37th International Cosmic Ray Conference
12–23 July 2021

ICRC 2021

THE ASTROPARTICLE PHYSICS CONFERENCE
Berlin | Germany

Content

LOC Institutes and Organisations

Sustainability of / for / in science

an introduction

Knud Jahnke
Max Planck Institute for Astronomy
Heidelberg, Germany

Input and discussions by:
MPIA Sustainability Group
Astronomers For Planet Earth

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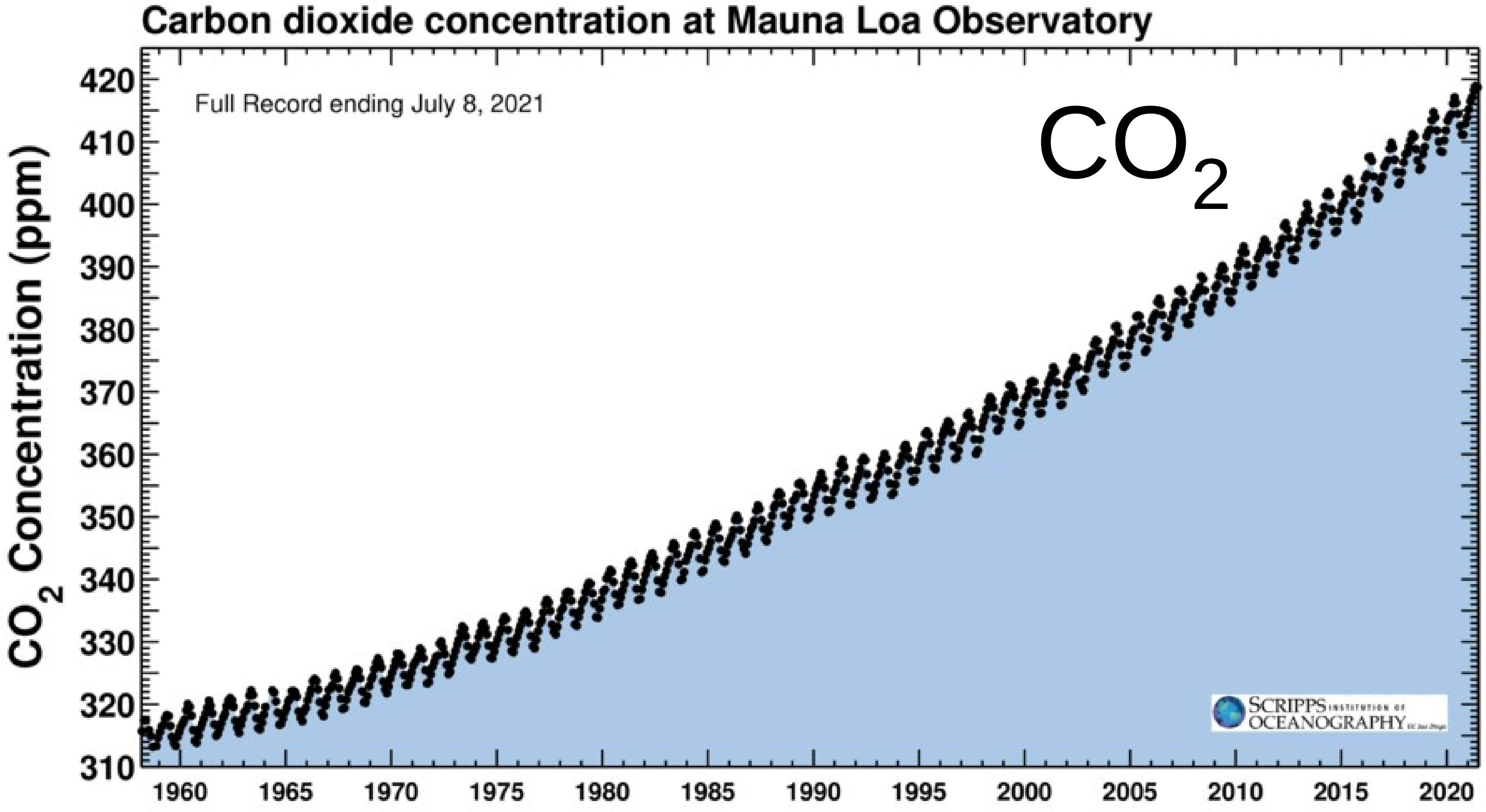
astronomersforplanet.earth

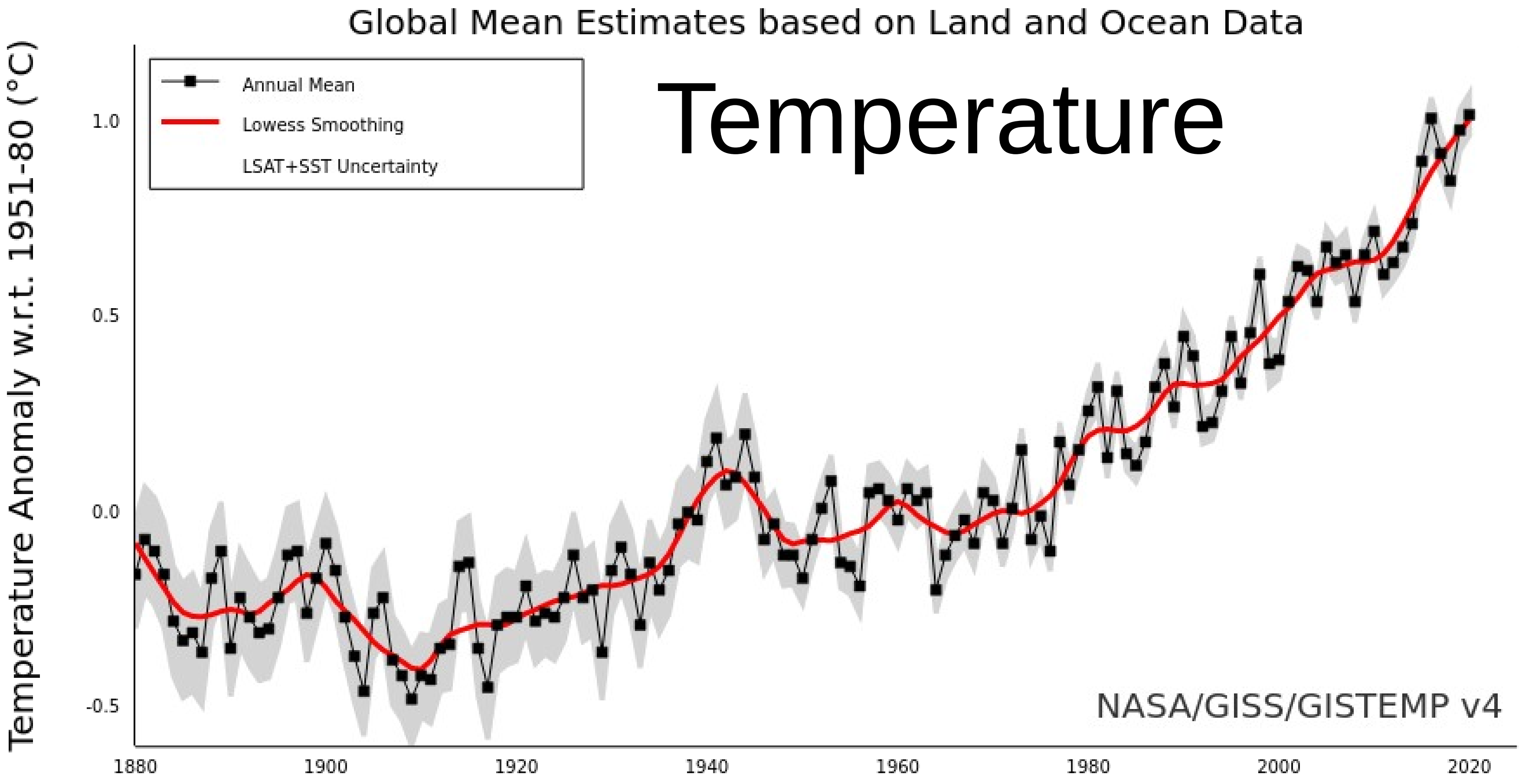
Sustainability?

“making only such use of natural, renewable resources that people can continue to rely on their yields in the long term”



Scripps Institution of Oceanography
keelingcurve.ucsd.edu

Temperature



https://data.giss.nasa.gov/gistemp/graphs_v4

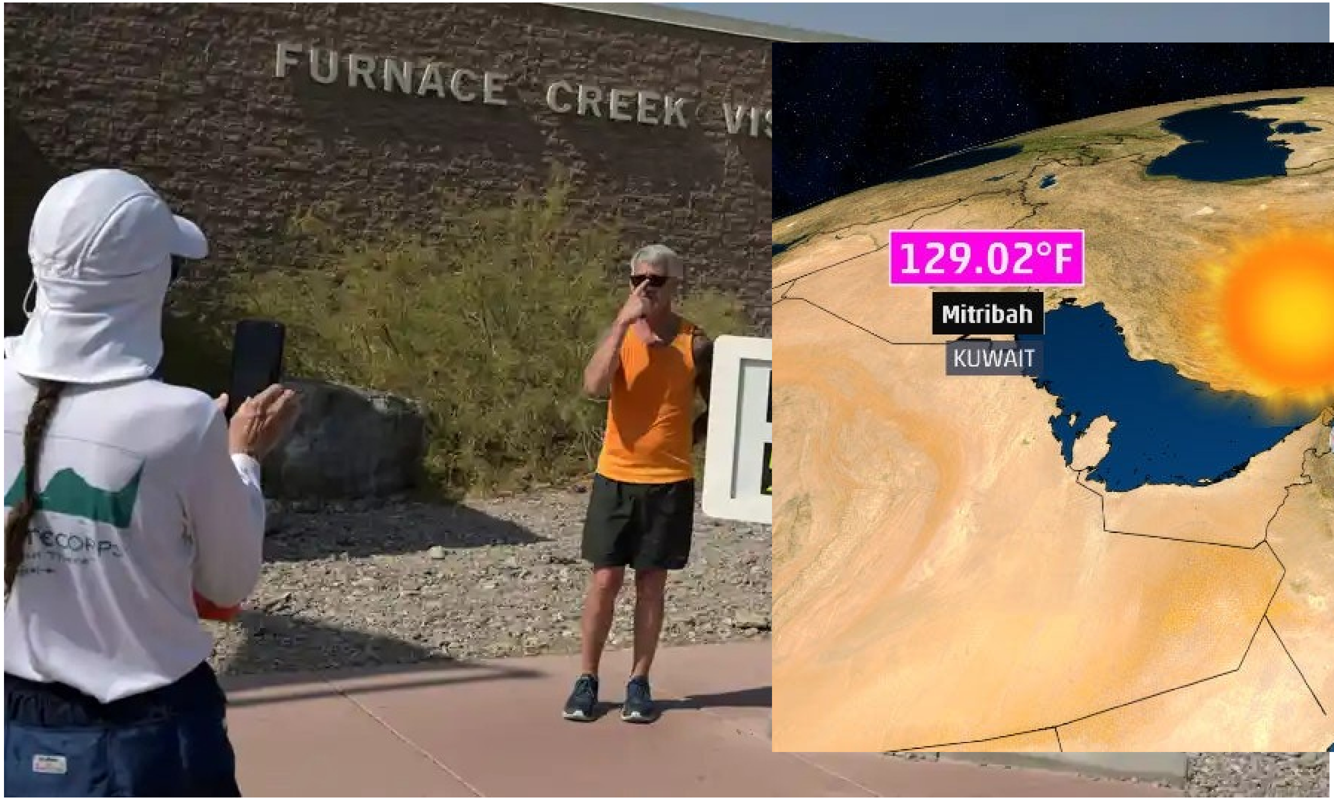
Consequence: Climate Crisis

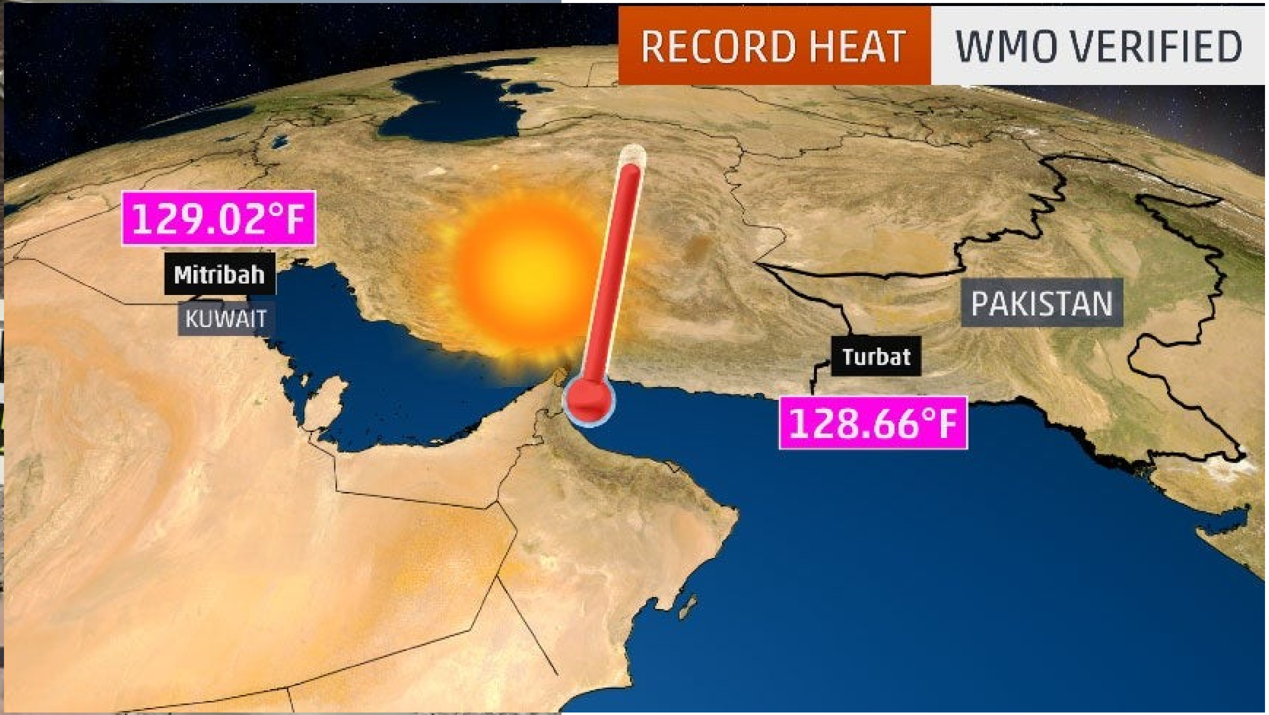
- Global sea-level rise
- More extreme weather
- Worse extreme weather
- Local climate impacts

Consequence: Climate Crisis

Bridget Bennet/Reuters via The Guardian (July 2021)

Consequence: Climate Crisis





2016/2019 records, weather.com

Bridget Bennet/Reuters via The Guardian (July 2021)

Lytton, Canada, 2021

Darryl Dyck, The Canadian Press via CBC.ca

Australia, 2020
Matthew Abbott for The New York Times

Germany, 2020
Imago-images.de/Jan Eifert, Florian Karlstedt

Germany, last week

Consequence: Climate Crisis

Solomon islands

Jakarta 2020
AP photo

Consequence: Climate Crisis

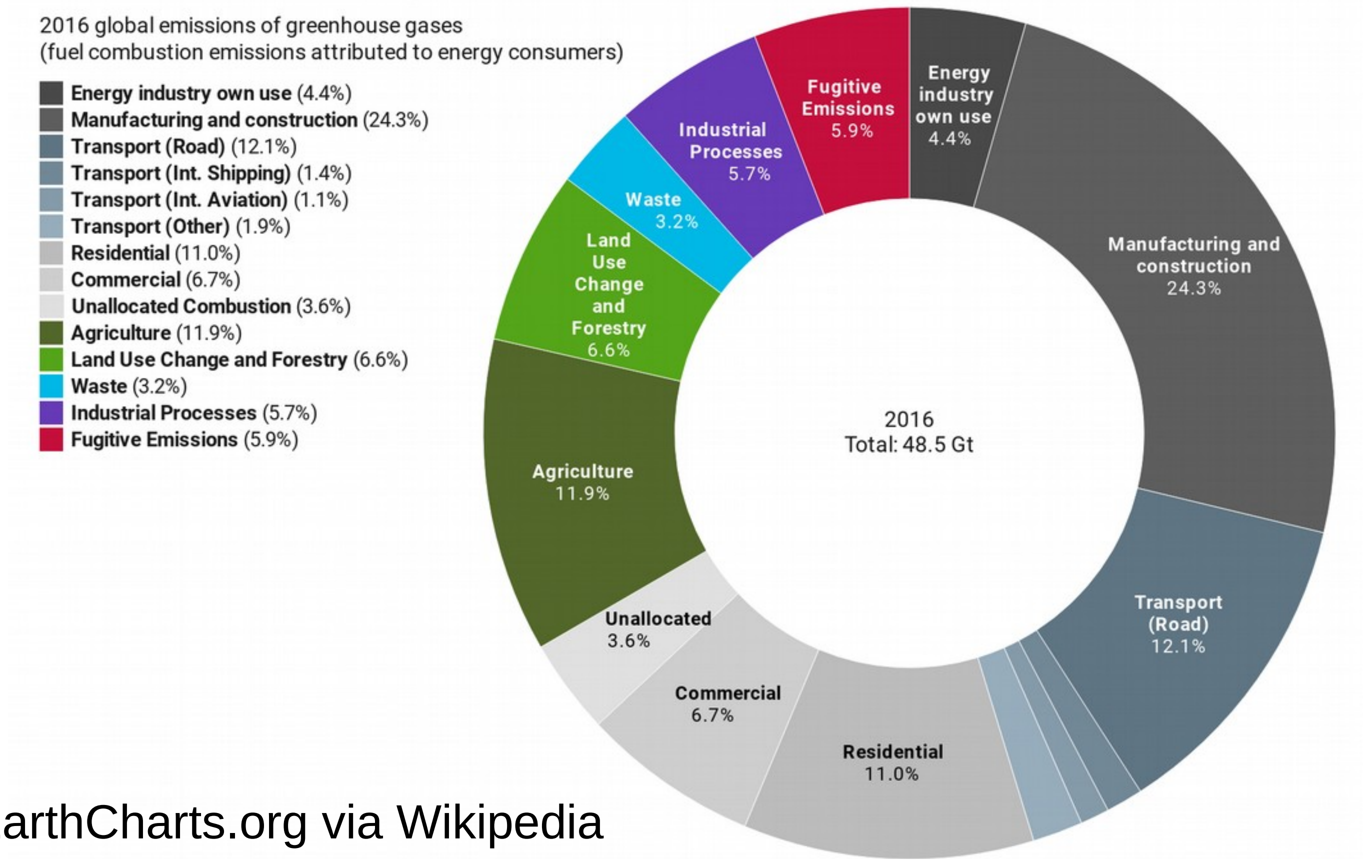
Madagascar, right now
REUTERS via tagesschau.de

Climate crisis could displace 1.2bn people by 2050, report warns

Countries unable to withstand ecological threats among world's least peaceful, analysis finds

The Guardian
2020

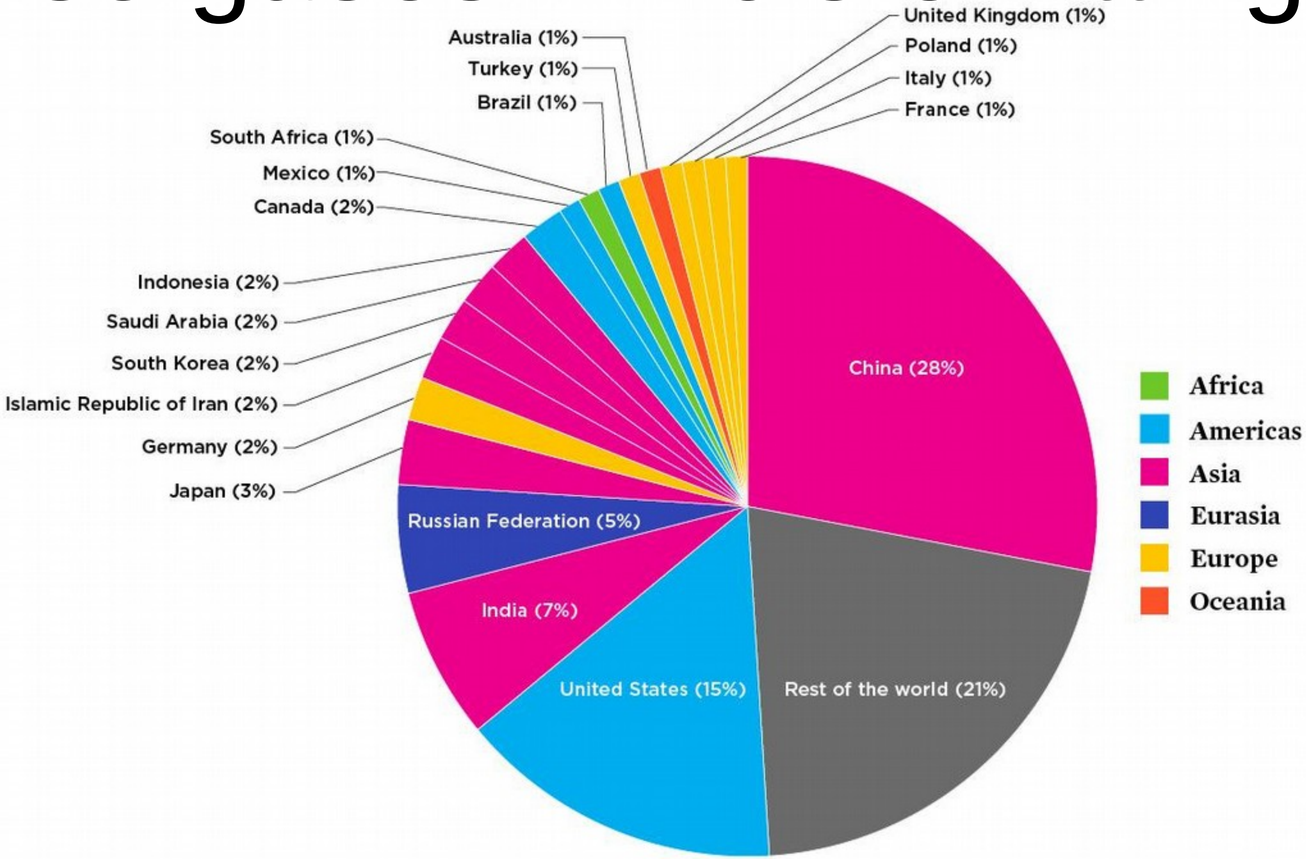
Greenhouse gases: who’s emitting?



By sector

Simon Rayner/EarthCharts.org via Wikipedia

Greenhouse gases: who's emitting?



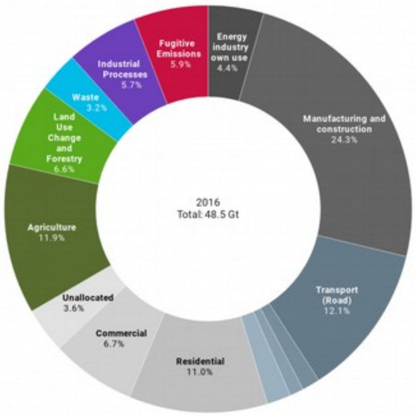
By country

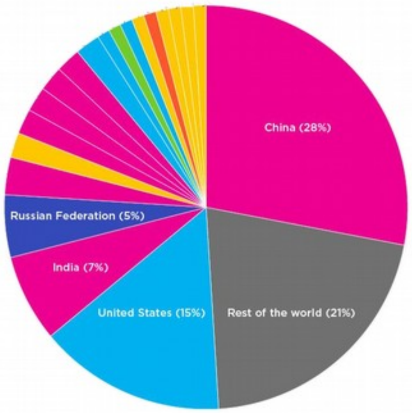
Union of Concerned Scientists, ucsusa.org

Greenhouse gases: who’s emitting?

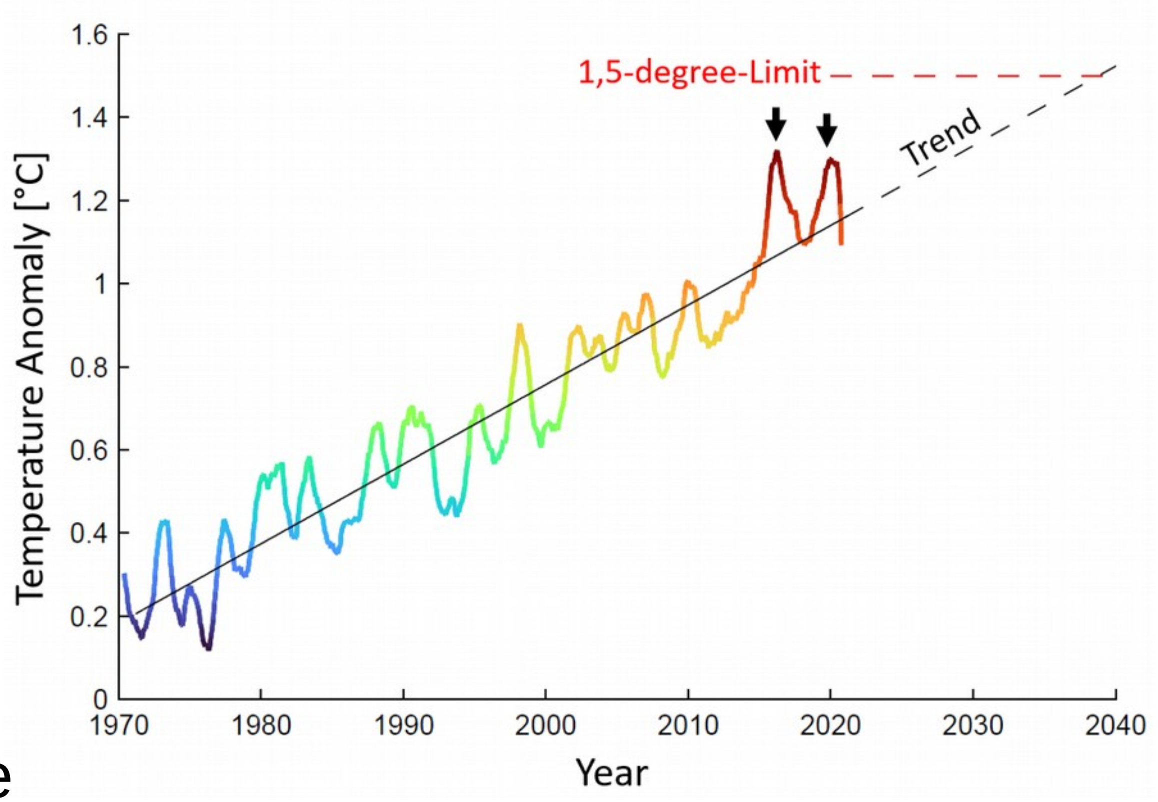
1) It is us

2) The total is the sum of the parts



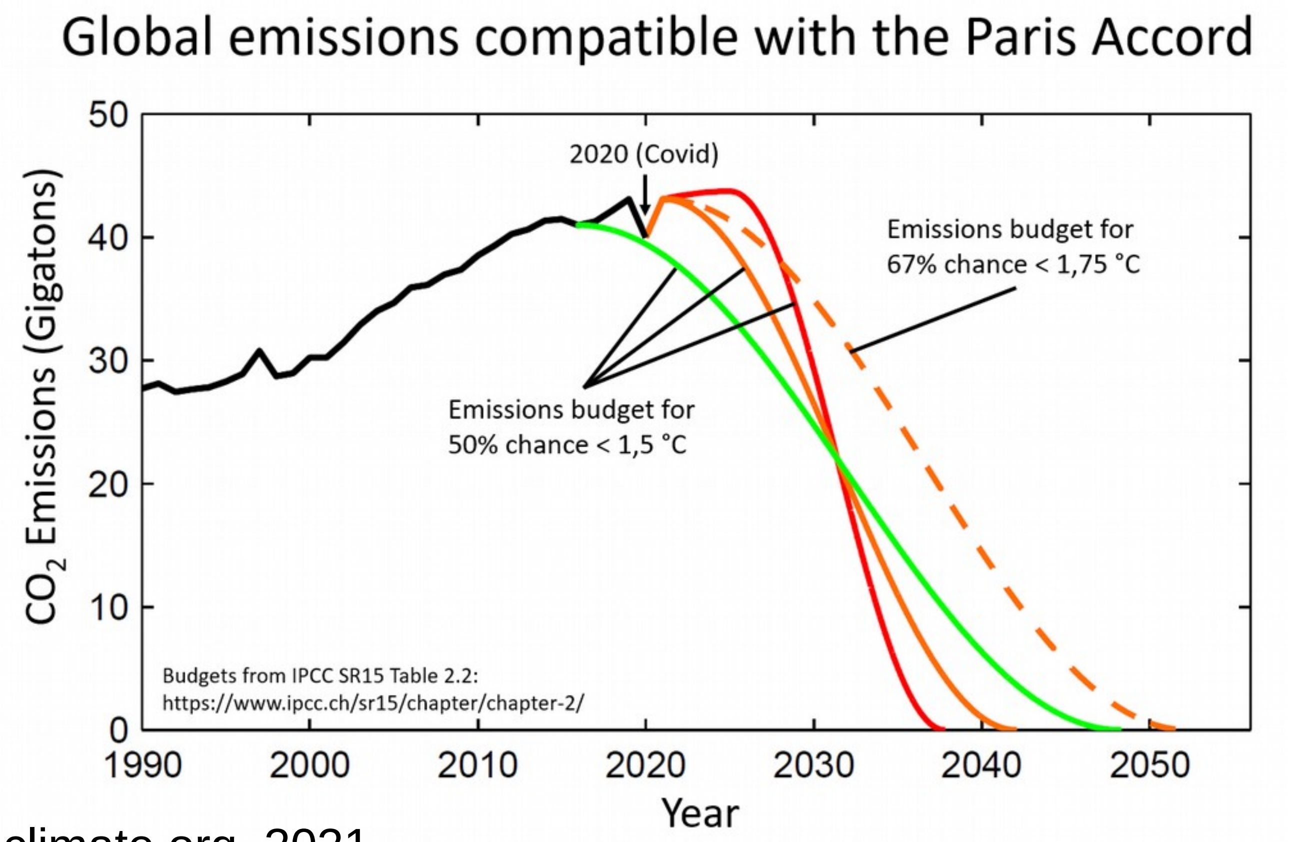


Paris Agreement: < +1.5°C



Global temperature
Stefan Rahmstorf, realclimate.org, 2021

Paris Agreement: < +1.5°C



Remaining CO_2

Stefan Rahmstorf, realclimate.org, 2021

Decarbonizing science, rapidly

- Moral angle: We are responsible for our science-related emissions

  → *We have to reduce*

- Selfish angle: Will our research function in a low carbon future?

  → *Where are we actually relying on emissions?*

Decarbonizing steps

1) Assess emission sources and amounts
2) Find decarbonizing solutions; identify actors
3) Implement solutions
4) Periodically evaluate effect; adjust implementation

1) Assessment

Max Planck Institute for Astronomy, Heidelberg, Germany

Fundamental astronomy/astrophysics research + instrument building for large observatories

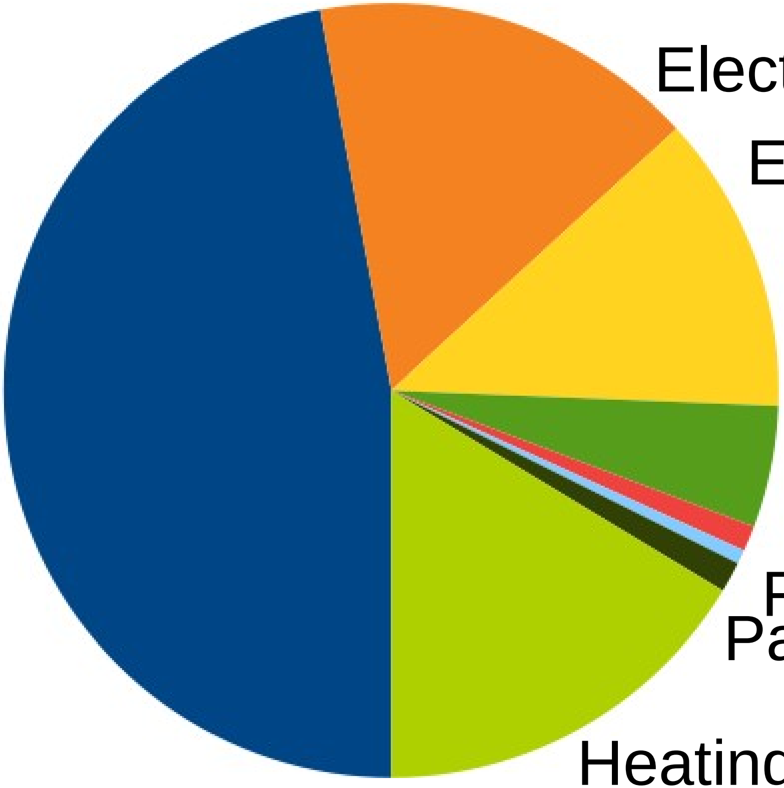
2018: ~300 employees, 150x astro, 80x engineers

1) Assessment

Travel (air)	1030 flights	1280 tCO_2eq
Commuting (car)	792,000 km	139 tCO_2eq
Electricity (on/off campus)	3,150,000 kWh	779 tCO_2eq
Heating (oil)	150,000 liter	446 tCO_2eq
Computer (lap-/desktops)	57 units	29 tCO_2eq
Paper / cardboard	0.15 / 7 t	35 tCO_2eq
Meat (canteen)	1000 kg	16 tCO_2eq

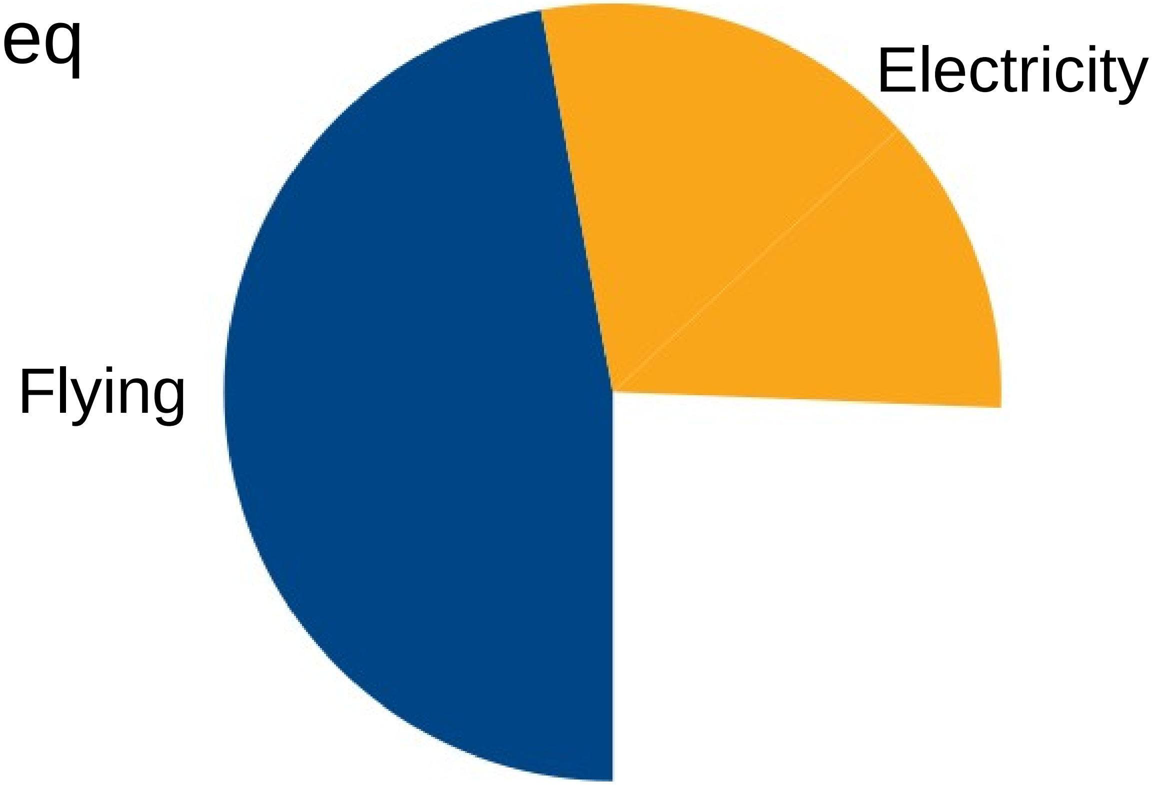
1) Assessment

2730 tCO_2eq



1) Assessment

2730 tCO_2eq



1) Assessment

Emissions total:	2730 tCO_2eq
w/ 150 researchers: (work only)	18 tCO_2eq per person and year
Germany average: (all sectors + sources)	10 tCO_2eq per person and year
India average: (all sectors + sources)	2 tCO_2eq per person and year
593 refereed articles: (lead- + co-authors)	4.6 tCO_2eq per paper

Summary

- We emit, a lot
- Mix of personal, institutional, community solutions
- Focus on flying, electricity
- We need to rapidly decarbonize science!

Climate Crisis & Academic Travel

Victoria Grinberg
(ESA/ESTEC - here as private person!)

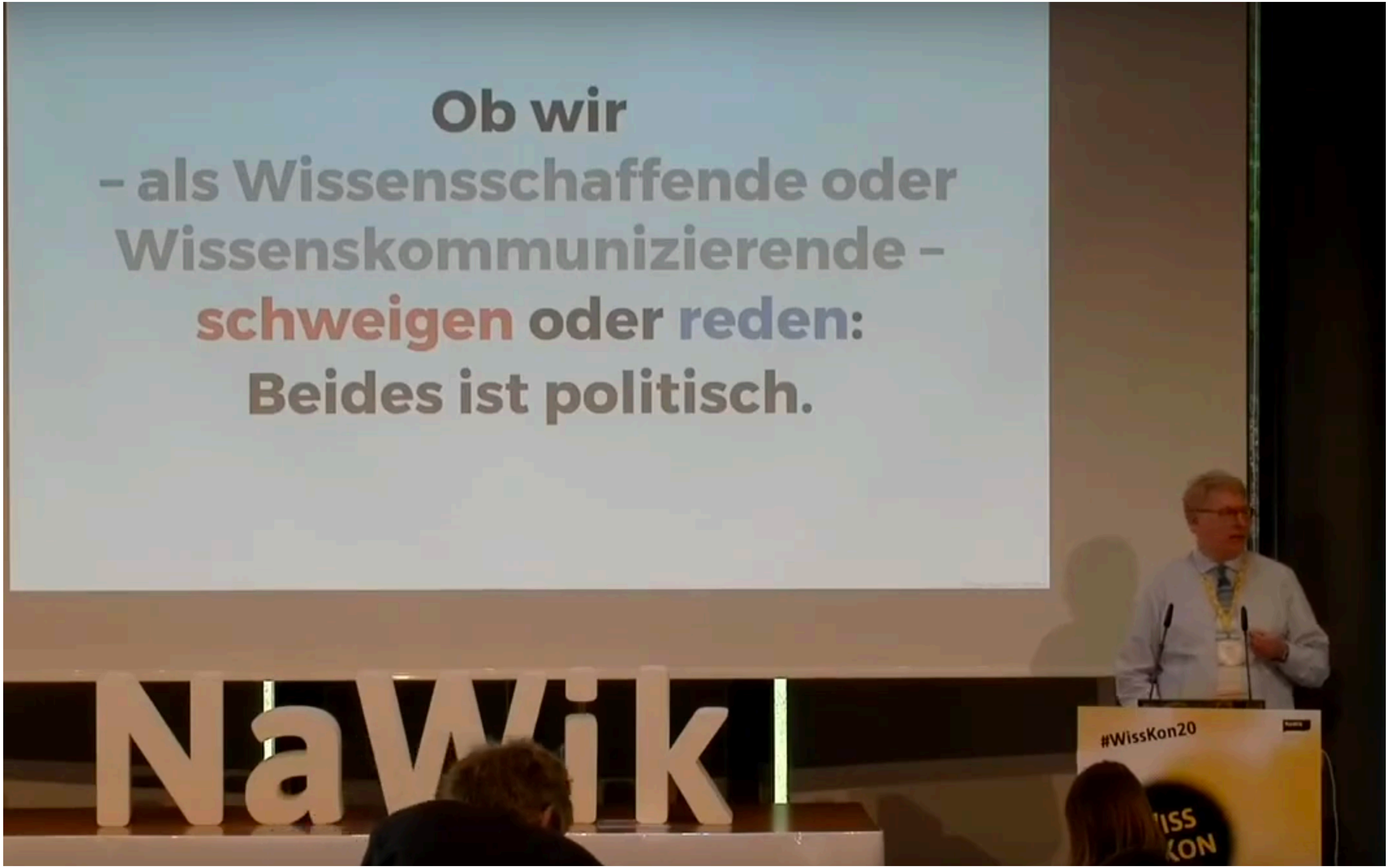
@vicgrinberg / @astro4earth
astronomersforplanet.earth

the most sustainable travel:
no travel at all

Who is talking?

- Liaison scientist @ ESA/ESTEC (since May, previously junior research group leader @ Uni Tübingen, Germany)
- science: high energy astronomy, accretion onto compact objects & stellar winds esp. from massive stars

- a citizen who wants to secure her and her fellow humans' future
- a scientist who wants to secure her field's future
- one of the founding members of the European side of Astronomers for Planet Earth movement
- a group leader responsible for her (early career researcher - ECR) group members
- until recently: ECR herself



„Scientists for Future: Aufklärung gegen die Klimakrise“ Dr. Gregor Hagedorn @ WissKon 2020
https://www.youtube.com/watch?v=NnCDF0YCwKE

academic travel: personal decisions vs. systemic constraints

What is academic travel?

It’s not only conferences!
But conferences are maybe clearest how to address …

Purpose	Description
Full-week conference	Classic few-days conference or workshop
Colloquium (1–2 days)	Invited talk w/ or w/o extra day for discussions
Proposal review	HST, ALMA, ESO,... panels
Move to new job	Often reimbursed
Visiting partner/relatives/friends	Usually privately paid
Project meeting (hardware)	Planning, reviews
Instrument construction	Engineers
Instrument commissioning	Engineers, scientists going to observatory
Project meeting astrophysics	Planning, writing, data analysis
Observing run	Visitor’s mode
Staffing observatories (local travel)	Travel e.g. Santiago–Paranal
Staffing observatories (“home” travel)	Travel e.g. ESO HQ–Santiago for Euro astronomers
Research visit (>few days)	Week(s) to month(s)
Job interview	Few days, getting to know place and people
Visiting/evaluation/funding committees	Institute, project evaluation, meetings with funding agencies
Summer school	1-2 weeks, mainly aimed at younger colleagues (PhD students, postdoc) but also lecturers travel
PhD defense committee member	usually 1d visit

Jahnke et al., in prep.

numbers

MPIA green house gas emission 2018

Jahnke et al., Nat. Astro 2020

Table 1 | Summary of the MPIA's GHG emissions in 2018

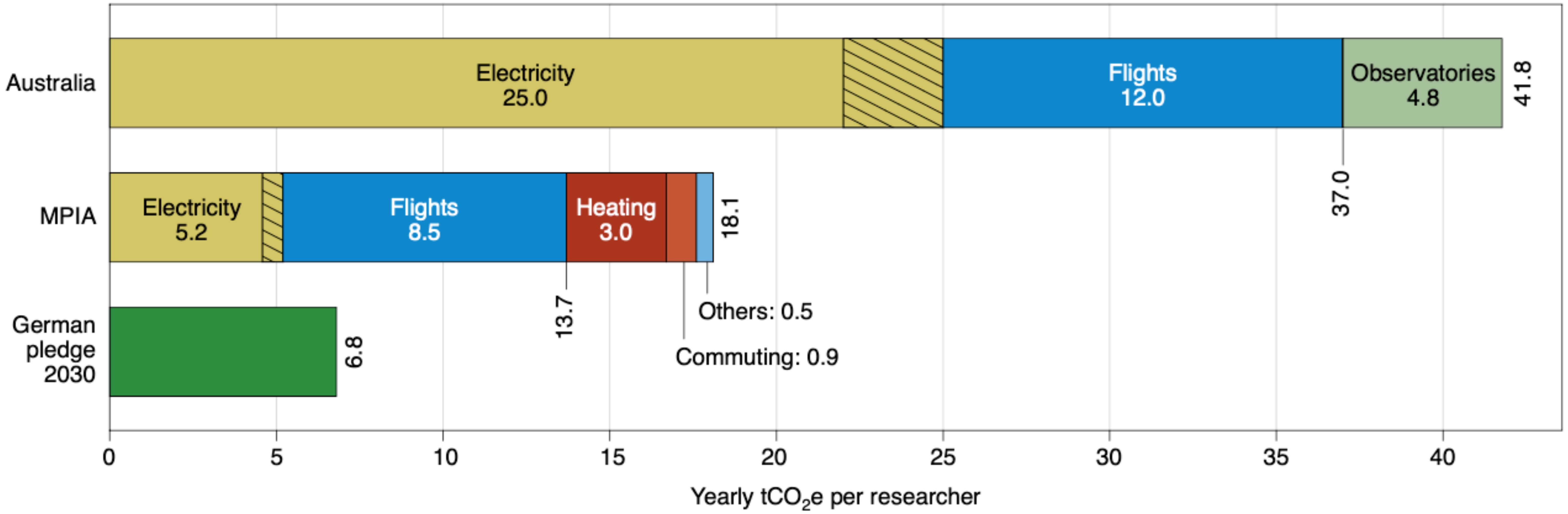
Source	Amount	tCO_2e	tCO_2e per researcher	Percentage (%)
Travel (air)	1,030 flights	1280	8.5	47
Electricity (on/off campus)[a]	3,400,000 kWh	779	5.2	29
Heating (oil)	150,000 l	446	3.0	16
Commuting (car)	792,000 km	139	0.9	5
Paper (cardboard)	0.15 (7) t	35	0.2	1
Computers (desktops/laptops)	57 purchased	29	0.2	1
Meat (canteen)	1,000 kg	16	0.1	<1
Total		~2,720	18.1	100%

[a]Note that electricity includes both consumption at the MPIA campus, as well as in external supercomputing centres used by MPIA.

MPIA green house gas emission 2018

Jahnke et al., Nat. Astro 2020

MPIA vs. Australian emission



Flight emission:

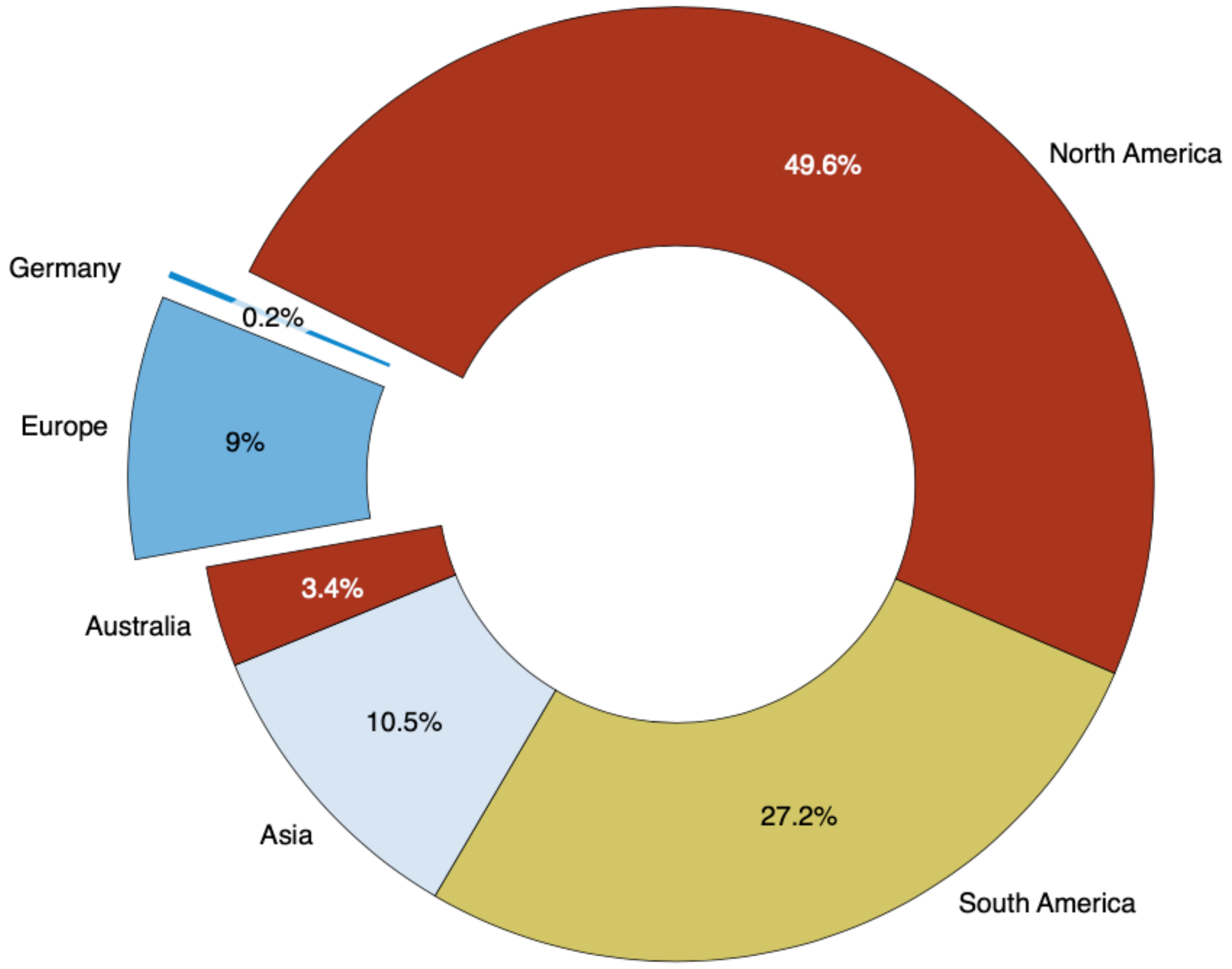
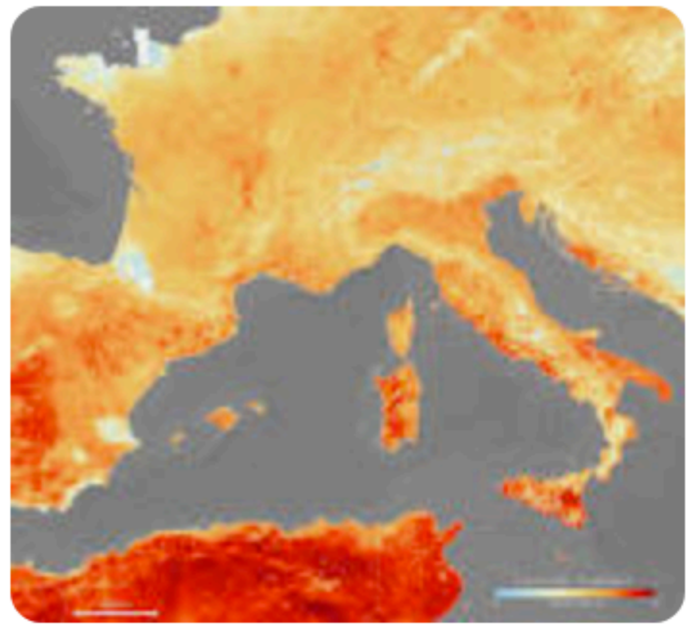


Fig. 2 | Relative GHG emissions broken down by flight destination for MPIA employees.

Carbon footprint of large astro meetings

Butscher et al., Nat. Astro 2020

In July **2019**, **France** experienced its second **heat wave** in less than a month, beating several regional and national temperature records. In the previous month, a national record temperature of 46.1 °C (115.0 °F) was measured in the southern commune of Gallargues-le-Montueux.



Date: 24 June 2019 – 2 July 2019

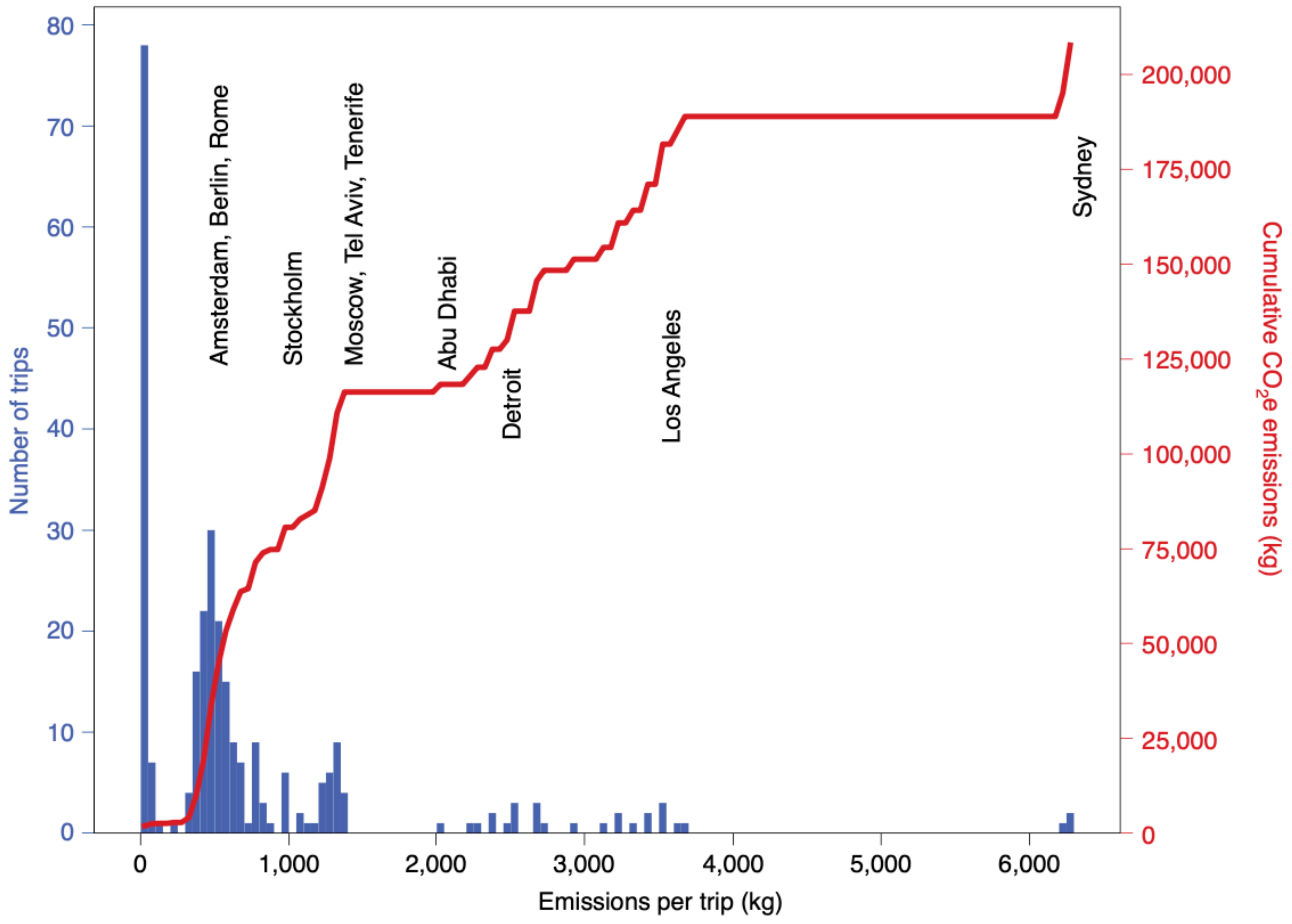
Location: Europe

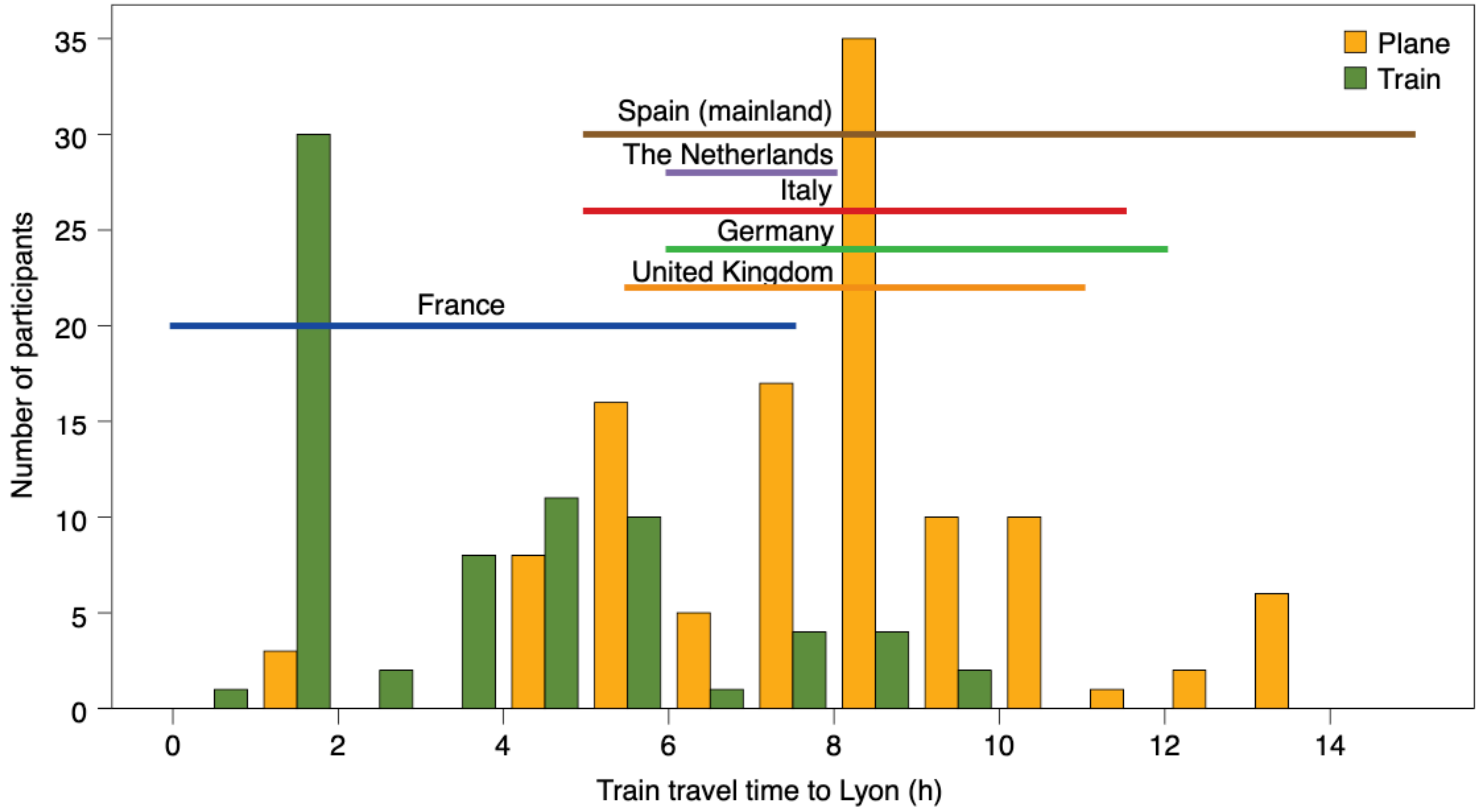
en.wikipedia.org › wiki › 2019_European_heat_wave

2019 European heat wave - Wikipedia

Carbon footprint of large astro meetings

Butscher et al., Nat. Astro 2020





Carbon footprint of large astro meetings

Butscher et al., Nat. Astro 2020

Box 1 | Estimation of carbon emissions of EAS 2020

Network-related emissions

5 days × 80% participation per day × 1,777 participants × 5.5 hours online per day × 1.2 Mbps × 3,600 s h^{-1} × 1/8 byte bit^{-1} × 1/1,024 GB MB^{-1} × 0.06 kWh GB^{-1} × 0.24 kg kWh^{-1} = 297 $kgCO_2e$

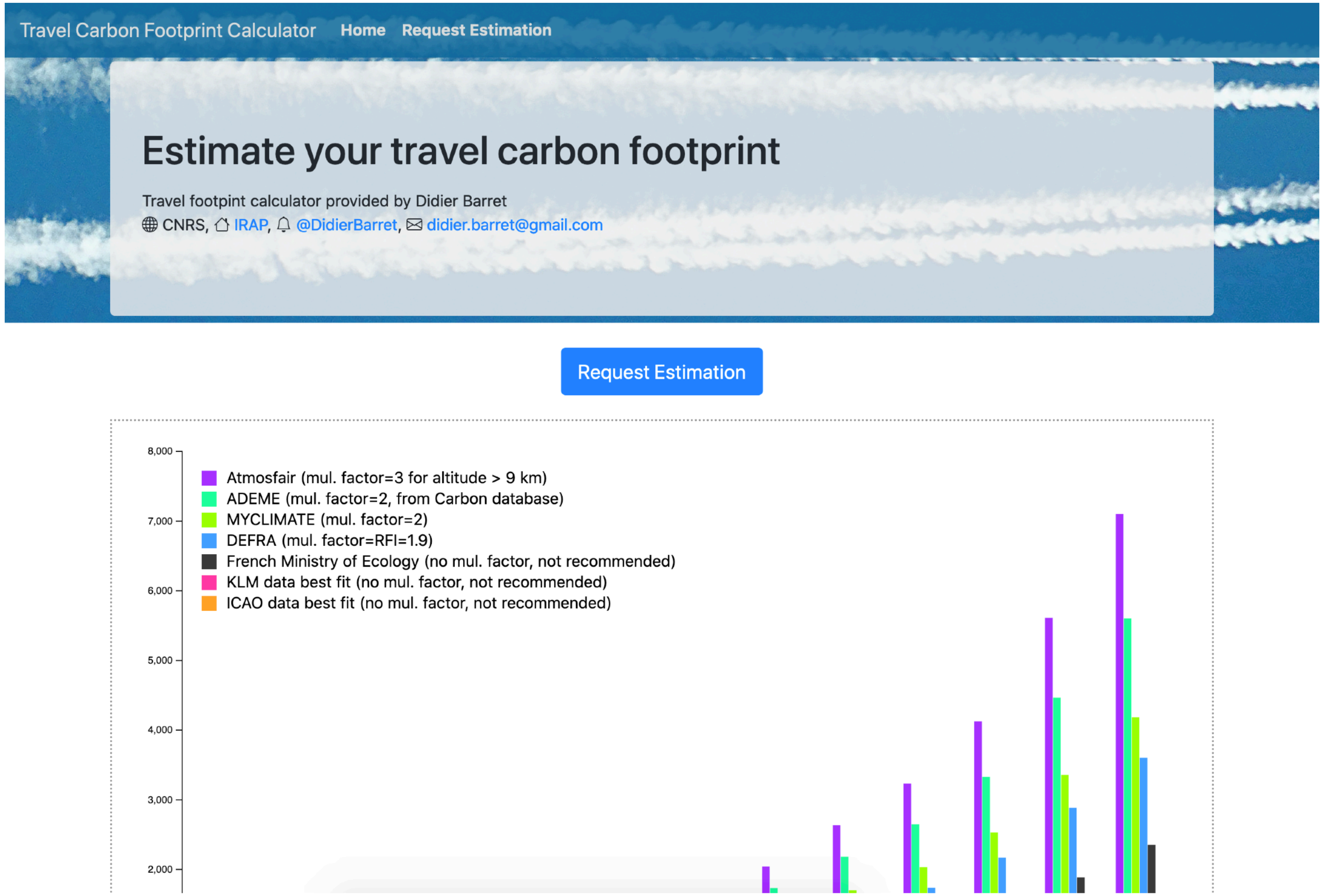
Laptop-related emissions

5 days × 80% participation per day × 1,777 participants × 5.5 hours online per day × 30 W × 1/1,000 kW W^{-1} × 0.24 kg kWh^{-1} = 281 $kgCO_2e$

Zoom-server related emissions

5 days × 10 hours per day × 300 W × 1/1,000 kW W^{-1} × 0.24 kg kWh^{-1} = 3.6 $kgCO_2e$

Travel footprint calculator for meetings



Estimating, monitoring and minimizing the travel footprint associated with the development of the Athena X-ray Integral Field Unit -- An on-line travel footprint calculator released to the science community

Show affiliations

Barret, Didier

Global warming imposes us to reflect on the way we carry research, embarking on the obligation to minimize the environmental impact of our research programs, with the reduction of our travel footprint being one of the easiest actions to implement, thanks to the advance of digital technology. The X-ray Integral Field Unit (X-IFU), the cryogenic spectrometer of the Athena space X-ray observatory of the European Space Agency will be developed by a large international consortium. The travel footprint associated with the development of the X-IFU is to be minimized. For that purpose, a travel footprint calculator has been developed and first released to the X-IFU consortium members. The calculator uses seven different emission factors and methods differing by up to a factor of ~5 for the same flying distance. The observed differences illustrate the lack of standards and regulations for computing the footprint of flight travels and are explained primarily, though partly, by different accountings of non-CO2 effects. The calculator enables us to compute the travel footprint of a large set of travels and can help identify a meeting place that minimizes the overall travel footprint for a large set of possible city hosts, e.g. cities with

https://travel-footprint-calculator.irap.omp.eu/

thoughts

Online only meetings?

environmental impact

accessibility

↔

in person interaction

spontaneous communication

We need to find a balance - and we should be careful not to confuse emergency online meetings with online-first conferences!

Online meetings: Ressources

Moss et al. 2021, Nat. Astro: “Forging a path to a better normal for conferences and collaboration”

Moss et al. 2020, Zenodo: “The Future of Meetings: Outcomes and Recommendations”

& references therein

Travel: Accessibility

ICRC 2019: Madison
857 participants
39 countries
1062 abstracts

ICRC 2021: Berlin
1601 participants
54 countries
1400 abstracts

⚡visa problems!

Travel: Accessibility

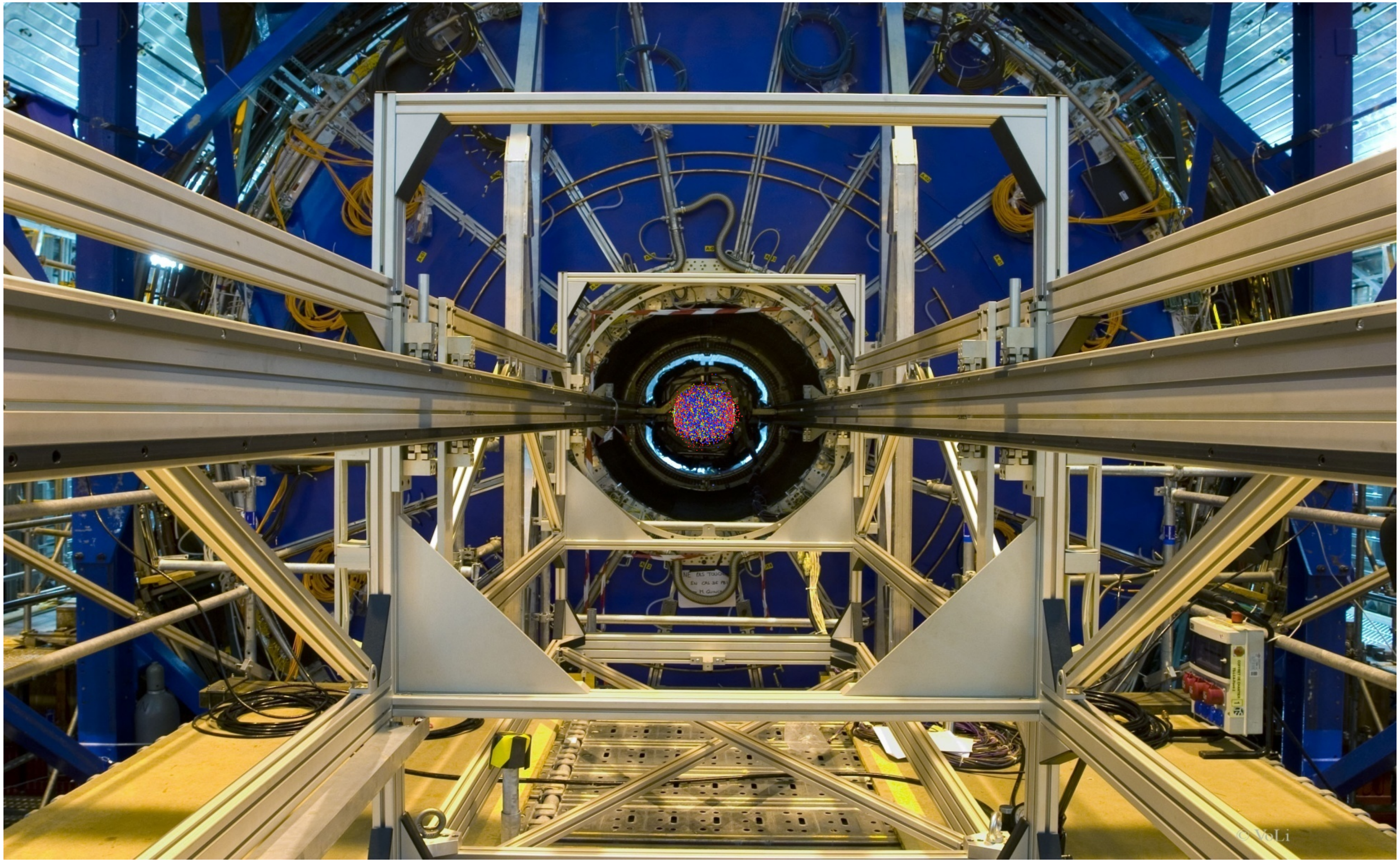
Dr. Sarah White:
An environment for everyone

(invited talk @ ESA 2021)

https://youtu.be/OG4Aakt8B0g

the most sustainable travel:
no travel at all

maybe (?) not doable, but both personal & systemic changes possible & necessary



ICRC 2021

Energy Efficient Computing

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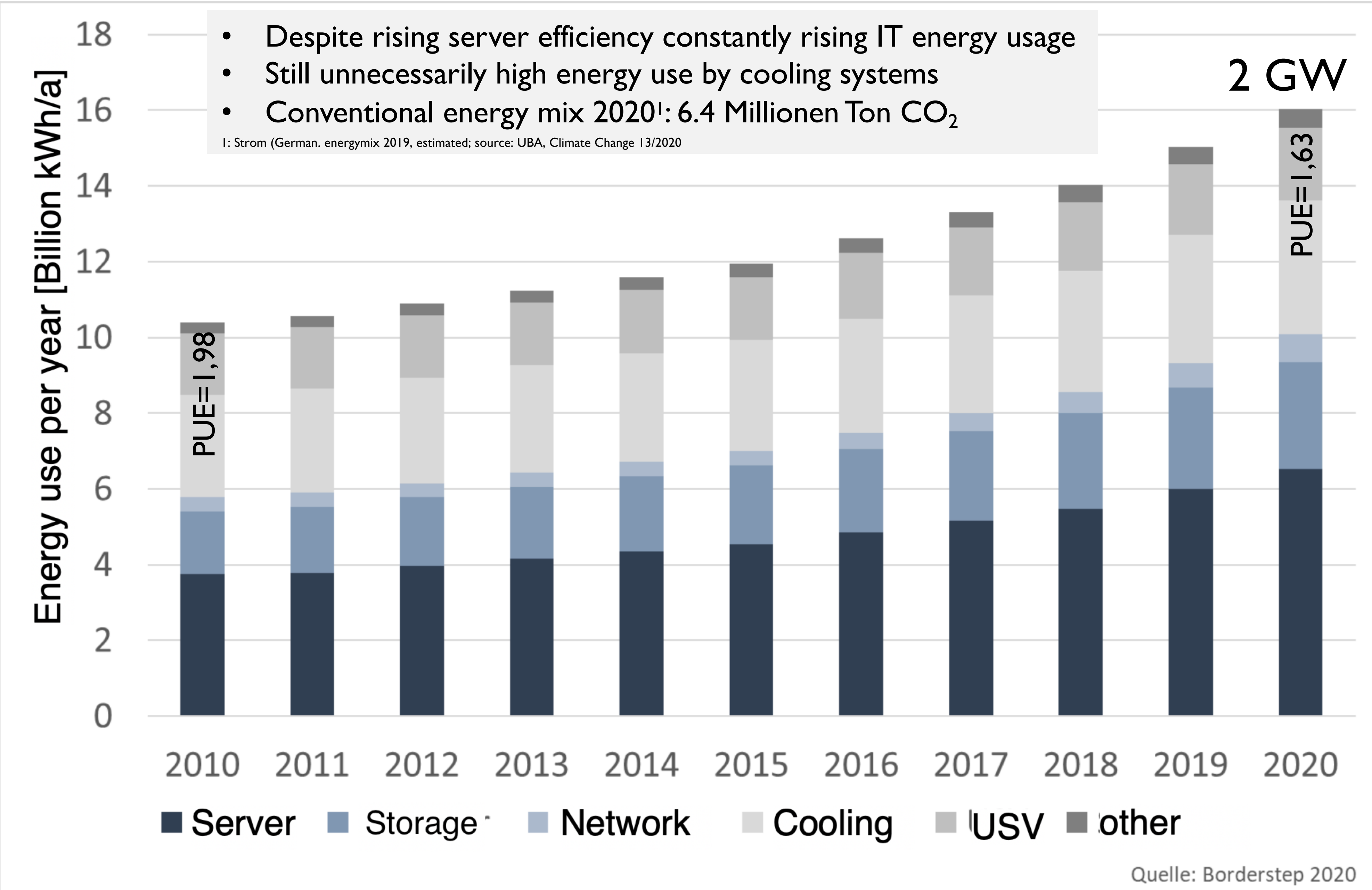


An Alarming Truth

World wide air-traffic causes around

2 % of the global CO_2 emission –

less than commercial IT! (ca. 40 GW)

[Gartner]

Data Center PUE 1,6

→ 38% or 15 GW

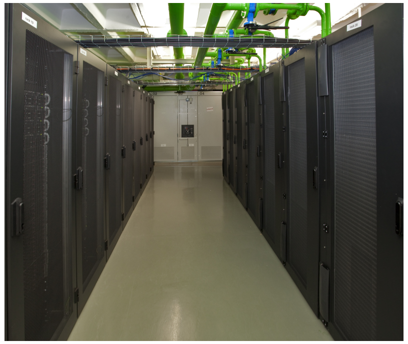
e3c PUE <1,1

→ 9% or 3,6 GW

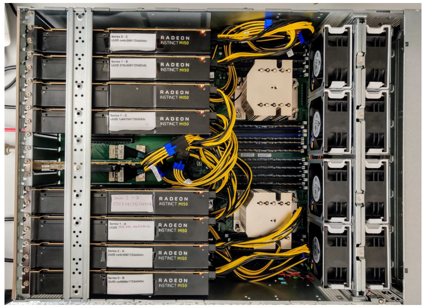
CO_2 saving: 65MT CO_2

Three main areas for optimization

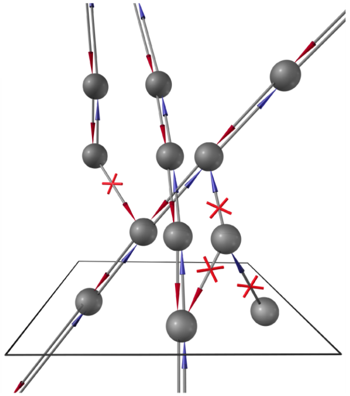
- **Data Center Architecture**



- **Computer Architecture**



- **Algorithm**



Heat Transmission via Air and Water

Required Volumetric Current: $$Q = \dot{V} = \frac{P}{c_p \cdot \rho \cdot \Delta T}$$

P : **Thermal Power Loss**
ΔT : **Temperature Difference**

Air	Specific Heat Capacity:	$c_p = 1{,}005 \, \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$	Density:	$\rho = 1{,}184 \, \frac{\text{kg}}{\text{m}^3}$	(Standard Conditions)

Example: Notebook-Computer (30 W)

Room: 25 ˚C

max. 50 ˚C

$\Delta T = 25\,\text{K}$

$\Rightarrow Q = 1{,}0 \, \frac{\text{l}}{\text{s}}$

Example: Data Center (1 MW)

Supply Air: 18 ˚C

Exit Air: 43 ˚C

$\Delta T = 25\,\text{K}$

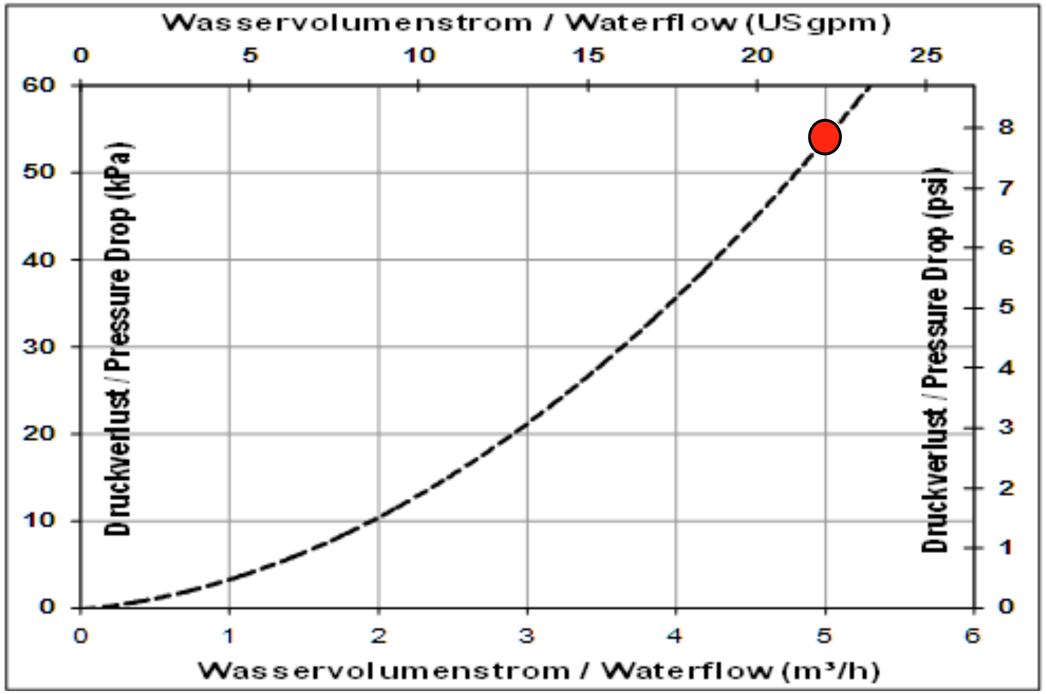
$\Rightarrow Q = 33.600 \, \frac{\text{l}}{\text{s}}$

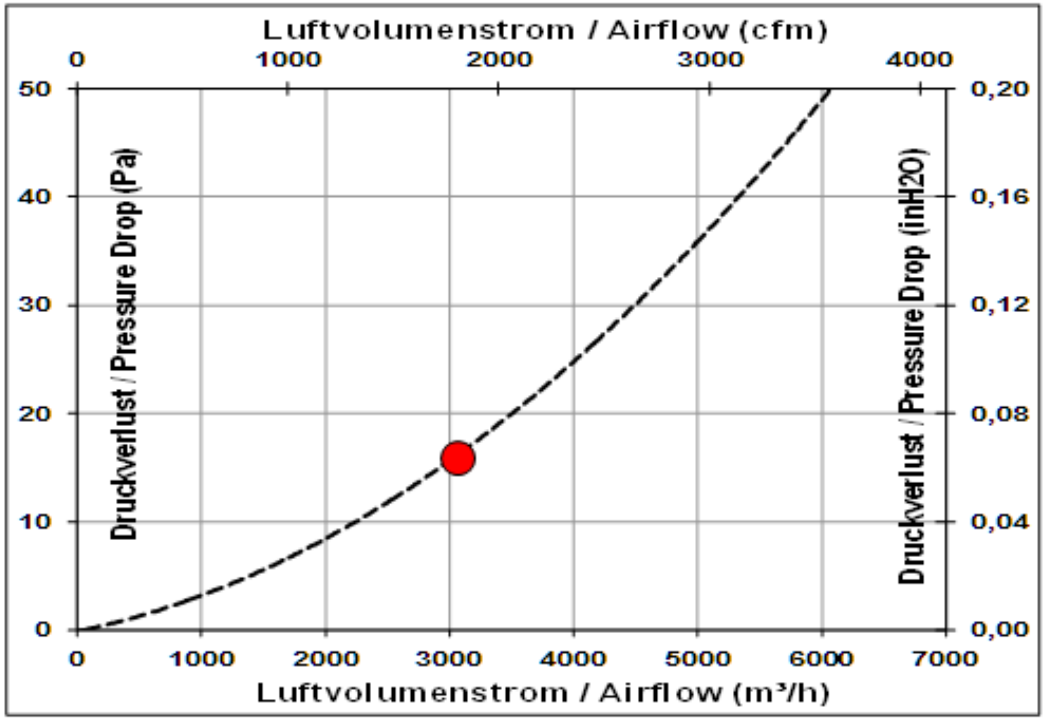
Water	Specific Heat Capacity:	$c_p = 4{,}183 \, \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$	Density:	$\rho = 997{,}0 \, \frac{\text{kg}}{\text{m}^3}$	(Standard Conditions)

Example: Data Center (1 MW)

$\Delta T = 5\,\text{K}$

$\Rightarrow Q = 48{,}0 \, \frac{\text{l}}{\text{s}}$



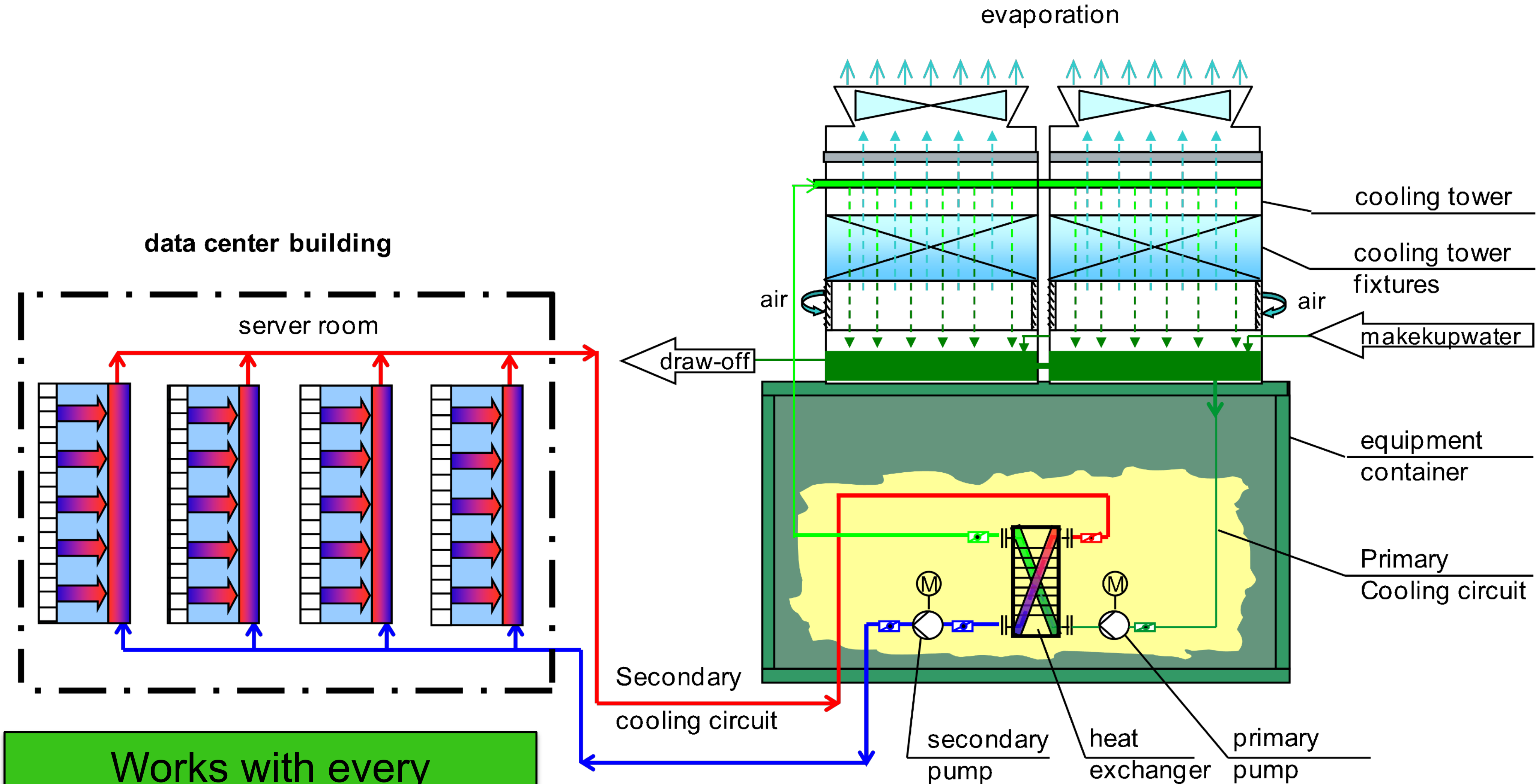


35+ kW/rack

knürr
environments for electronics

Heiko Ebermann

Innovative Cooling Architecture



Works with every commercial computer

(12) **United States Patent**
Lindenstruth et al.

(10) **Patent No.: US 9,476,605 B2**
(45) **Date of Patent: Oct. 25, 2016**

(54) **BUILDING FOR A COMPUTER CENTRE WITH DEVICES FOR EFFICIENT COOLING**

(75) Inventors: **Volker Lindenstruth**, Mainz (DE); **Horst Stöcker**, Oberursel (DE)

(73) Assignee: **e3 Computing GmbH**, Mainz (DE)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 551 days.

(21) Appl. No.: **13/001,947**

(22) PCT Filed: **Jun. 30, 2009**

(86) PCT No.: **PCT/EP2009/004704**

§ 371 (c)(1), (2), (4) Date: **Jun. 1, 2011**

(87) PCT Pub. No.: **WO2010/000440**

PCT Pub. Date: **Jan. 7, 2010**

(65) **Prior Publication Data**

US 2011/0220324 A1 Sep. 15, 2011

(30) **Foreign Application Priority Data**

Jun. 30, 2008 (DE) 10 2008 030 308

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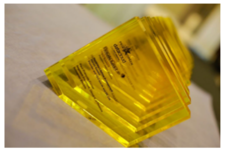
WO	WO 02052107	A2	*	7/2002
WO	WO-03/083631	A1		10/2003

* cited by examiner

Primary Examiner — Lon Tran

Awards

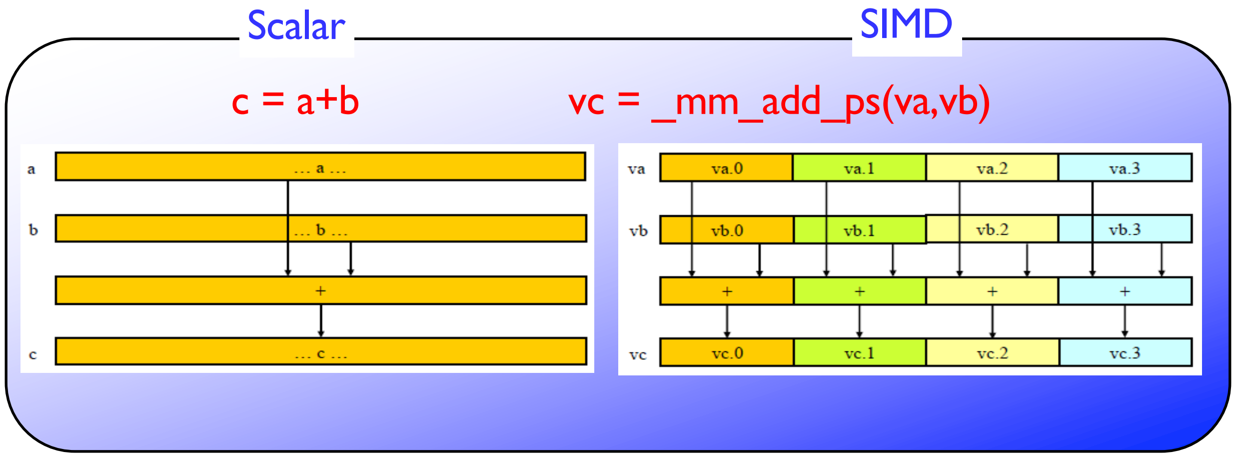


- Green-IT Award Bundesregierung „Visionäre Gesamtkonzepte“
- German data center price 2012 – energy efficiency
- German data center price 2013 – Visionary data center architecture
- Nominated for German data center price 2014 – energy efficiency
- DataCenterDynamics EMEA Award 2013 – Data Center Blueprint
- BroadGroup EMEA Awards Special Commendation – Energy Efficiency
- „Land of Ideas“2012 for LOEWE-CSC
- *Green Cube* Project the Month, BMBF
- 5 nominations with 4 second positions for Data Center Dynamics EMEA Awards – 2011, 2012, 2013
- 2. rank at German Internet award 2012
- 1. rank DataCloud Awards 2015, Monaco
- Blauer Engel
- …

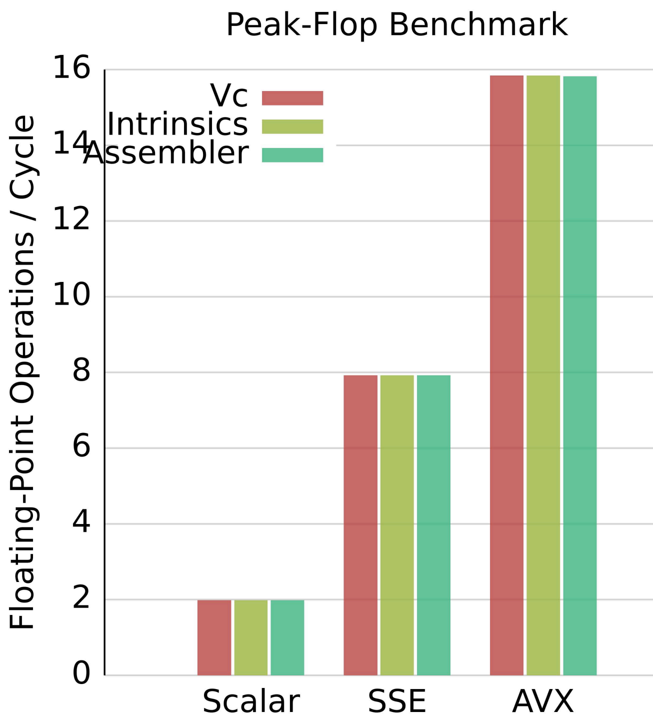
Computer Architecture

- Single core CPU performance scales only slowly
- Good CPU performance requires vectorization
- In general GPU power effectiveness much larger than CPU power effectiveness
- CPU cost for real applications >7x of GPU cost
- Well vectorized code will run also very well on GPU
- GPU optimized code will also run much faster on CPU

Vector Classes (Vc)



Vector classes overload scalar C operators with SIMD/SIMT extensions



Vector classes:

- provide full functionality for all platforms
  - support the conditional operators

phi(phi<0)+=360;

Vc increase the speed by the factor:

- ✓ SSE2 – SSE4 4x
- ✓ future CPUs 8x
- ✓ Xeon Phi 16x
- ➢ GPGPUs >16x

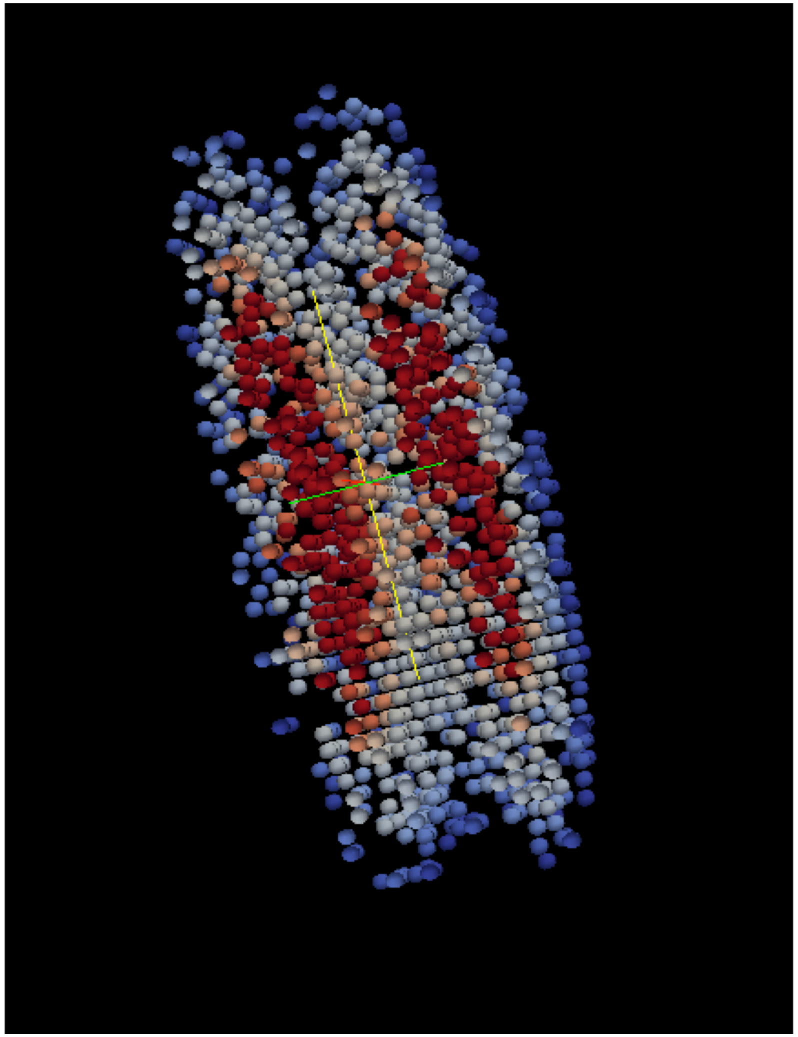
Vector classes enable easy vectorization of complex algorithms


L-CSC
TES1A-4C
The Green500 Top 10
November 2014
#1 L-CSC-GSI Helmholtz Center
5200 MF/W
#2 Suiren-High Energy Accelerator Research Organization /KEK
@ 1000 TF

Algorithmic Optimizations

- The largest potential in Energy and CO_2 saving is algorithmic optimization
- Design algorithm for vectorization and SIMT
- Pay attention to data structure layout and cache efficiency
- Avoid load/store by recompute wherever reasonable
- Pay attention to NUMA domains
- Bring as much as possible computing to GPU

Hybrid Quantum Molecular Dynamics

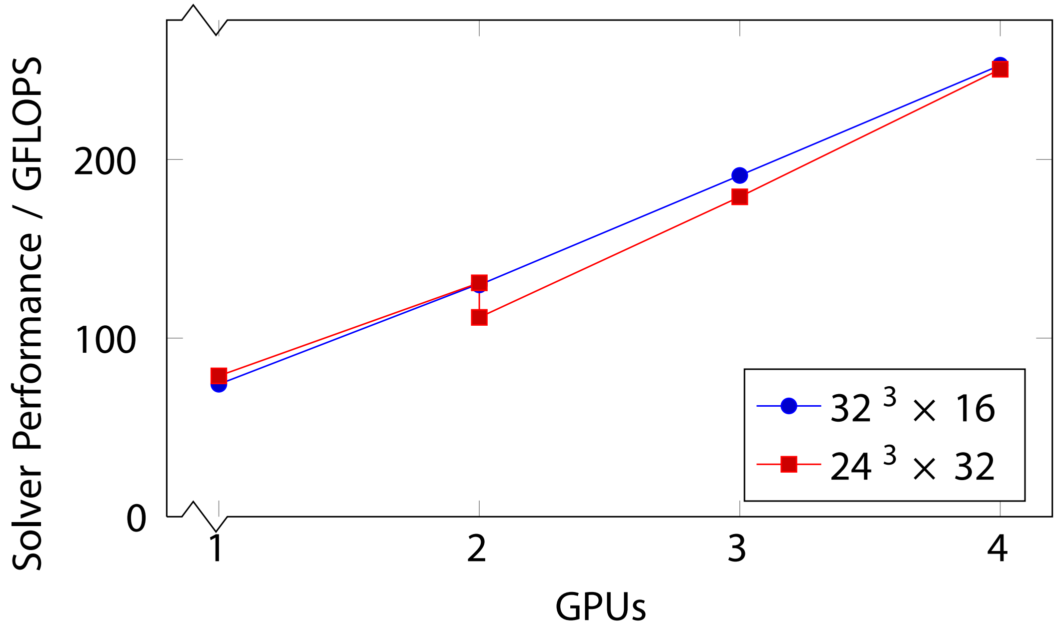


- Simulate Pb+Pb collisions with a gas phase.
- Use grid resolution of 0.2 fm.
- Millions of cells are used to compute quantities, like energy density or baryo-chemical potential.
- A very demanding computation: takes hours ...
- Redesign algorithms to work on modern hardware: LOEWE-CSC has more than 800 GPUs ...
- **New code 160 x faster than old code, but uses only 1/5 of memory**
- Now unprecedented event-by-event calculations can be carried out.
- Better statistics

OpenCL Lattice QCD

- Lattice QCD
- QCD = Strong Interaction
- Lattice QCD = Only a priory approach for QCD
- Discretize Space in 4-dim Lattice, extrapolate solutions from different lattice spacings
- Computationally sparse 2,1 Bytes / FLOP

Inverter Performance – weak scaling



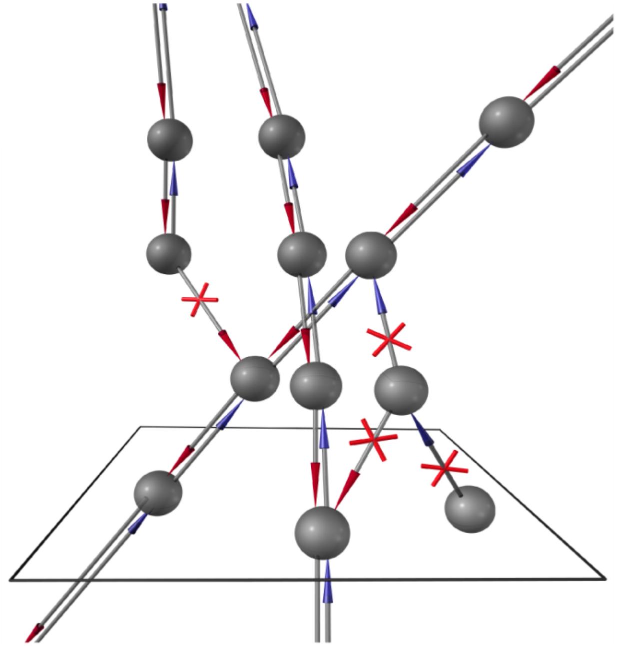
Direct GPU-GPU DMA in Open-CL
2 AMD FirePro S10000
85% Efficiency

Modern Programming

CBM

Summarized stages of the porting procedure

Stage	Description	Time/track	Speedup
	Initial scalar version	12 ms	–
1	Approximation of the magnetic field	240 μs	50
2	Optimization of the algorithm	7.2 μs	35
3	Vectorization	1.6 μs	4.5
4	Porting to SPE	1.1 μs	1.5
5	Parallelization on 16 SPEs (2 Cells)	0.1 μs	10
	Final SIMDized version	0.1 μs	120,000



Fast simdized Kalman filter based track fit
U. Kebschull, **I. Kisel**, V. Lindenstruth, W.F.J. Müller
Computer Physics Communication **2007**

ALICE

O2 system:

- 2000 AMD MI50 GPUs
- 16000 ROME CPUs
- Real-time on-line processing of ALICE data (>600 GB/s)

Hardware options for the parallel computation:

- SIMD CPU instructions (Vectorization)
- multi-threading
- multi-core CPU
- many-core hardware (Graphics cards, Larrabee, …)

Summary

- 3D Green Cube Data Center
  - Data center architecture allows cost significant savings:
    - » CAPEX: 1.5 €/W for Tier-3 like data center
    - » OPEX: PUE < 1.1
    - » Very small foot print, Green Cube: >30 kW/m^2
  - No assumptions about computer hardware required
  - Indirect free cooling most cost effective
  - Unique and unprecedented cost (CAPEX/OPEX)
  - World wide potential savings 15 GW or 65 MT CO_2
- Computer Architecture another area of energy and CO_2 saving
  - Use vectorization of CPU code
  - Use of GPUs wherever possible
- Algorithmic optimization has huge saving potential
  - Demonstrated GPU cost/energy effectiveness >7x of CPU
  - GPU optimized code also performs better on CPU
  - Performance improvements often >100, demonstrated 10000 in particle physics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Green Experiments?
A case study for KM3NeT

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With contributions from T. Georgitsioti, G. Androulakis, R. Papaleo, S. Beurthey
On behalf of KM3NeT Collaboration

Dedicated to the memory of Giorgos Androulakis (1978-2021)

A feasibility study (2018-2019) for the preparation of establishing KM3NeT as a Zero Carbon Footprint Infrastructure.

Investigation on

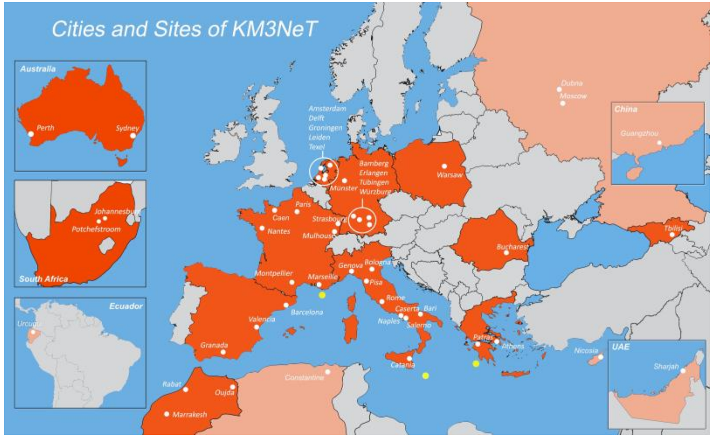
- ✓ Possible strategies and technical choices
- ✓ Legal Issues
- ✓ Technical Study
- ✓ Financial considerations

Is this feasible? Does it make sense? How?

Setting the scene…

✓Zero Carbon Footprint during Operation, including Detectors and Shore Stations

❖Does not include Production, Assembly, Installation and Activities in Individual Institutions.



We estimate the energy budget during operation for each site with full detector to be in the range 580-650 kW (615 kW average, 5.4GWh/year, 1330 tCO_2 eq)

→ a small – to – medium size Renewable Energy Infrastructure (REI)

Distributed Infrastructure with 2+1 sites

- France – South of Toulon
- Italy – South-East of Capo Passero, Sicily
- Greece – South West Peloponnese

How?

1. Use certified green energy providers over the grid – ok choice, but no added value, limited exposure and scope for the public, difficult to communicate in an engaging manner.
2. Collaborate with renewable energy providers to add to their infrastructure – not feasible as we are ‘small fry’ for them.
3. Establish our own infrastructure, provided it makes sense financially, also counting in, the added value in terms of public engagement.

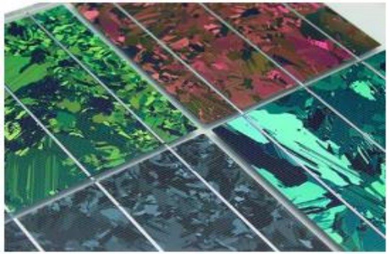
- Choice 1 is the only working scenario for France (mature green energy provider market, complicated procedures can easily result in many years to completion).
- Choice 3 is an attractive solution for Italy and Greece – strong collaboration with local authorities / local communities.

Technology choices (1/2)

Off-the-shelf mature technologies, well suited to the sites: Mediterranean climate means lots of sun and lots of wind!

Solar → usual PV panels (large scale)

PV façade panels (small scale)



Wind → Horizontal axis turbines (large scale)

Vertical axis turbines (small scale)

Technology choices (2/2)

No tidal, wave, geothermal, offshore wind, floating wind, OTEC solutions.

Our working model is to

- ✓ **Produce the energy required, provide it to the grid and get it back in the 'normal' way. No energy storage.**
- ✓ **Supplement the large-scale REI with small scale infrastructure of high aesthetic value, designed to be installed in the urban environment. Provide surplus electricity to local schools / hospitals / public buildings, in exchange of the real-estate necessary for REI installation.**

Legal issues

- Detailed investigation of the Italian / Greek and European legislature identified no major legal issues / obstacles on having REI owned and operated by legal entities like the research institutions responsible for the installation sites of KM3NeT.

Does all this make sense financially?

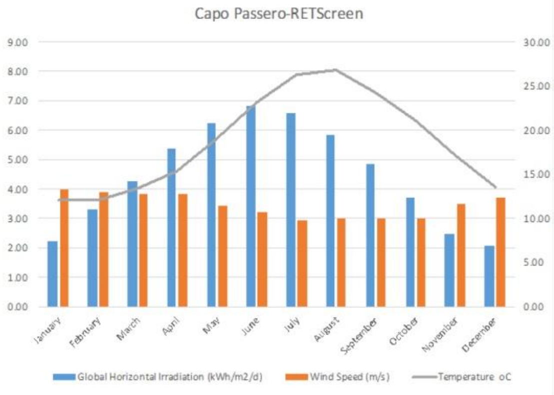
- Define various scenarios of REI configurations with full specs for each of them
- Detailed, realistic simulations of energy production
- Proper calculation of the actual cost of energy production with realistic estimates of REI installation and running costs
- Comparison with normal grid energy costs

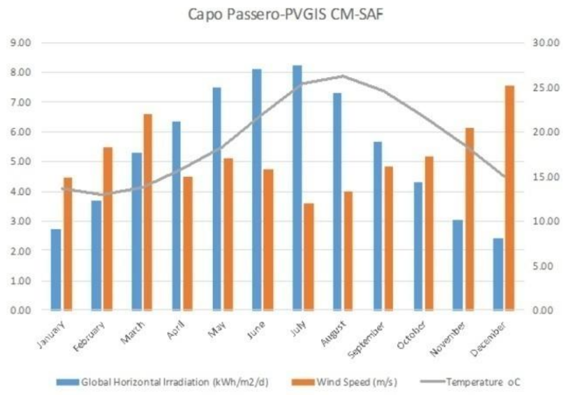
Simulation strategy

- Weather data from several databases (PVGIS, PVGISCM-SAF, RETScreen, etc) provide hourly data with spatial resolution of 3km over land, using land based stations, satellite data and extrapolation over several years:
    - ambient temperature
    - atmospheric pressure
    - solar irradiation
    - wind speed and direction
    - info on the terrain and surrounding landscape
    - Choice of REI system configuration and specs
- Are fed to simulation programs like PVsyst, SAM and HOMER to calculate the energy production over the lifetime of the project.
    - Losses are taken into account, including variations of irradiance levels, temperature, soiling, ohmic losses, power and voltage threshold losses, turbine performance degradation, etc.

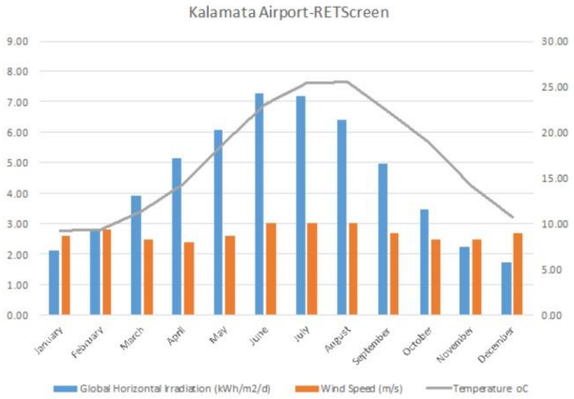
Weather Data

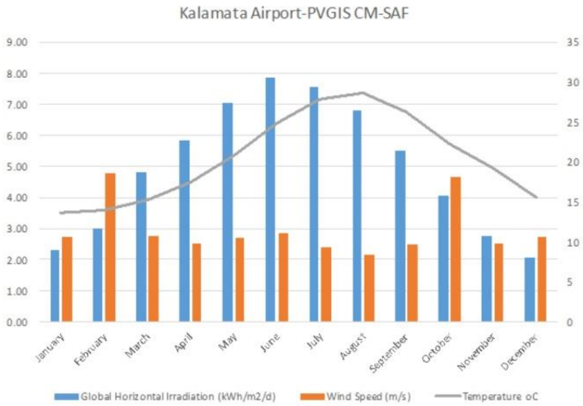
Italy





Greece



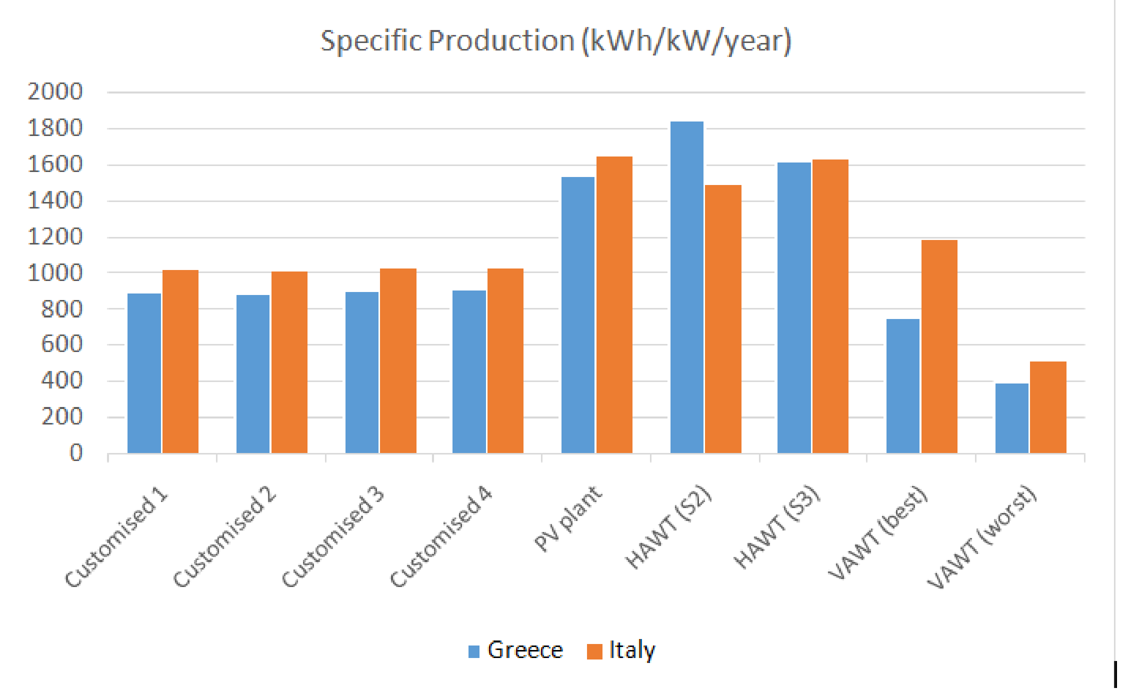


REI configurations

- Capo Passero:
  - 1 Horizontal axis wind turbine at 3 MW installed capacity (Enercon E-82 E4)
  - 60 kW capacity of vertical axis wind turbines (6 x Aeolos V)
  - PV systems of 140 kW of total installed capacity, including 40kW of PV facades

- Kalamata:
  - 1 Horizontal axis wind turbine at 2.3 MW installed capacity (Enercon E-103 EP2)
  - 60 kW capacity of vertical axis wind turbines (6 x Aeolos V)
  - PV systems of 440 kW of total installed capacity, including 40kW of PV facades

Specific energy production



Scenarios	Yearly energy yield
	MWh/year
Capo Passero (max)	5956.80
Capo Passero (min)	4766.00
Kalamata (max)	5387.40
Kalamata (min)	4310.00

Customized 1-4: Different façade PV panel models
HAWT: Horizontal Axis Wind Turbine
VAWT: Vertical Axis Wind Turbine

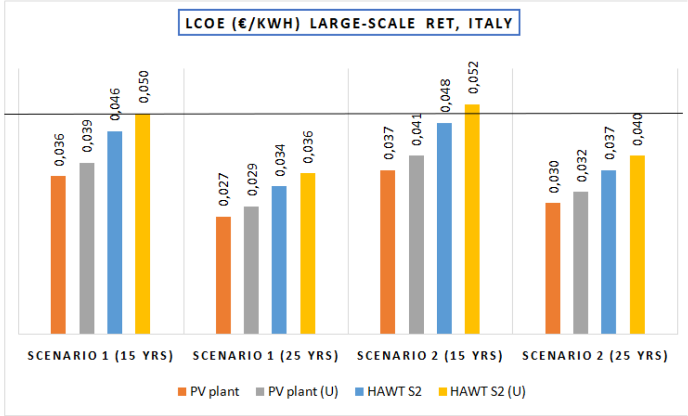
…does all this make sense financially?

If Levelized Cost of Energy compares favorably with the electricity cost through normal channels (wholesale - retail)

$$LCOE = \frac{Total\ Life\ Cycle\ Cost}{Total\ Lifetime\ Energy\ Production}$$

We calculate LCOE with cost including actual pricing through quotations for materials, installation, maintenance, replacements, 2 scenarios of inflation (historic average and double) and 2 scenarios for the lifetime of the system (15 and 25 years).

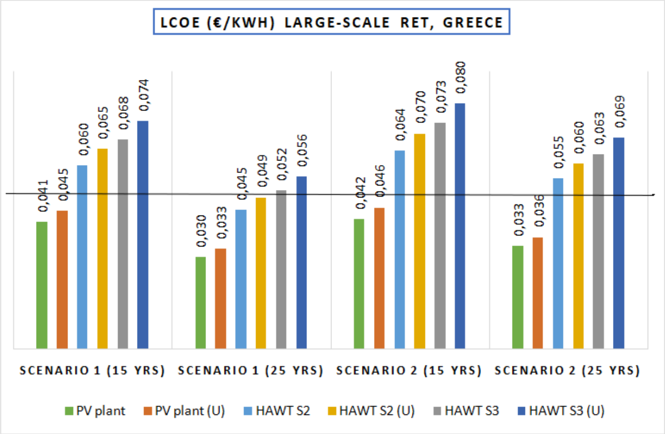
LCOE



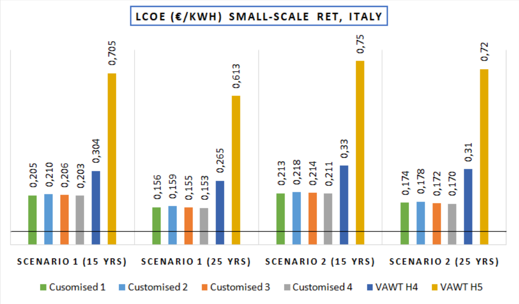
LCOE large-scale systems (Scenarios 1 and 2), Italy

Scenario 1
Average inflation
(10 years)

Scenario 2
2 x Average inflation
(10 years)

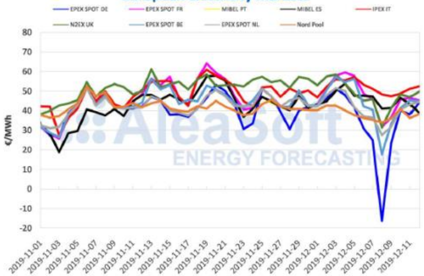


LCOE large-scale systems (Scenarios 1 and 2), Greece

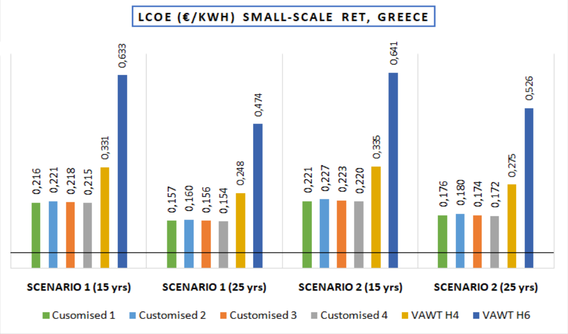


LCOE small-scale systems (Scenarios 1 and 2), Italy

European electricity markets



European electricity markets (1st November-11th December 2019)



LCOE small-scale systems (Scenarios 1 and 2), Greece

Conclusions

- It is possible technically,
  - It makes sense financially over the project lifetime,
    - It can be a great way to pass the right message to the public,
      - It can be the perfect vehicle to engage local and national authorities