

# **Green Algorithms, Green DiSC and GREENER principles: making computational science more environmentally sustainable**

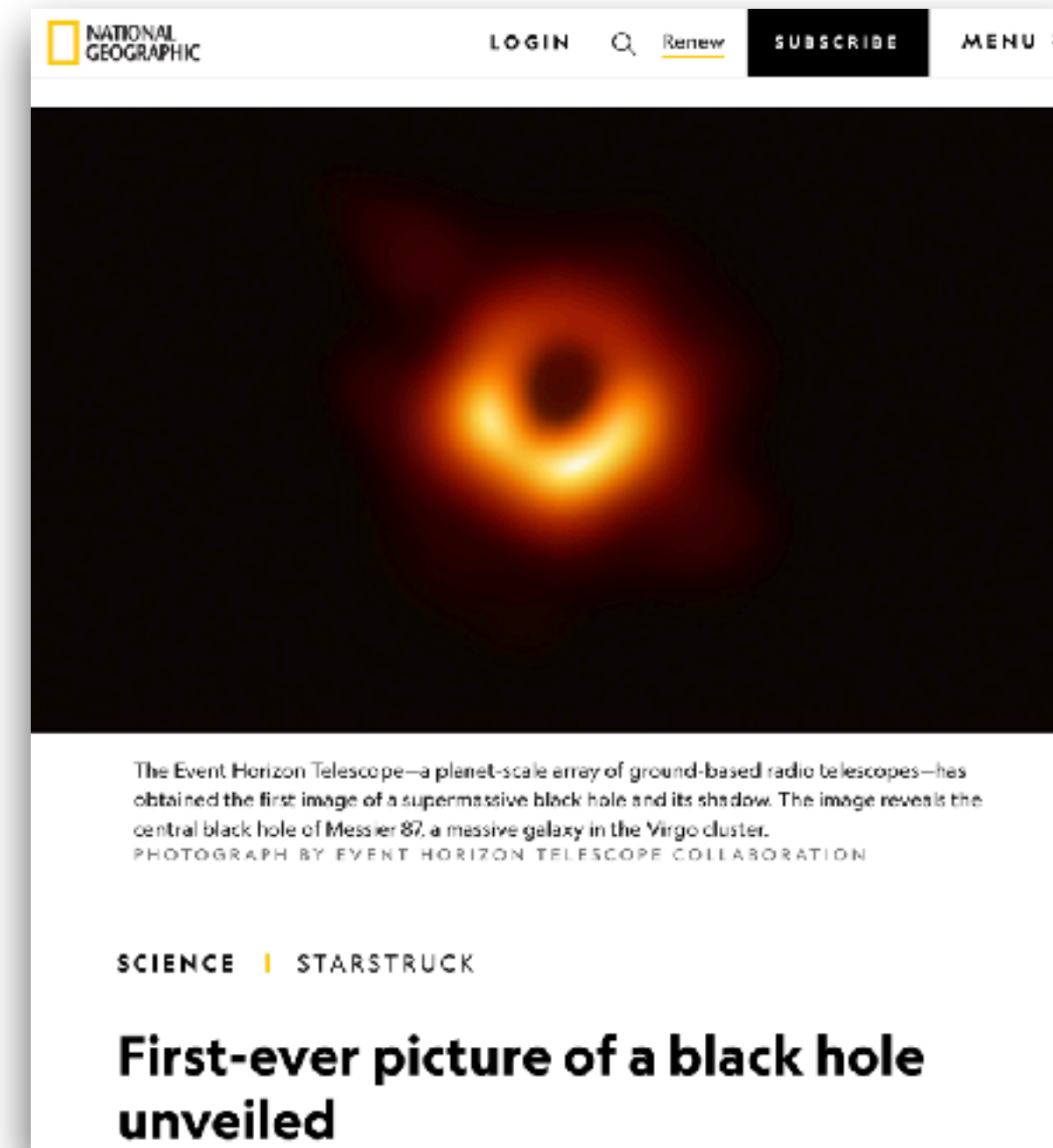
**Loïc Lannelongue, PhD**  
*Cambridge Sustainable Computing Lab*  
*Assistant Research Professor, University of Cambridge*  
*Fellow, Software Sustainability Institute*  
*NetDRIVE Champion for Transformational Change*  
*Visiting Scientist, EMBL-EBI*

**LL582@cam.ac.uk**

**[www.cam-sustainablecomputing.org](http://www.cam-sustainablecomputing.org)**

**High-performance  
computing has enabled  
amazing discoveries**

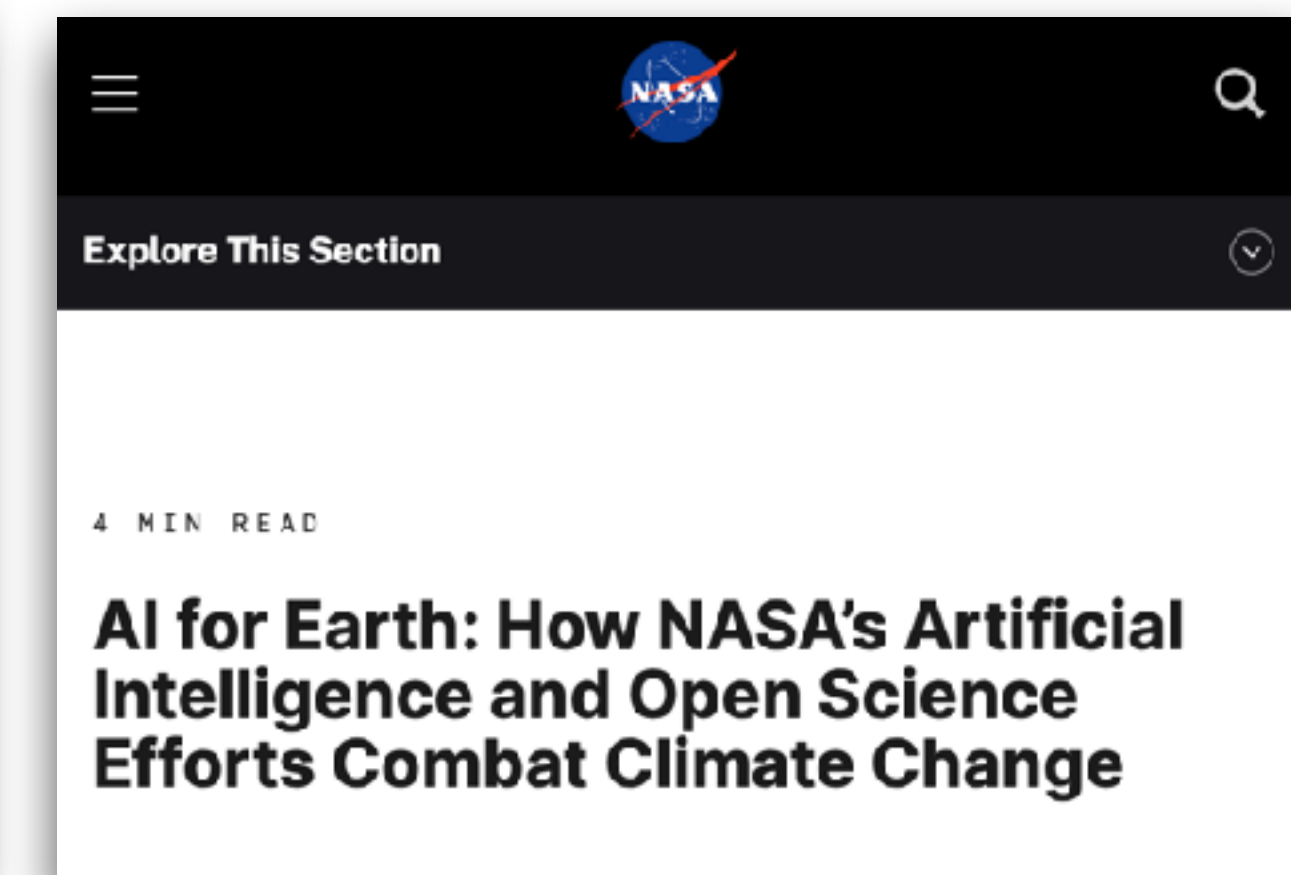
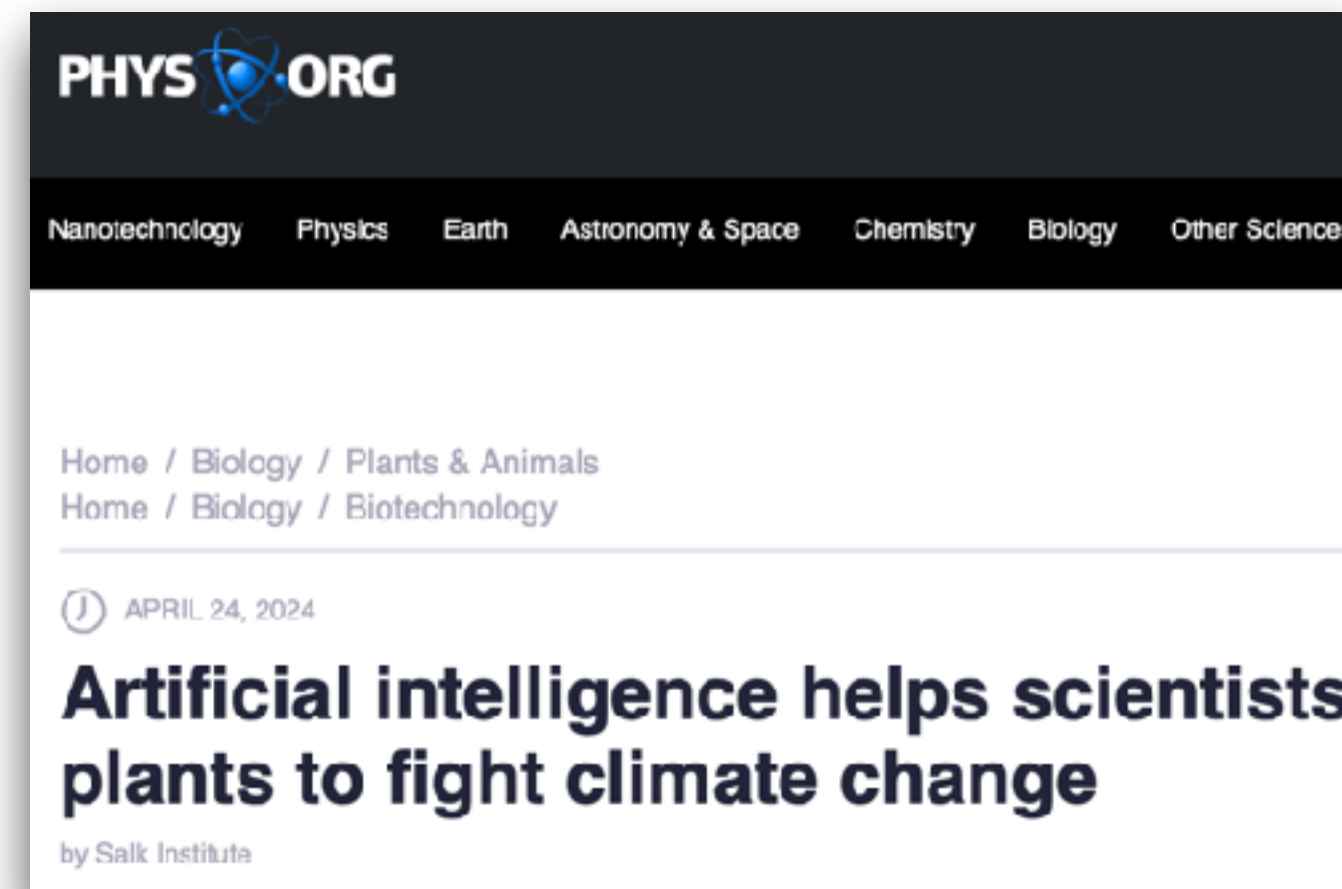
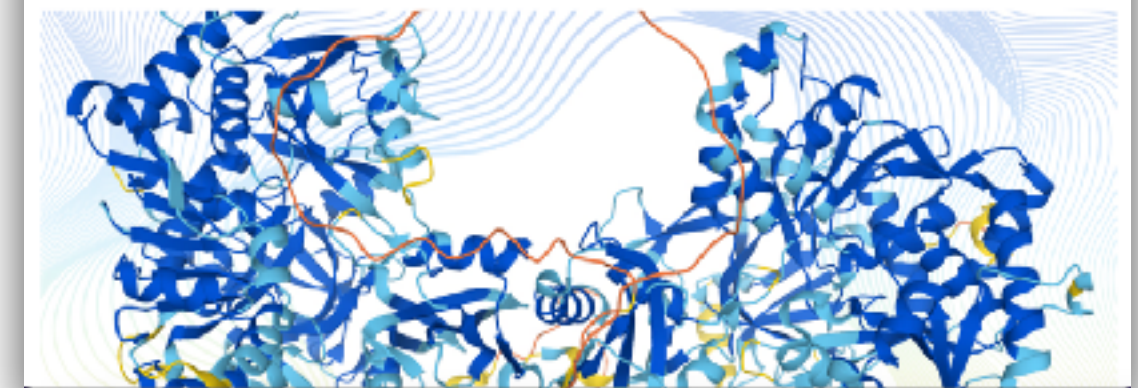
**Including in the fight  
against climate change**



## **DeepMind and EMBL release the most complete database of predicted 3D structures of human proteins**

This article is also available in Deutsch, Français, Italiano and Español.

Partners use AlphaFold, the AI system recognised last year as a solution to the protein structure prediction problem, to release more than 350,000 protein structure predictions including the entire human proteome to the scientific community.





# Not without costs



Malmodin et al. 2024, "ICT sector electricity consumption and greenhouse gas emissions – 2020 outcome"  
<https://www.epa.gov/system/files/documents/2024-05/420f24022.pdf>



# 45%

**To align with the Paris Agreement, the global ICT industry will have to reduce its GHG emissions by 45 per cent from 2020 to 2030.**



2

**tonnes of CO<sub>2</sub>e / year / person**

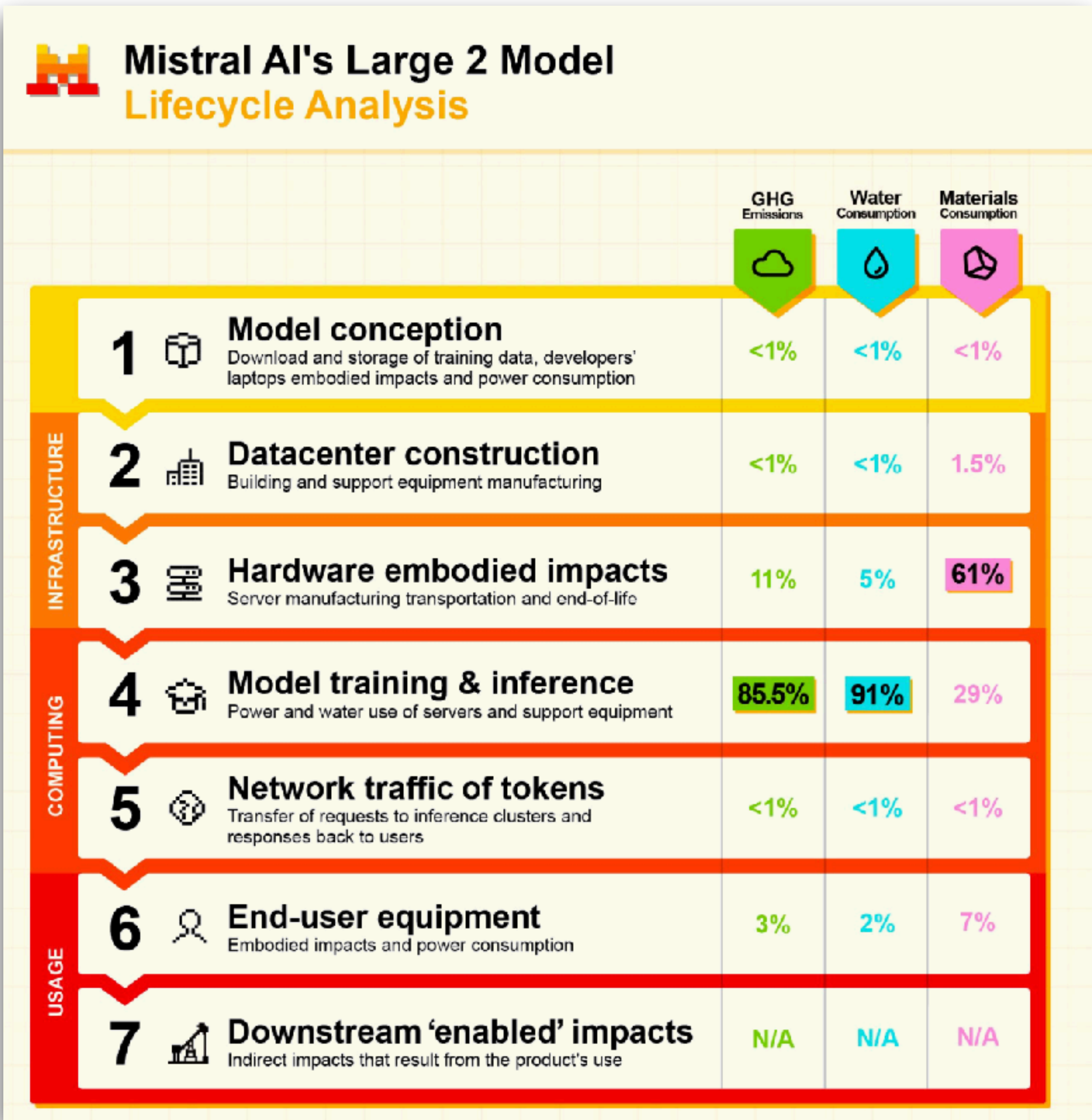
# Some AI examples to start

Over an 18 months period, the impact of training Large 2 is:

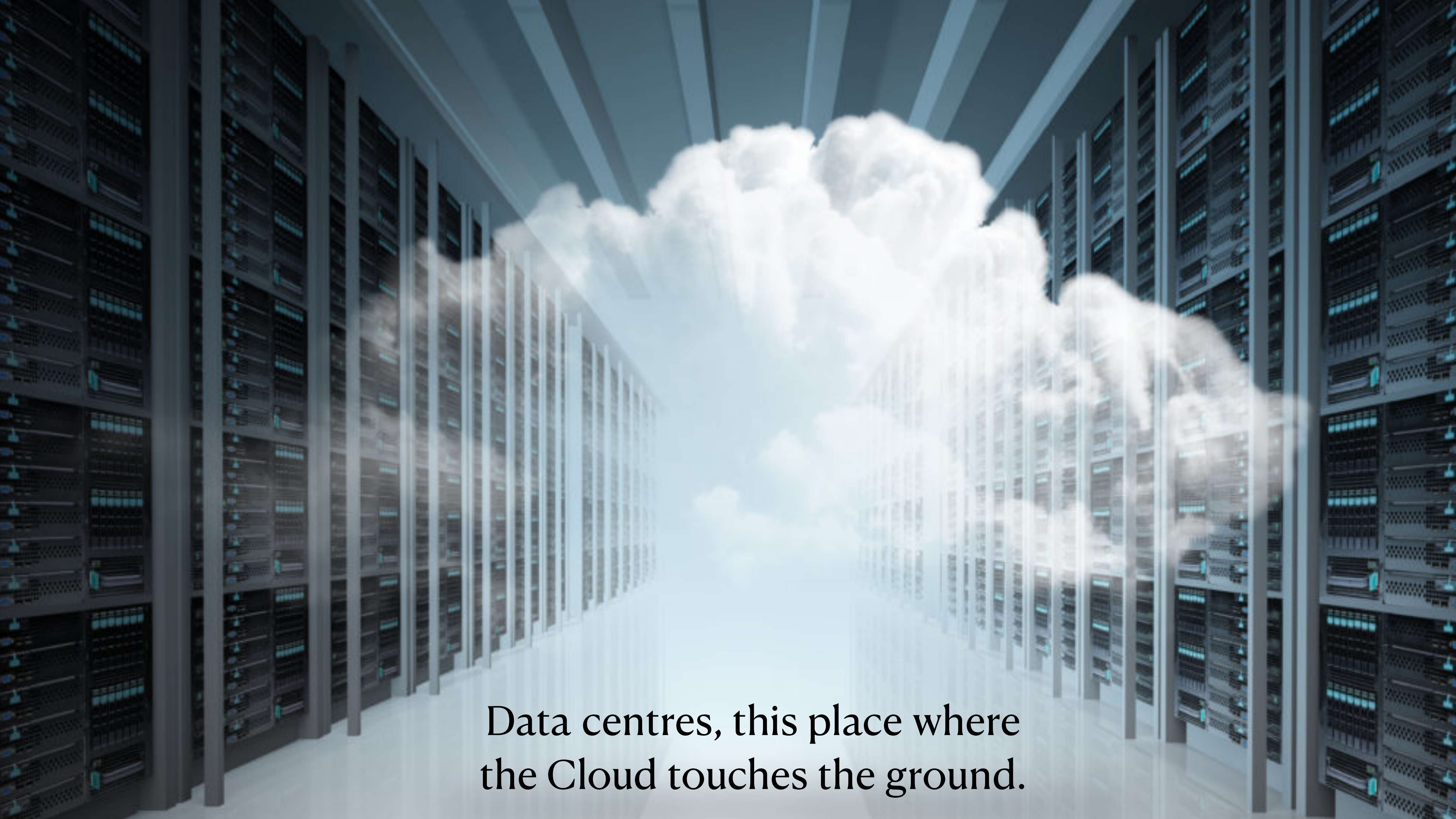
20,400 tCO<sub>2</sub>e

281,000 m<sup>3</sup> of water consumed

660 kg Sb eq







Data centres, this place where  
the Cloud touches the ground.



Computing is not free.



Computing is not free.

But from a user point of view,  
it may look like it.

# The environmental impacts of computing

One issue, many angles

Embodied

Carbon footprint

Computing

VS

VS

VS

Operational

Broader environmental impacts

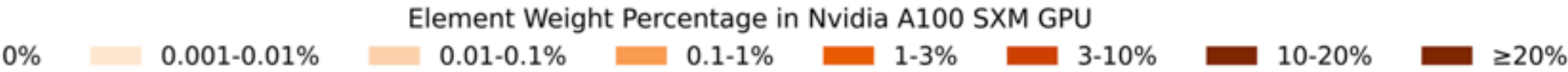
Storage



# Embodied impacts

Elemental Composition of Nvidia A100 SXM GPU

|                      |                       |                       |                            |                          |                         |                        |                       |                         |                           |                          |                          |                         |                        |                          |                          |                         |                        |
|----------------------|-----------------------|-----------------------|----------------------------|--------------------------|-------------------------|------------------------|-----------------------|-------------------------|---------------------------|--------------------------|--------------------------|-------------------------|------------------------|--------------------------|--------------------------|-------------------------|------------------------|
| 1<br>H<br>Hydrogen   |                       |                       |                            |                          |                         |                        |                       |                         |                           |                          |                          |                         |                        |                          |                          |                         | 2<br>He<br>Helium      |
| 3<br>Li<br>Lithium   | 4<br>Be<br>Beryllium  |                       |                            |                          |                         |                        |                       |                         |                           |                          |                          | 5<br>B<br>Boron         | 6<br>C<br>Carbon       | 7<br>N<br>Nitrogen       | 8<br>O<br>Oxygen         | 9<br>F<br>Fluorine      | 10<br>Ne<br>Neon       |
| 11<br>Na<br>Sodium   | 12<br>Mg<br>Magnesium |                       |                            |                          |                         |                        |                       |                         |                           |                          |                          | 13<br>Al<br>Aluminum    | 14<br>Si<br>Silicon    | 15<br>P<br>Phosphorus    | 16<br>S<br>Sulfur        | 17<br>Cl<br>Chlorine    | 18<br>Ar<br>Argon      |
| 19<br>K<br>Potassium | 20<br>Ca<br>Calcium   | 21<br>Sc<br>Scandium  | 22<br>Ti<br>Titanium       | 23<br>V<br>Vanadium      | 24<br>Cr<br>Chromium    | 25<br>Mn<br>Manganese  | 26<br>Fe<br>Iron      | 27<br>Co<br>Cobalt      | 28<br>Ni<br>Nickel        | 29<br>Cu<br>Copper       | 30<br>Zn<br>Zinc         | 31<br>Ga<br>Gallium     | 32<br>Ge<br>Germanium  | 33<br>As<br>Arsenic      | 34<br>Se<br>Selenium     | 35<br>Br<br>Bromine     | 36<br>Kr<br>Krypton    |
| 37<br>Rb<br>Rubidium | 38<br>Sr<br>Strontium | 39<br>Y<br>Yttrium    | 40<br>Zr<br>Zirconium      | 41<br>Nb<br>Niobium      | 42<br>Mo<br>Molybdenum  | 43<br>Tc<br>Technetium | 44<br>Ru<br>Ruthenium | 45<br>Rh<br>Rhodium     | 46<br>Pd<br>Palladium     | 47<br>Ag<br>Silver       | 48<br>Cd<br>Cadmium      | 49<br>In<br>Indium      | 50<br>Sn<br>Tin        | 51<br>Sb<br>Antimony     | 52<br>Te<br>Tellurium    | 53<br>I<br>Iodine       | 54<br>Xe<br>Xenon      |
| 55<br>Cs<br>Cesium   | 56<br>Ba<br>Barium    | 57<br>La<br>Lanthanum | 72<br>Hf<br>Hafnium        | 73<br>Ta<br>Tantalum     | 74<br>W<br>Tungsten     | 75<br>Re<br>Rhenium    | 76<br>Os<br>Osmium    | 77<br>Ir<br>Iridium     | 78<br>Pt<br>Platinum      | 79<br>Au<br>Gold         | 80<br>Hg<br>Mercury      | 81<br>Tl<br>Thallium    | 82<br>Pb<br>Lead       | 83<br>Bi<br>Bismuth      | 84<br>Po<br>Polonium     | 85<br>At<br>Astatine    | 86<br>Rn<br>Radon      |
| 87<br>Fr<br>Francium | 88<br>Ra<br>Radium    | 89<br>Ac<br>Actinium  | 104<br>Rf<br>Rutherfordium | 105<br>Db<br>Dubnium     | 106<br>Sg<br>Seaborgium | 107<br>Bh<br>Bohrium   | 108<br>Hs<br>Hassium  | 109<br>Mt<br>Meitnerium | 110<br>Ds<br>Darmstadtium | 111<br>Rg<br>Roentgenium | 112<br>Cn<br>Copernicium | 113<br>Nh<br>Nihonium   | 114<br>Fl<br>Flerovium | 115<br>Mc<br>Moscovium   | 116<br>Lv<br>Livermorium | 117<br>Ts<br>Tennessine | 118<br>Og<br>Oganesson |
|                      |                       |                       | 58<br>Ce<br>Cerium         | 59<br>Pr<br>Praseodymium | 60<br>Nd<br>Neodymium   | 61<br>Pm<br>Promethium | 62<br>Sm<br>Samarium  | 63<br>Eu<br>Europium    | 64<br>Gd<br>Gadolinium    | 65<br>Tb<br>Terbium      | 66<br>Dy<br>Dysprosium   | 67<br>Ho<br>Holmium     | 68<br>Er<br>Erbium     | 69<br>Tm<br>Thulium      | 70<br>Yb<br>Ytterbium    | 71<br>Lu<br>Lutetium    |                        |
|                      |                       |                       | 90<br>Th<br>Thorium        | 91<br>Pa<br>Protactinium | 92<br>U<br>Uranium      | 93<br>Np<br>Neptunium  | 94<br>Pu<br>Plutonium | 95<br>Am<br>Americium   | 96<br>Cm<br>Curium        | 97<br>Bk<br>Berkelium    | 98<br>Cf<br>Californium  | 99<br>Es<br>Einsteinium | 100<br>Fm<br>Fermium   | 101<br>Md<br>Mendelevium | 102<br>No<br>Nobelium    | 103<br>Lr<br>Lawrencium |                        |



GPT-4:

up to 8,800 GPUs

7 tonnes of toxic elements

S. Falk, N. K. Corrêa, S. Luccioni, L. Biber-Freudenberger, A. van Wynsberghe, (2025).  
“From FLOPs to Footprints: The Resource Cost of Artificial Intelligence.”



# Embodied impacts

Baotou, Mongolia

<https://www.bbc.co.uk/future/article/20150402-the-worst-place-on-earth>



# Embodied impacts



Baotou, Mongolia



## Children and digital dumpsites

E-waste exposure and  
child health





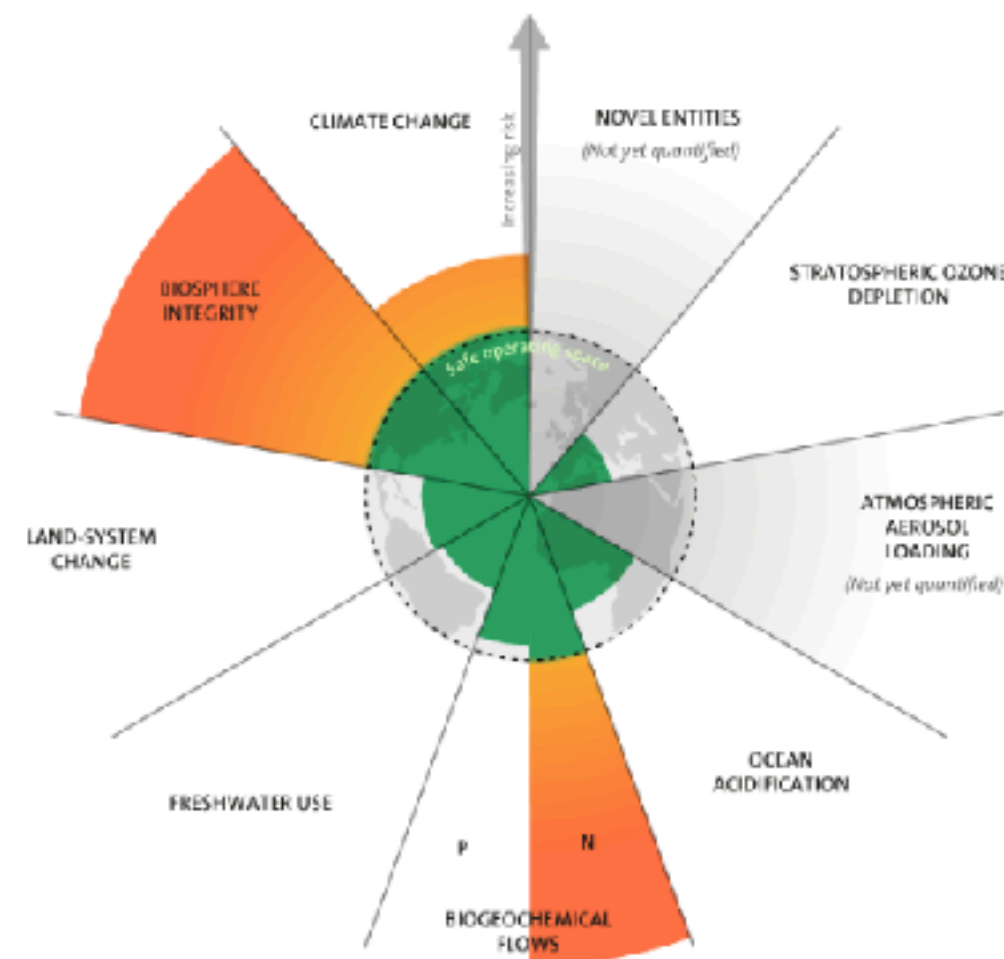
***All about carbon?***





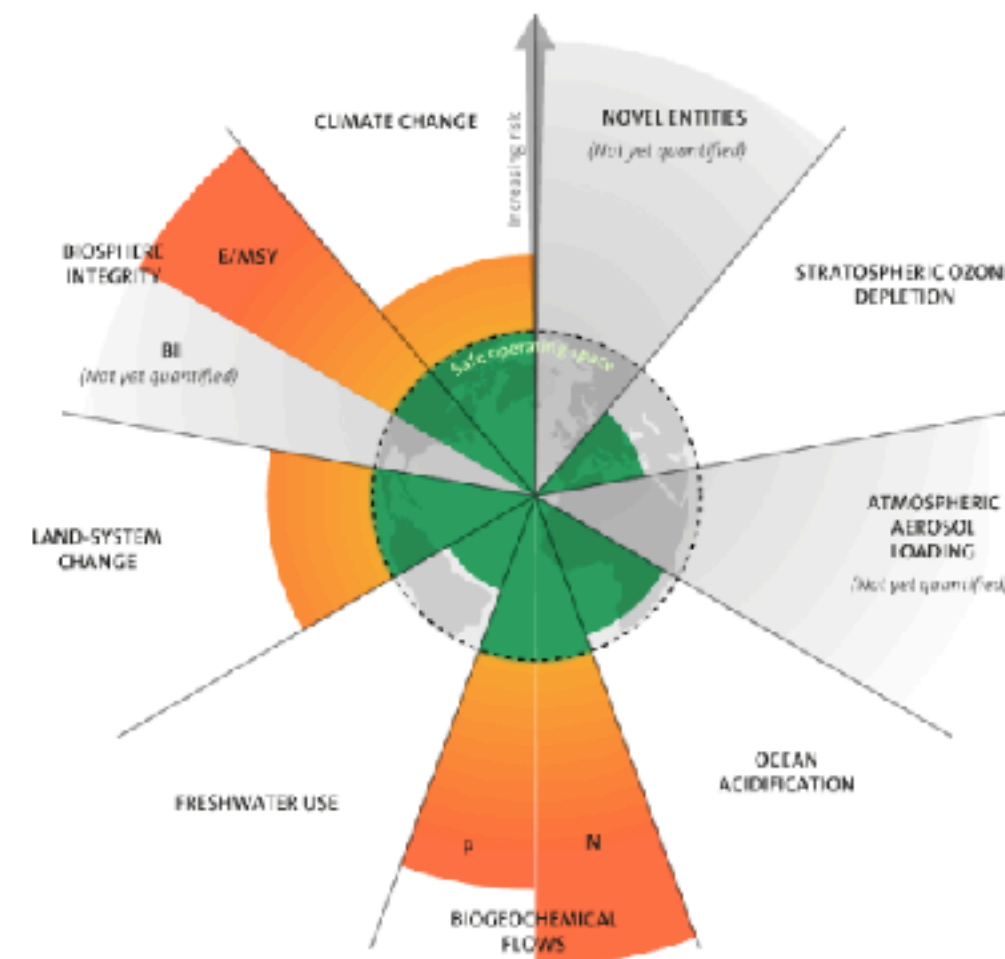
# Planetary boundaries

2009



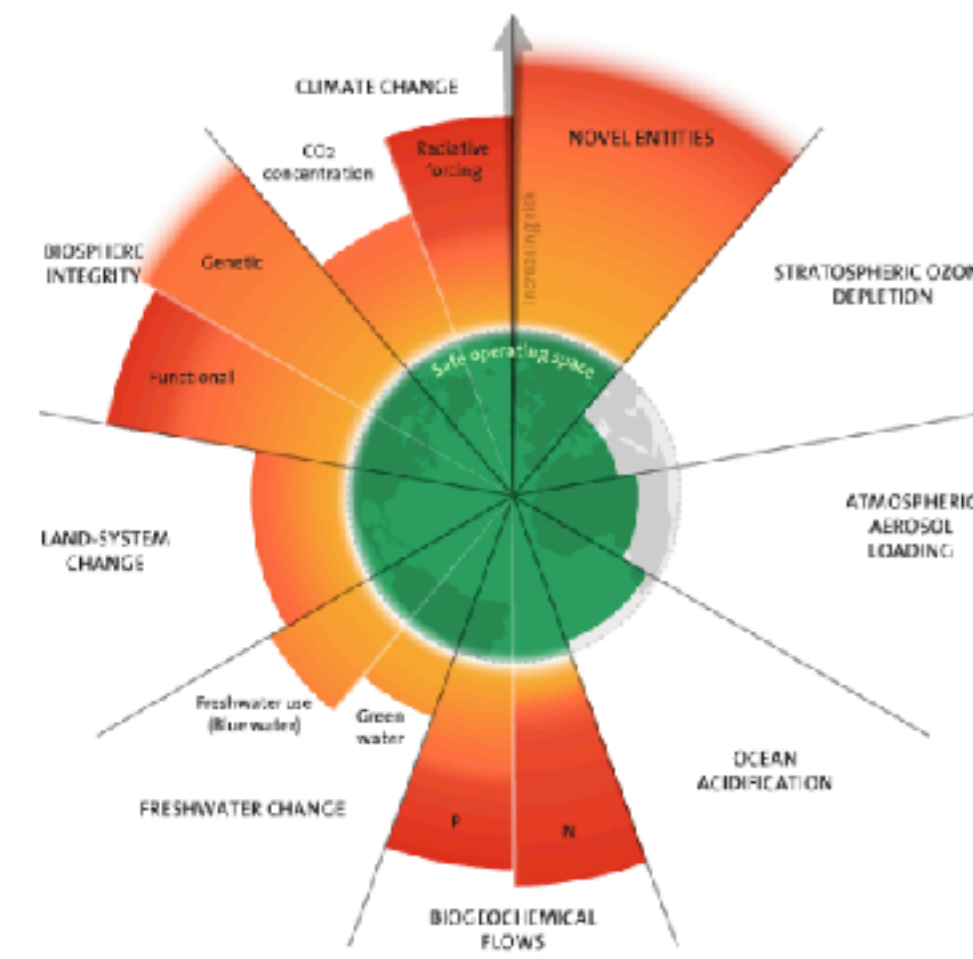
7 boundaries assessed,  
3 crossed

2015



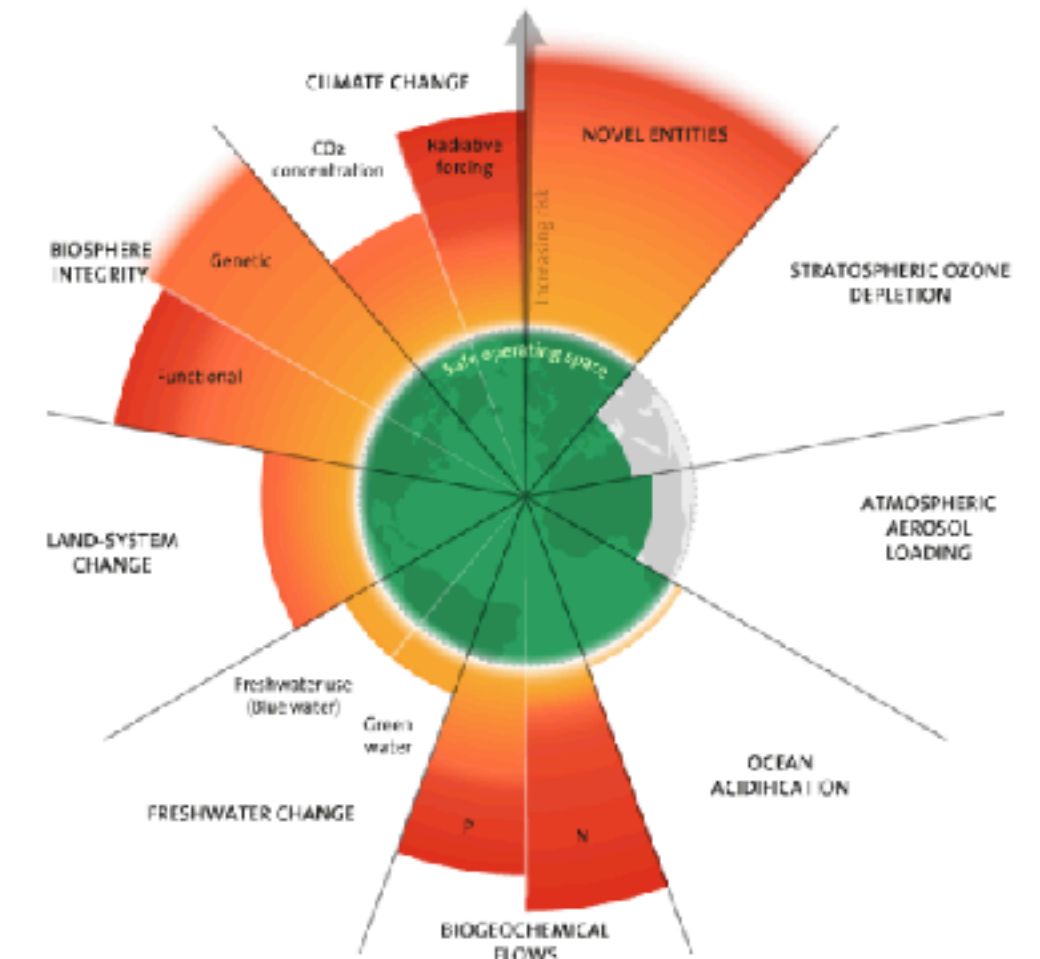
7 boundaries assessed,  
4 crossed

2023



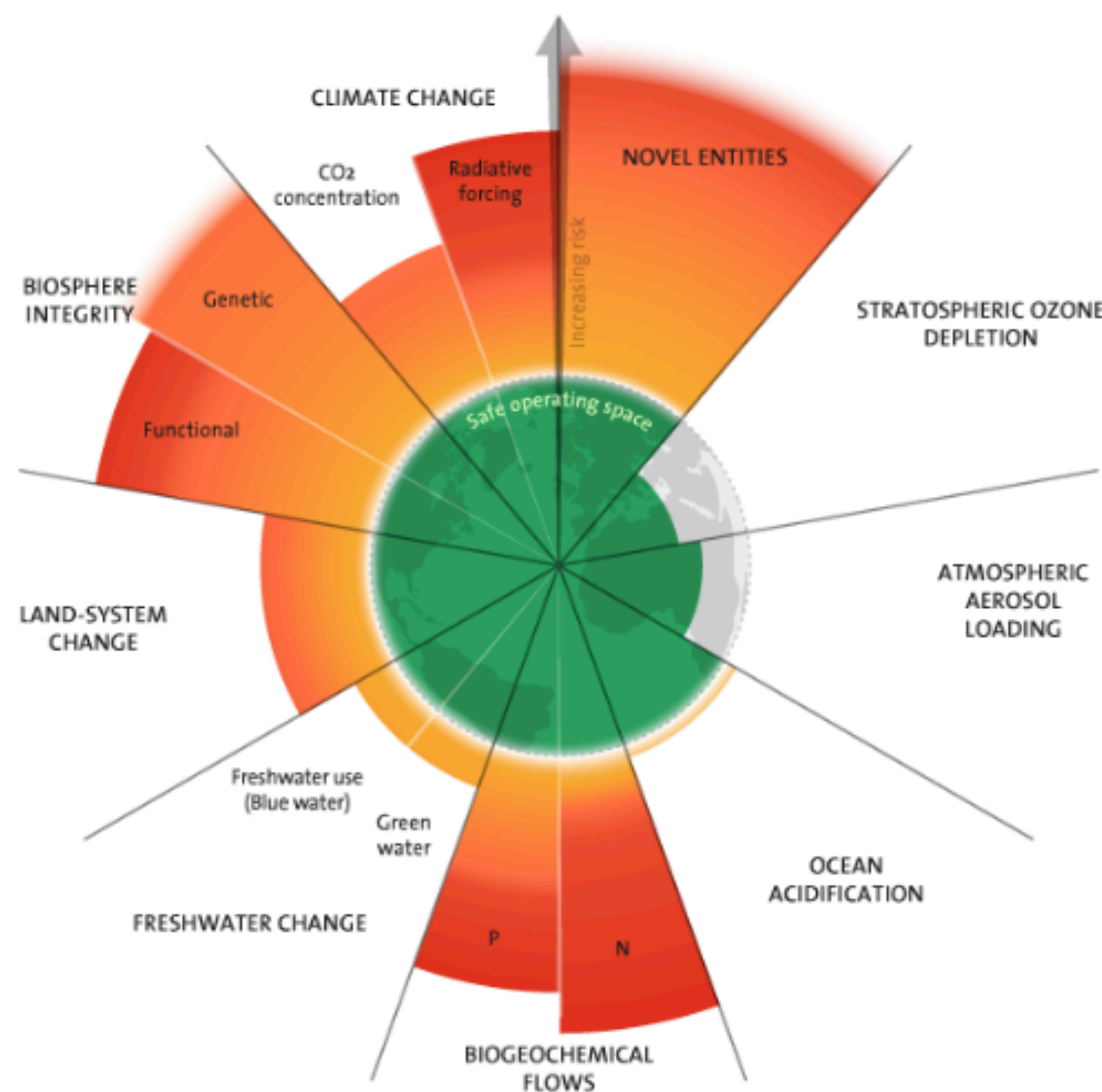
9 boundaries assessed,  
6 crossed

2025



9 boundaries assessed,  
7 crossed

# 2025



9 boundaries assessed,  
7 crossed

Azote for Stockholm Resilience Centre, Stockholm University. Based on Sakschewski and Caesar et al. 2025, Richardson et al. 2023, Steffen et al. 2015, and Rockström et al. 2009.



# Operational carbon footprint

Or the cost of running stuff

Carbon footprint = energy used x carbon intensity

*gCO<sub>2</sub>e*

*kWh*

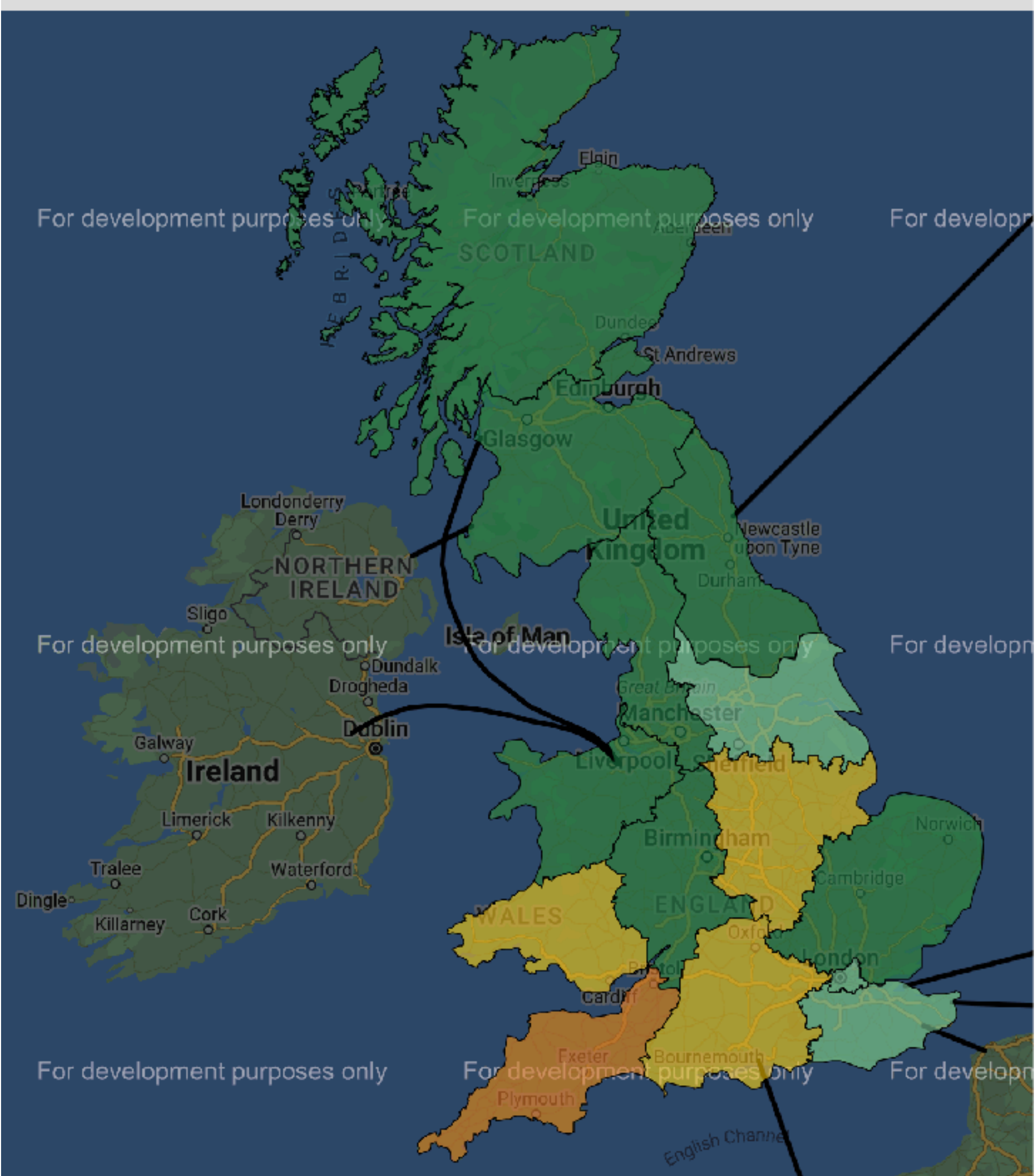
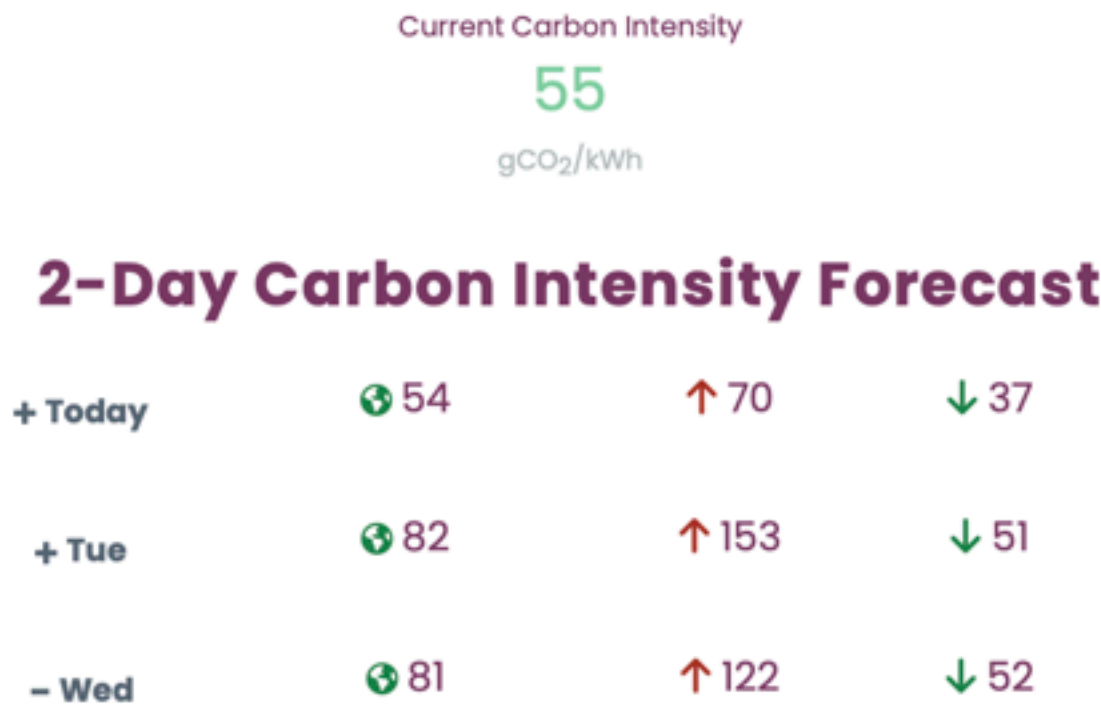
*gCO<sub>2</sub>e/kWh*

# Carbon Intensity API

National Energy System Operator (NESO), in partnership with Environmental Defense Fund Europe, University of Oxford Department of Computer Science and WWF, have developed the world's first Carbon Intensity forecast with a regional breakdown.

The Carbon Intensity API uses state-of-the-art Machine Learning and sophisticated power system modelling to forecast the carbon intensity and generation mix 96+ hours ahead for each region in Great Britain.

Our OpenAPI allows consumers and smart devices to schedule and minimise CO<sub>2</sub> emissions at a local level.



Click on interconnectors to see their names  
Key: Very High - High - Moderate - Low - Very Low



**Methods and tools** to empower computational scientists, organisations and funders to understand and mitigate the environmental impacts of their work.

[www.green-algorithms.org](http://www.green-algorithms.org)





Navirah Kamal

Even Matencio

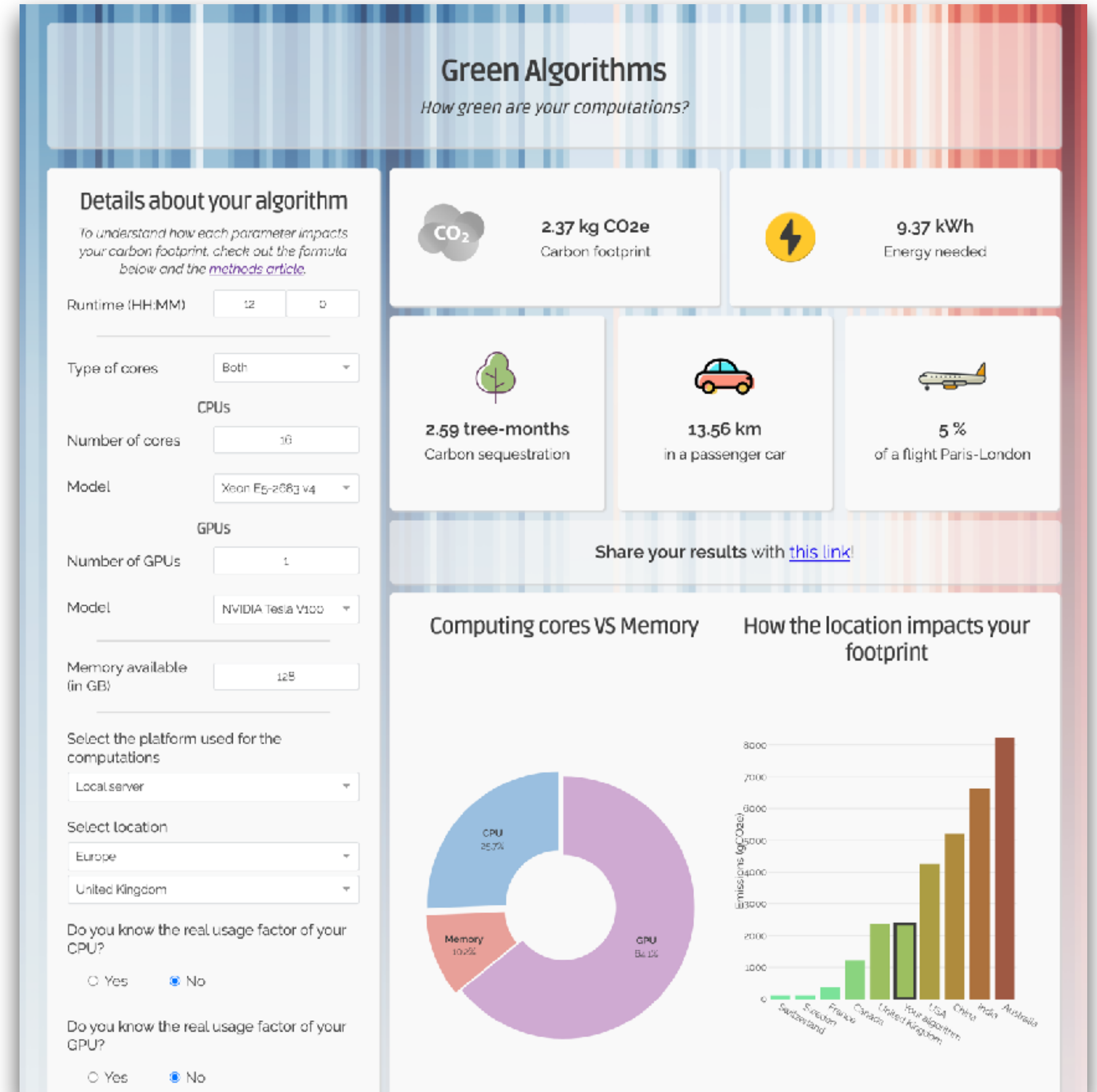
Michael Inouye

# The Green Algorithms calculator

[calculator.green-algorithms.org](https://calculator.green-algorithms.org)



L. Lannelongue, J. Grealey, M. Inouye, *Advanced Science* (2021).  
“Green Algorithms: Quantifying the Carbon Footprint of Computation.”







Navirah Kamal

Even Matencio

Michael Inouye

# The Green Algorithms calculator

[calculator.green-algorithms.org](https://calculator.green-algorithms.org)



**The Green Algorithms calculator, adapted for artificial intelligence**

This new page is especially dedicated to AI-related computations, where compute is usually divided between training and inference phases. The methods is the same as in the original tool, it simply facilitates the reporting of AI systems' environmental impacts over a fixed period of time, e.g. one year.

Share your results [as a csv file!](#)

Import results  
Drag and drop or click to select your .csv file.

**Reporting period**

The reporting period is to the period of time over which you want to estimate the environmental impacts of your AI system (training and inference). This is particularly relevant in the case of ongoing deployment of the system. Typical values might be one year or the whole estimated lifespan of your system.

*The value is only used by the calculator when you select 'continuous inference' to report the total energy and carbon footprint over the reporting period. It is nonetheless good practice to enter it to clarify the scope of your estimations.*

1 Year(s)

**TRAINING**

Form Help

Report your training-related computations. For more information about R&D experiments, retrainings or overall tips regarding your reporting, please refer to the Help tab.

Runtime (HH:MM) 12 0

Type of cores CPU

Number of cores 12

Model Xeon E5-2683 v4

Memory available (in GB) 64

Select the platform used for the computations Local server

Select location Europe Austria

Do you know the real usage factor of your GPU?

**INFERENCE**

Form Help

Report your inference-related computations. For more information about continuous inference scheme or overall tips regarding your reporting, please refer to the Help tab.

☐ Apply continuous inference scheme

Runtime (HH:MM) 12 0

Type of cores CPU

Number of cores 12

Model Xeon E5-2683 v4

Memory available (in GB) 64

Select the platform used for the computations Local server

Select location Europe

L. Lannelongue, J. Grealey, M. Inouye, *Advanced Science* (2021).  
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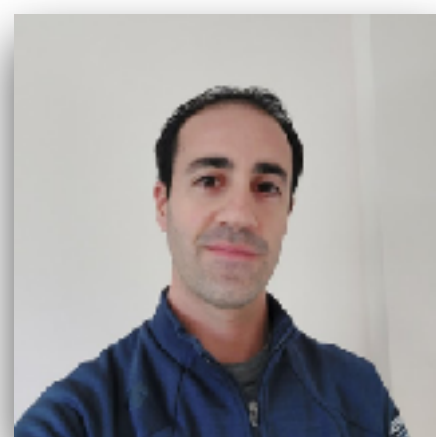
# Just out as pre-release: Green Algorithms Dashboard

An open source, easy to deploy, reliable and transparent dashboard that allows users to see energy usage and carbon emissions at user/group/department level.

[www.green-algorithms.org/dashboard](http://www.green-algorithms.org/dashboard)



Navirah Kamal



Laurent Gil



Christina Bremer



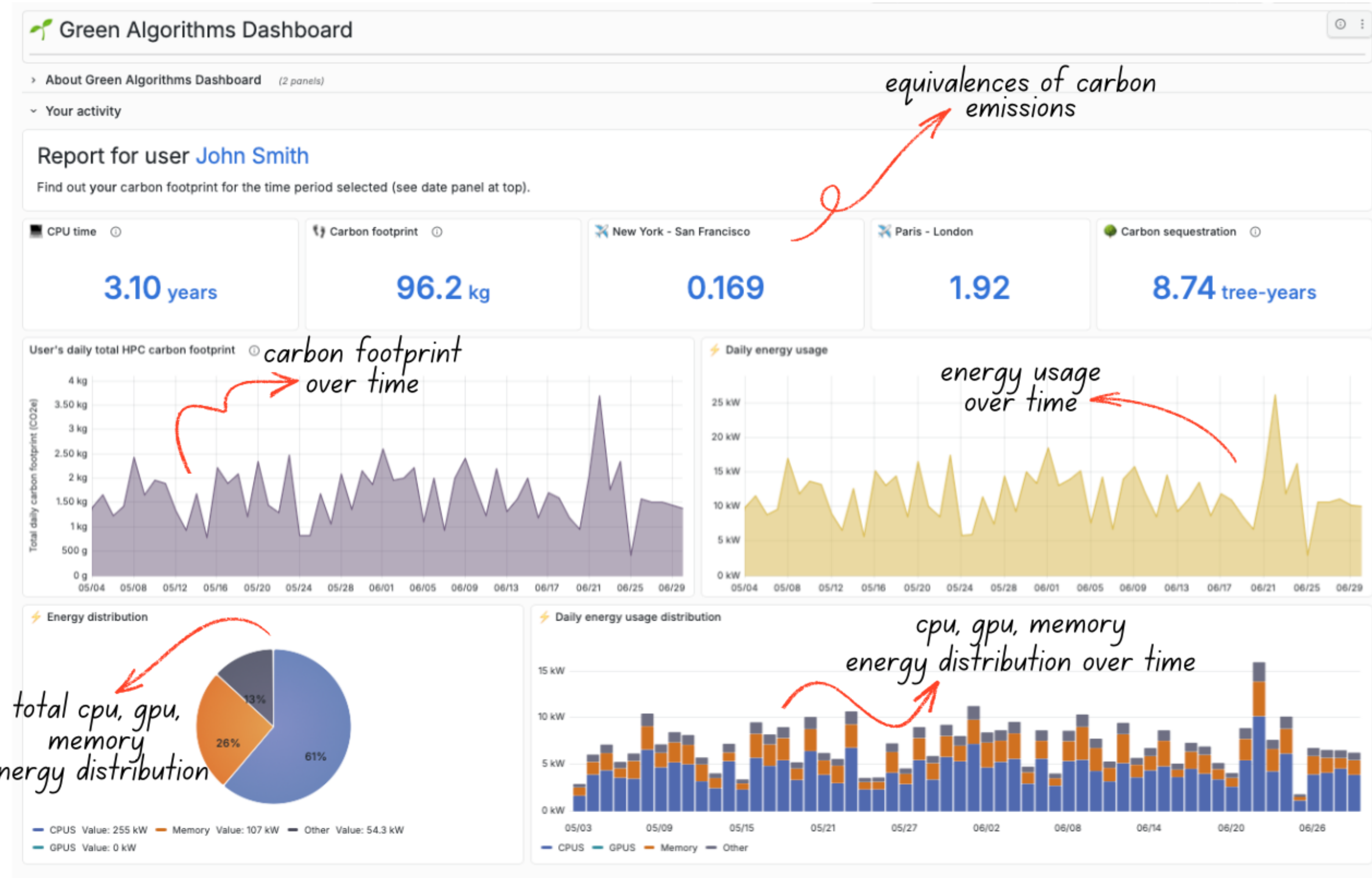
Matthias Blum



Alex Bateman



# Green Algorithms Initiative



See prototype at: [dashboard.green-algorithms.org](https://dashboard.green-algorithms.org)

## Successful vs Failed Jobs (user John Smith)

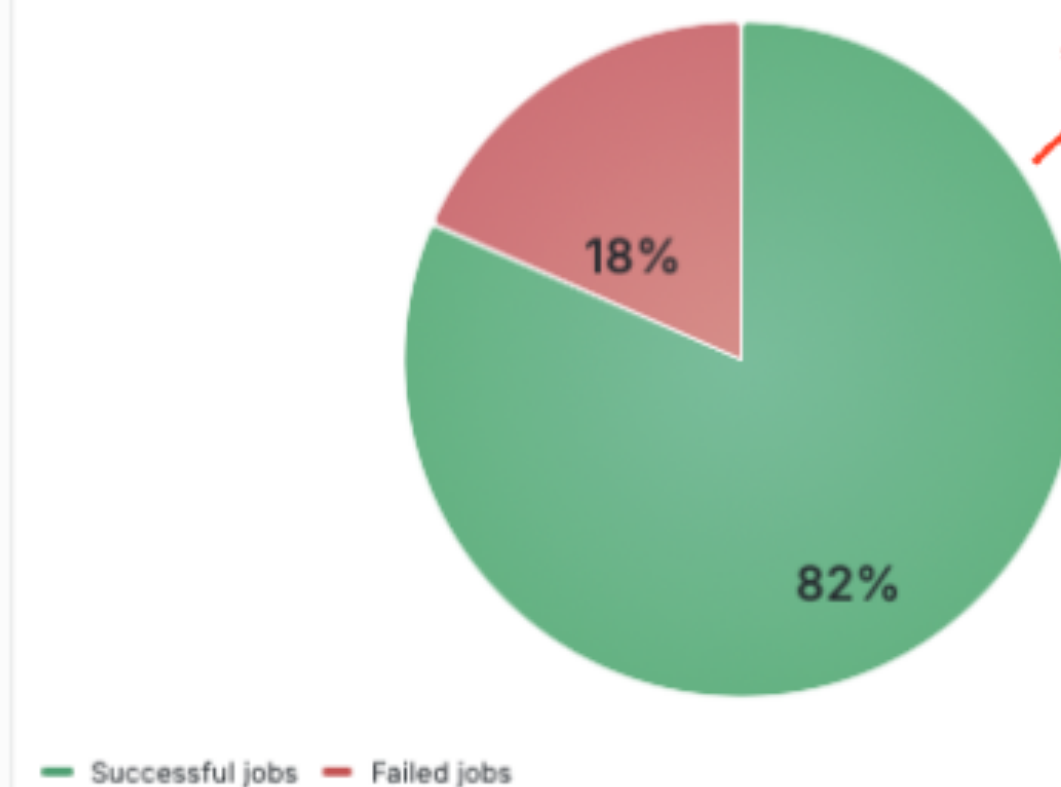
Because any resource spent on a job is wasted if the job fails, it is important to test scripts and pipelines on small datasets. The chart below shows the daily success and failure rates of jobs that completed in the time period selected (see date panel at top).

User's total number of jobs submitted ⓘ

664

*failed jobs vs  
successful jobs*

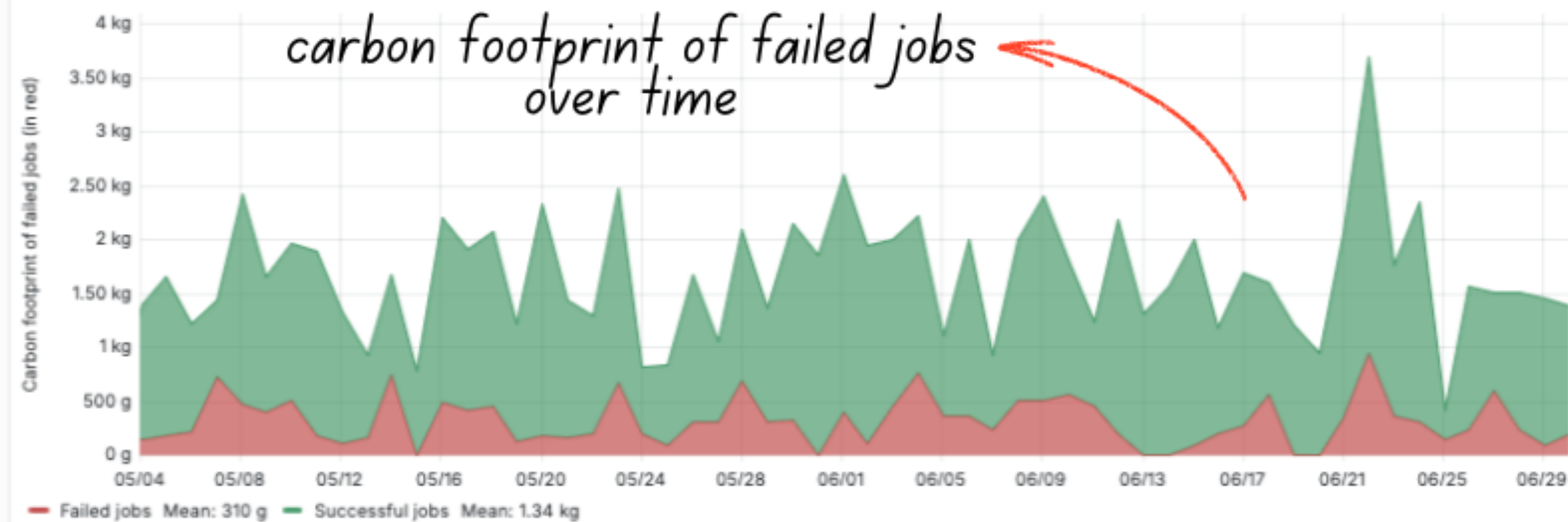
User's distribution of failed and successful jobs



Cost of user's failed jobs

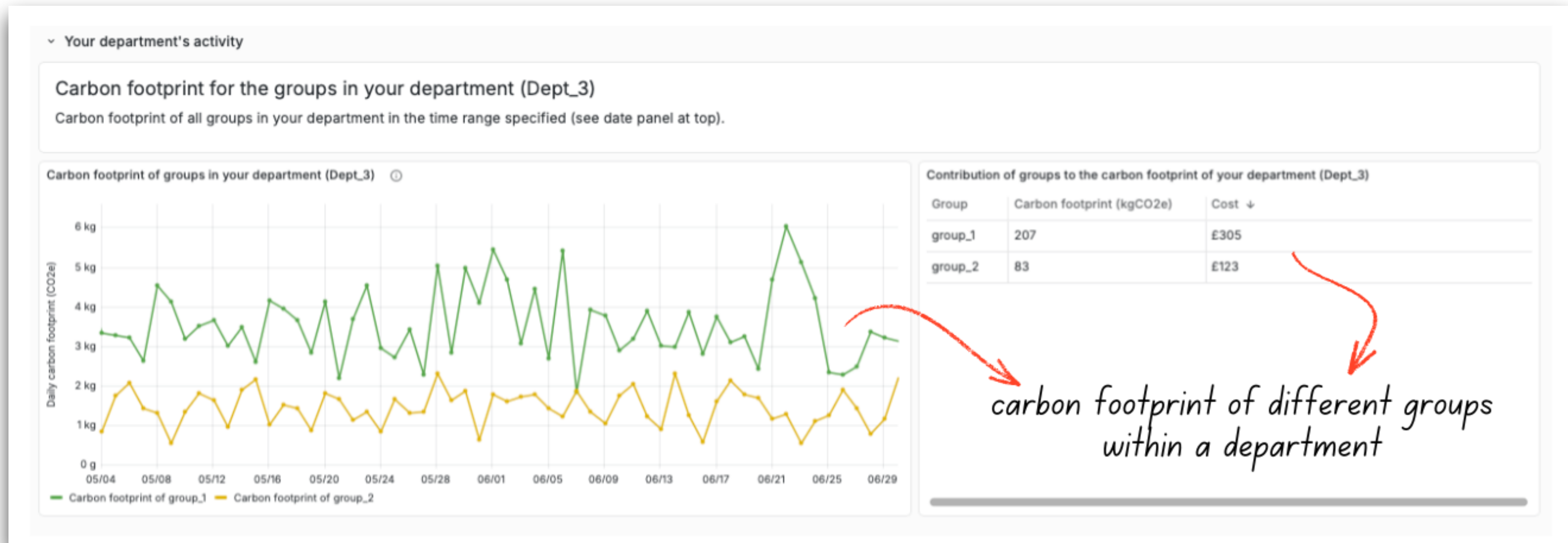
| No. of jobs completed | Failed jobs' footprint (kgCO2e) | Cost of failed jobs | % of failed jobs ↓ |
|-----------------------|---------------------------------|---------------------|--------------------|
| 664                   | 18.29                           | £27                 | 18.37              |

User's carbon footprint of Failed vs Successful jobs



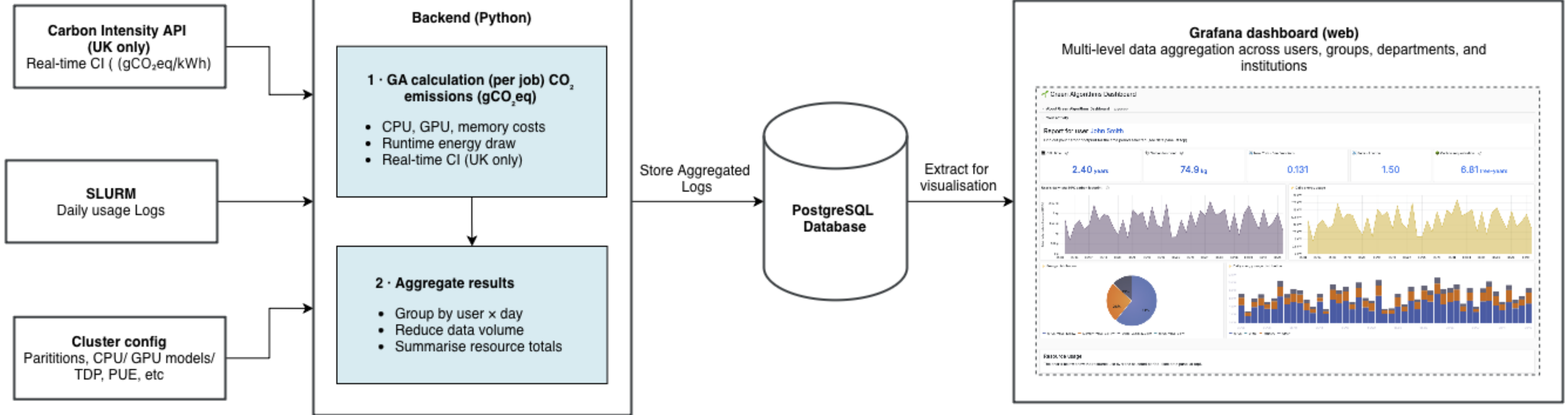
See prototype at: [dashboard.green-algorithms.org](https://dashboard.green-algorithms.org)





See prototype at: [dashboard.green-algorithms.org](https://dashboard.green-algorithms.org)

Runs every 24 hours using cron exp.



Entire process done locally, within the institution



Measuring is great.  
Does it make any difference?

# E-SCOUT: Environmentally Sustainable Computing User Trial

E-SCOUT is a large-scale multi-centre trial to study the effectiveness of carbon reporting tools in reducing the environmental impacts of scientific computing.

**Research Questions:** To what extent does carbon tracking incentivise green computing practices? How can we make sure it does?



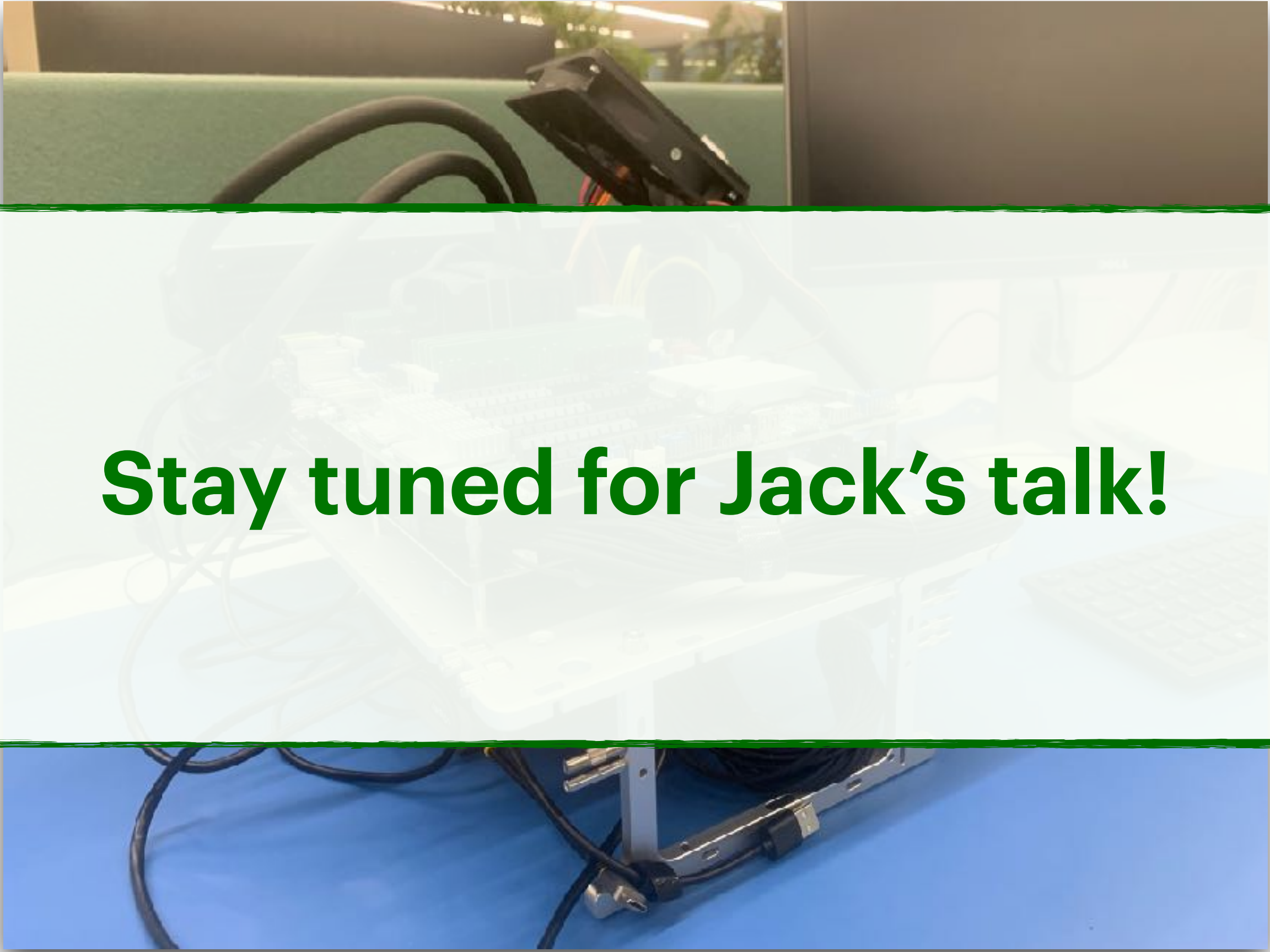
Christina Bremer



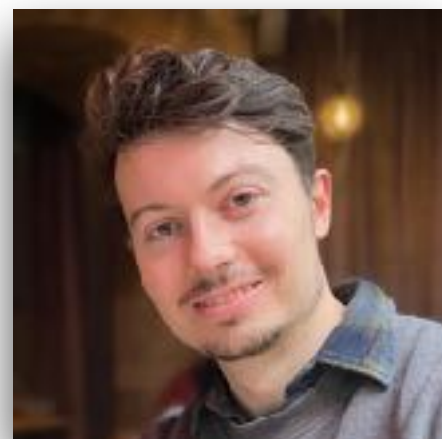
Jan van der Scheer



# Towards better power models



**Stay tuned for Jack's talk!**



Jack Coker

# Cultural change needs to be front and centre

*We need to change hearts and  
minds of researchers on the ground*





# About the ESCS community

This is still a work in progress! But you can already find below links to the main resources so far for the ESCS Community.



## Sign up to the newsletter

The easiest way to be kept updated on what is going on in the ESCS community. We send out a monthly digest of the latest news and developments in the sustainable computing space.

Subscribe See archive

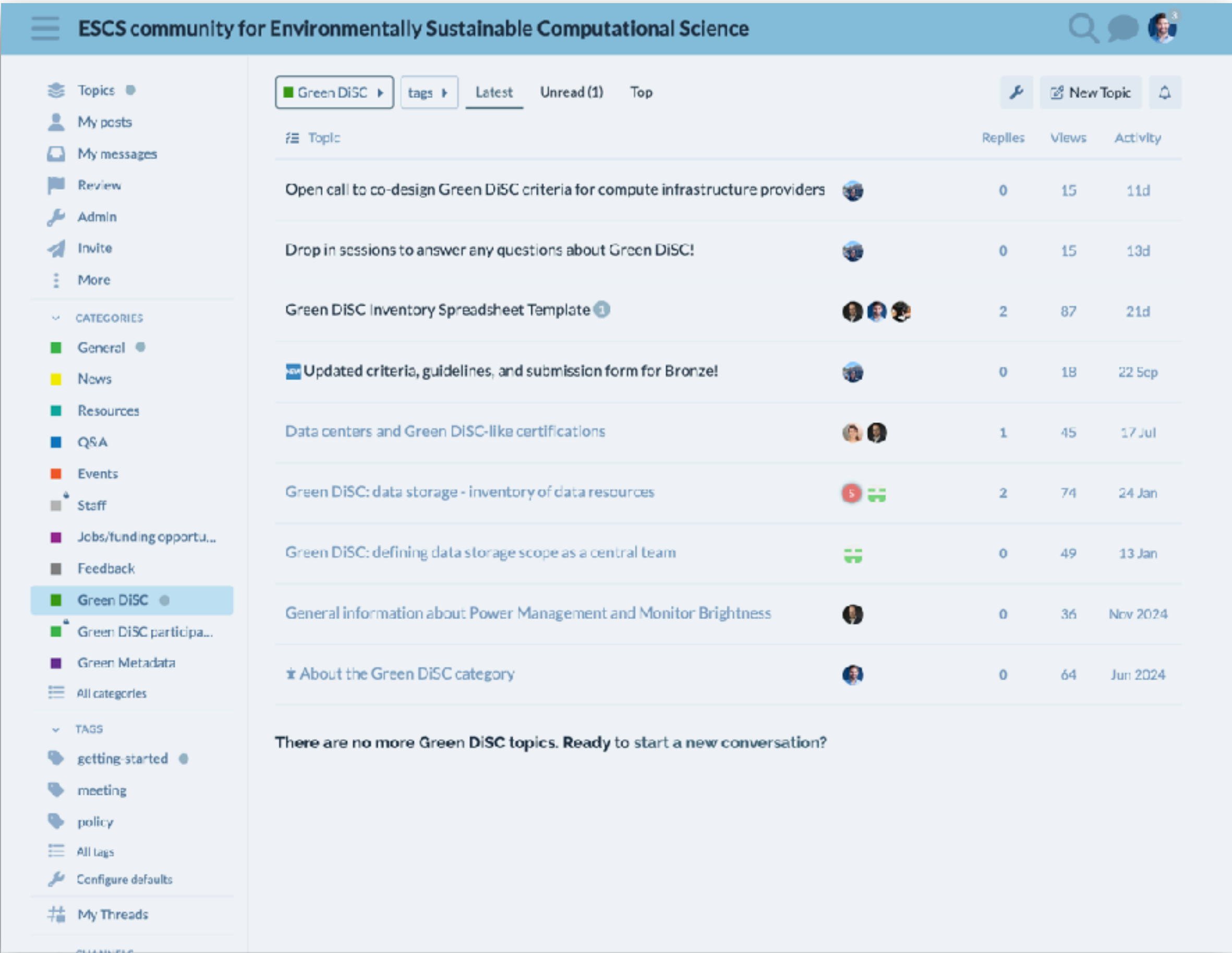
## The online forum

A place to connect, ask question and share resources.

Check it out



# Community building



Calculators are **not** the goal.



**“Digital technologies developed and deployed in pursuit of net zero must be **energy-proportionate** – ie they must bring environmental or societal benefits that outweigh their own emissions.”**

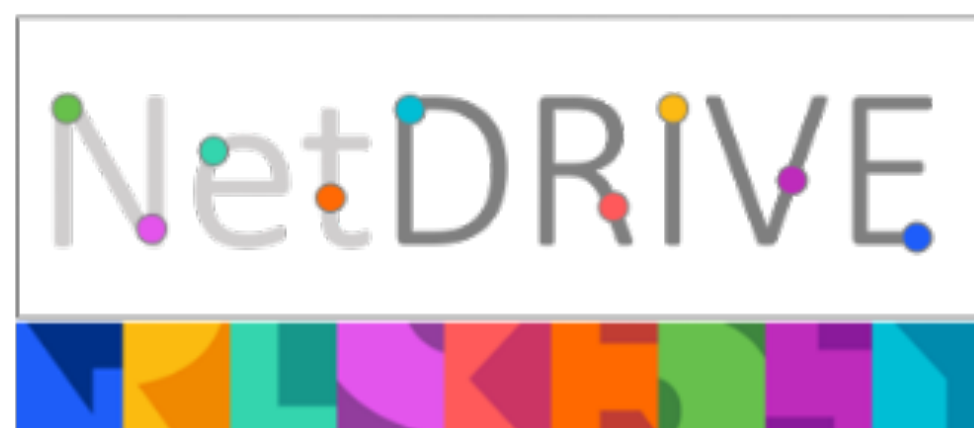
**The Royal Society “Digital Technology and the planet”**

**“Digital technologies developed and deployed in pursuit of net zero must be energy-proportionate – ie they must bring environmental or societal benefits that outweigh their own emissions.”**

**The Royal Society “Digital Technology and the planet”**



The solutions we develop, the code we write, the data centres we build benefit the least populations who suffer the most from climate change.



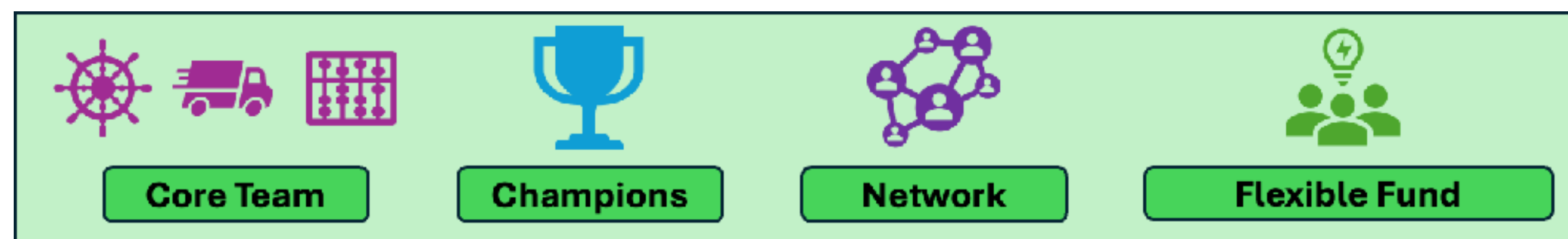
# NetDRIVE

<https://uknetdrive.org/>

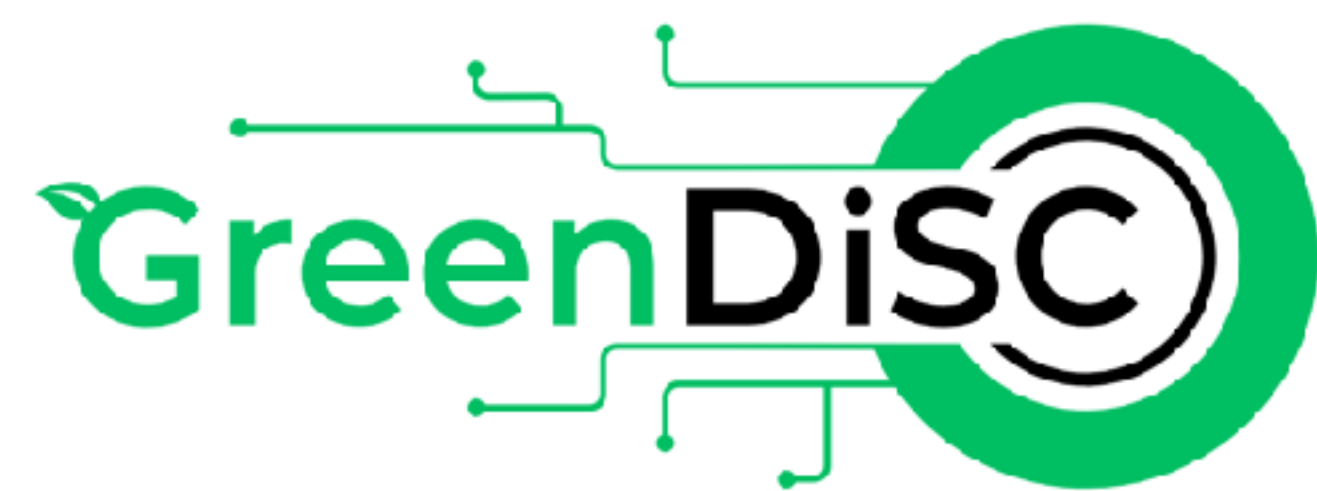
*The Network for sustainable Digital Research Infrastructure Vision and Expertise (NetDRIVE) has been set up to provide a forum for managers, software engineers, academics and others to come together to build a common vision for a sustainable future and to incite a transition to sustainable working practices in the Digital Research Infrastructure communities.*

## Ambitions

- Immediate and tangible progress towards net zero
- National and international thought leadership
- Confidence in our pathway to sustainability

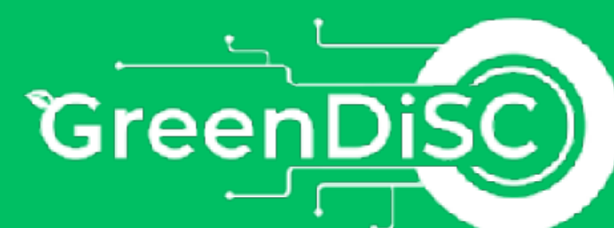








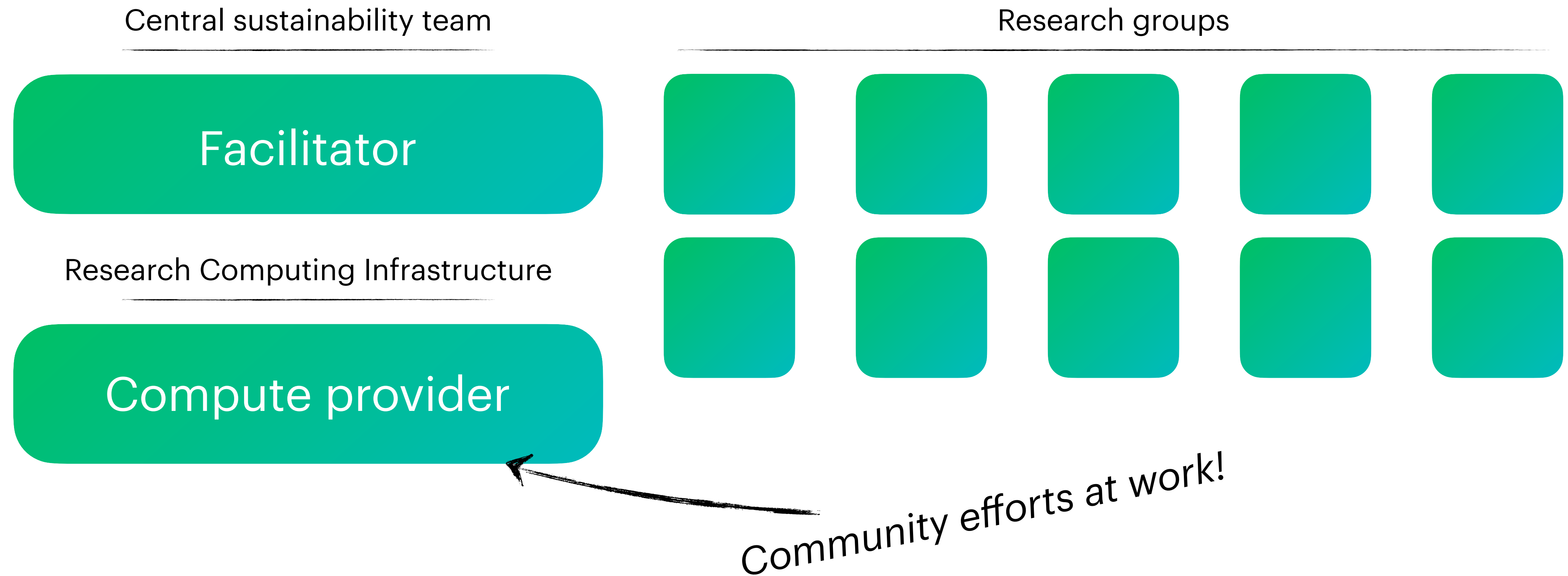
Green DiSC is a free and open-access certification scheme which provides a roadmap for research groups and institutions who want to tackle the environmental impacts of their computing activities.





# How does it work?

## Several sets of criteria

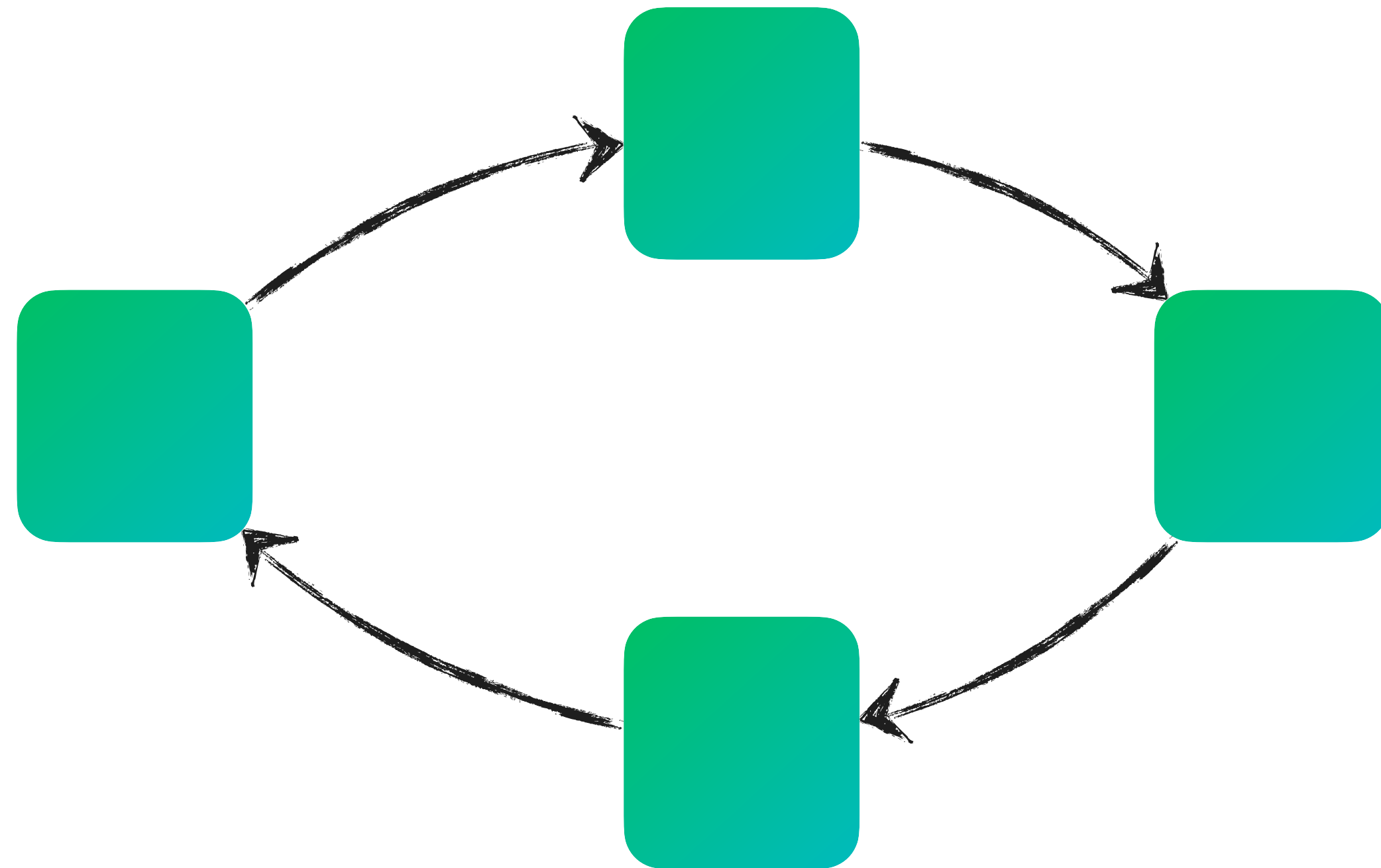


# Peer reviews for auditing

Scalable + knowledge exchange + independent audit

Three application rounds each year:

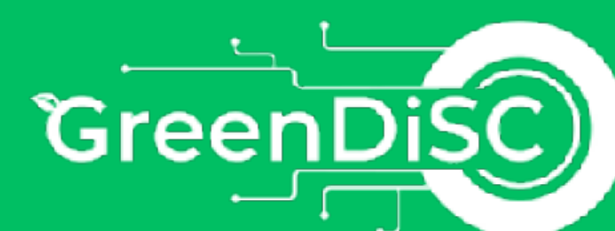
- mid-March
- mid-July
- mid-November



*Bonus: takes the pressure off the central sustainability team*



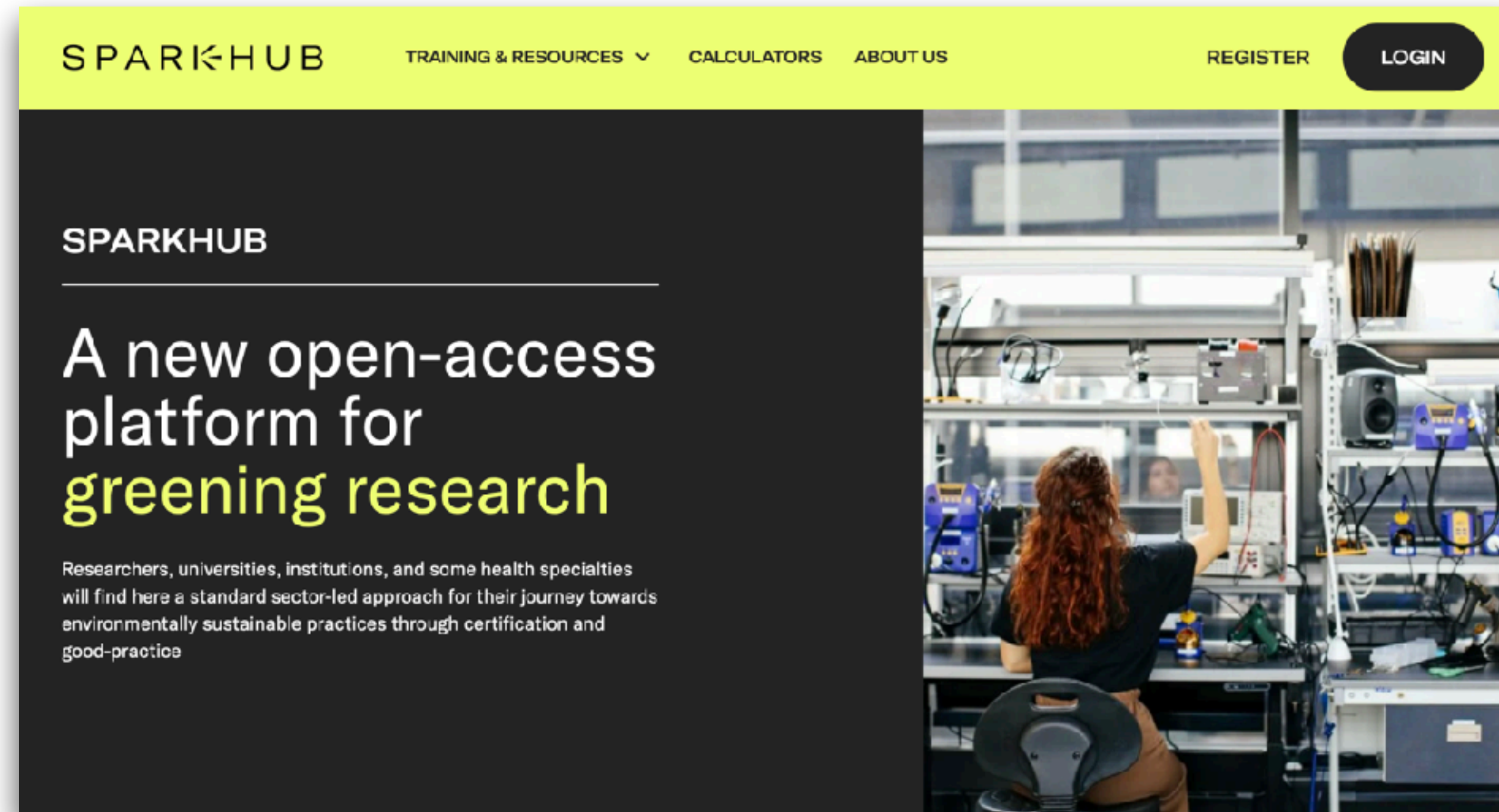






# Looking ahead

## Powering SPARKhub's Digital categories





# Next steps to take part

## The easy low-commitment options

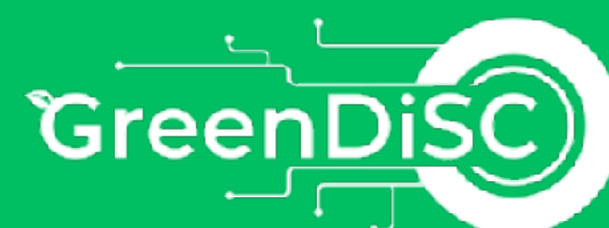
Sign up for the newsletter

<https://zcmp.eu/mwMp>

Follow us on LinkedIn and Bluesky  
(@green-disc.bsky.social)

Join our next monthly drop in session.

Check the website to learn more.



# About the ESCS community

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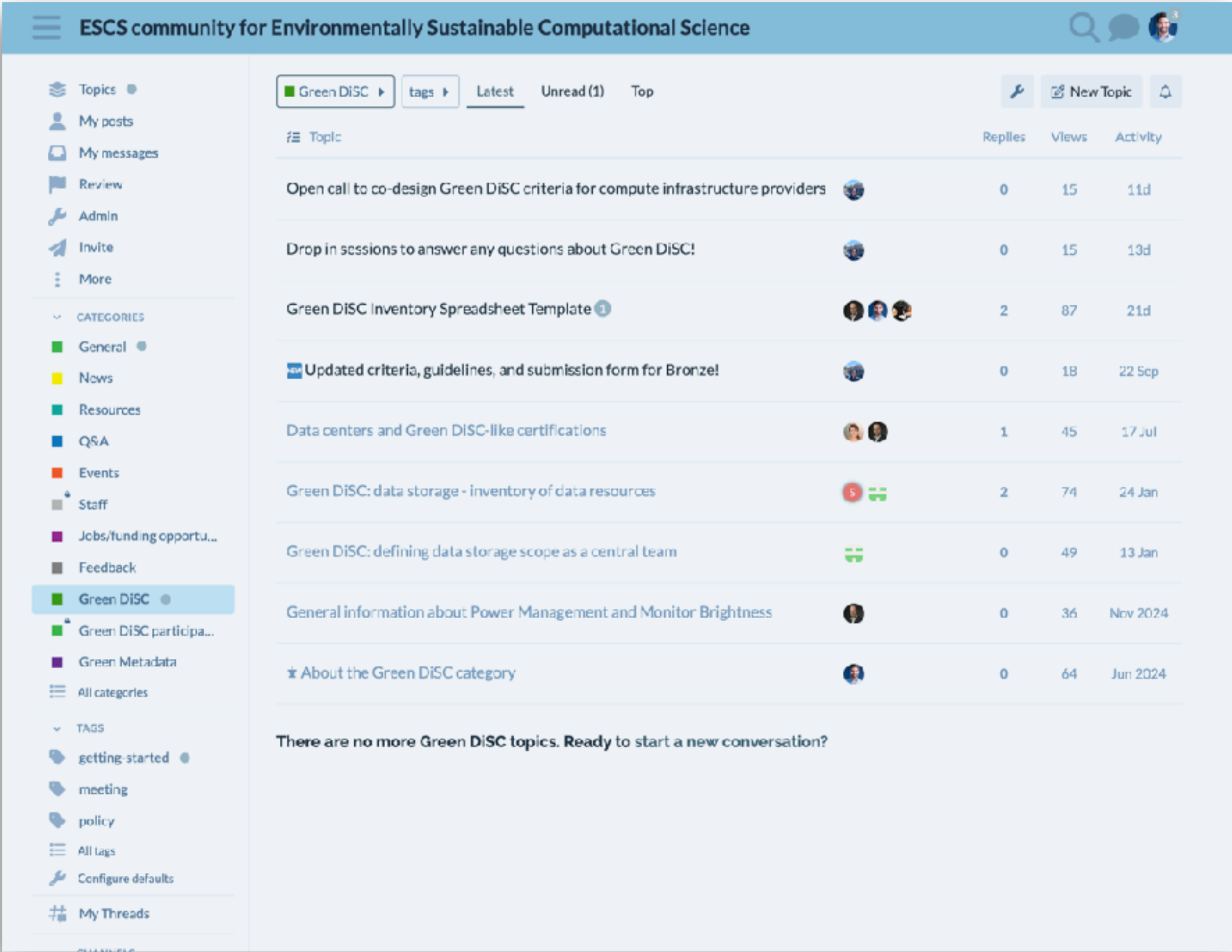
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A place to connect, ask question and share resources.

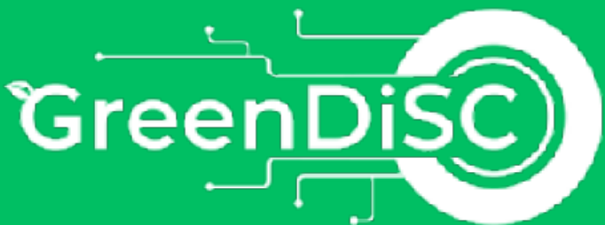
[Check it out](#)



# Join the community and find resources from other applicants



[forum.escs-community.org](https://forum.escs-community.org)





[info@greendisc.org](mailto:info@greendisc.org)

[www.software.ac.uk/GreenDiSC](http://www.software.ac.uk/GreenDiSC)

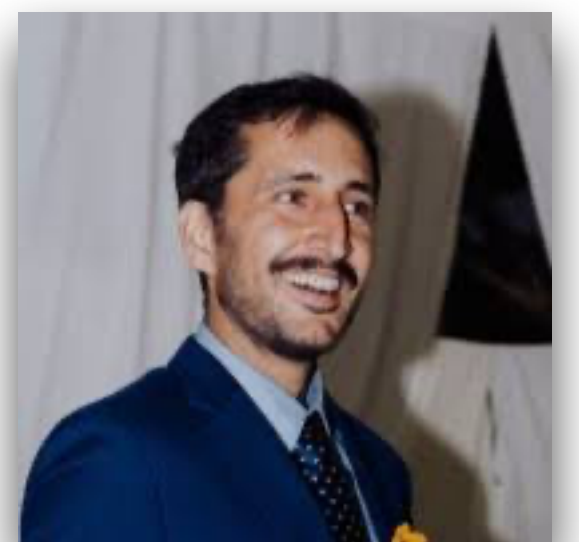


We are grateful to the brilliant  
Green DiSC community for  
their feedback and  
contributions to the scheme!

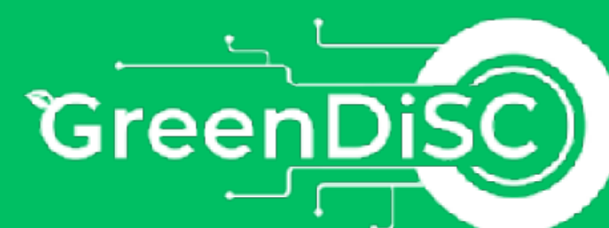


**Anica Araneta**  
*Green DiSC coordinator*

And the SSI team: Kirsty  
Pringle, Denis Barclay, Shoaib  
Sufi, Oscar Seip



**Martin Farley**  
*UKRI*





# SC4RC: a unique conference bringing together researchers across disciplines interested in sustainable computational science

First edition at CERN in May 2026,  
with ~150 participants





*And the many collaborators in  
Cambridge and in other  
institutions that have made  
this work possible!*



Contact: [LL582@cam.ac.uk](mailto:LL582@cam.ac.uk) [www.cam-sustainablecomputing.org](http://www.cam-sustainablecomputing.org)