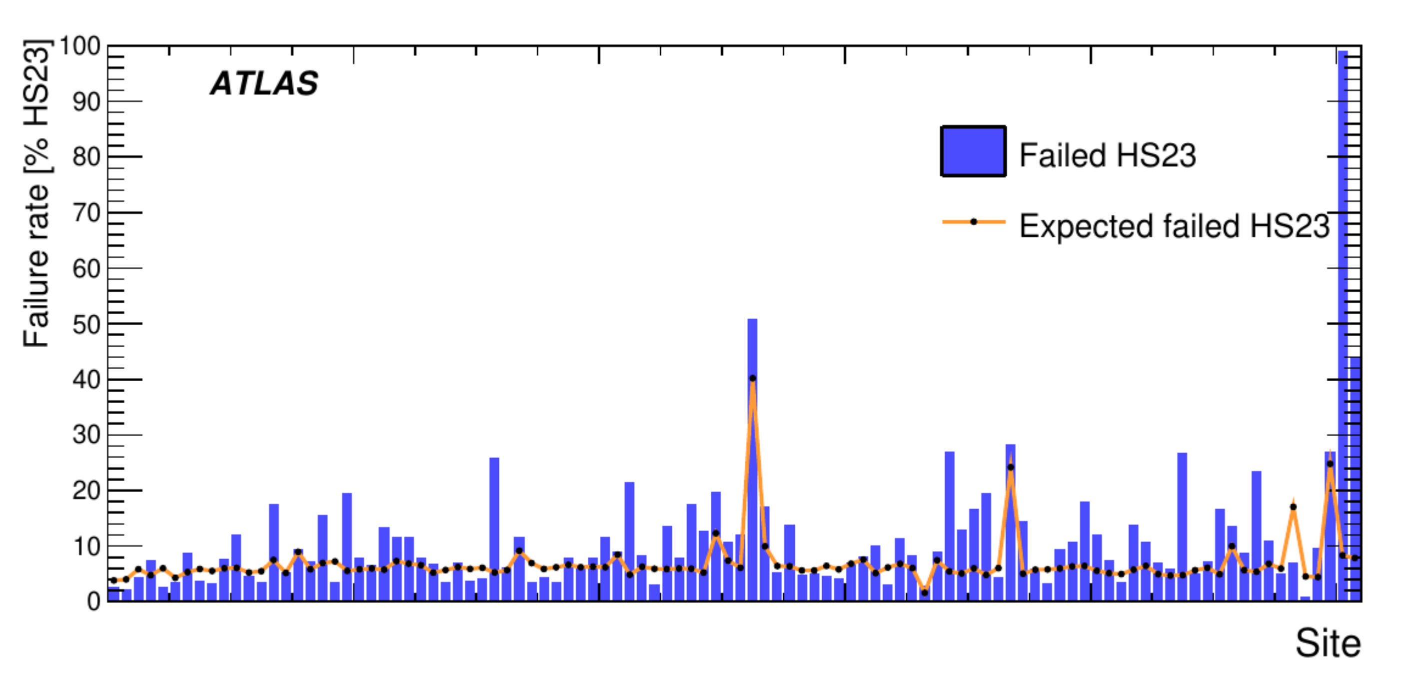
Optimising data centres

- Cooling: Increasing temperature (lowering fan speeds) by 10% leads to 15% energy saving
- Improving energy efficiency by using waste heat



Knowledge sharing

- Identification of sites with large job failure rate → starting point for diagnosing and improving these sites



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Conclusions

- Sustainability is a concern for the ATLAS collaboration

- Number of measures have been taken to improve emissions

- Progress on computing side published in paper:
  https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/SOFT-2024-01/