How to do particle physics in a climate emergency?

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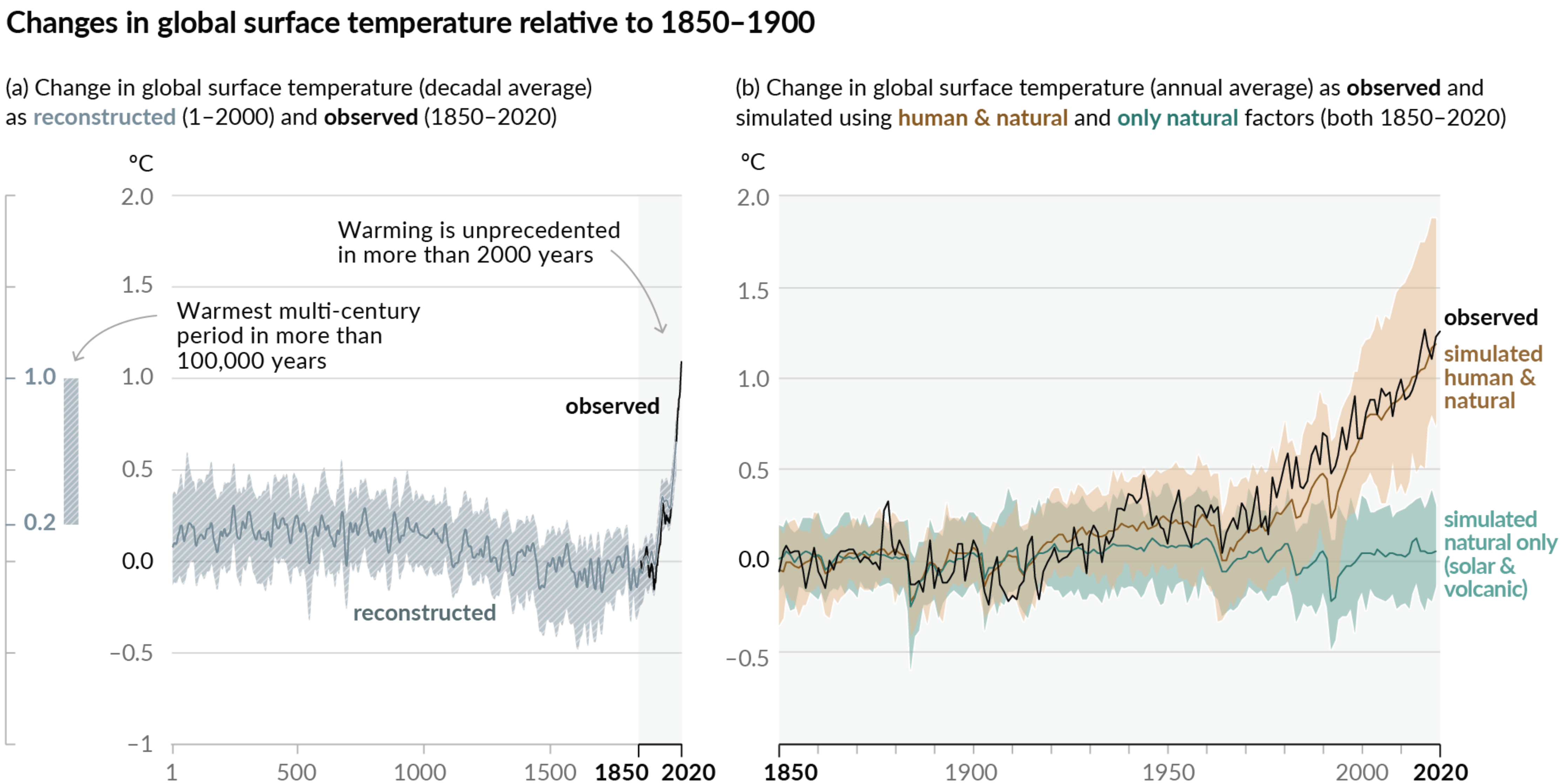
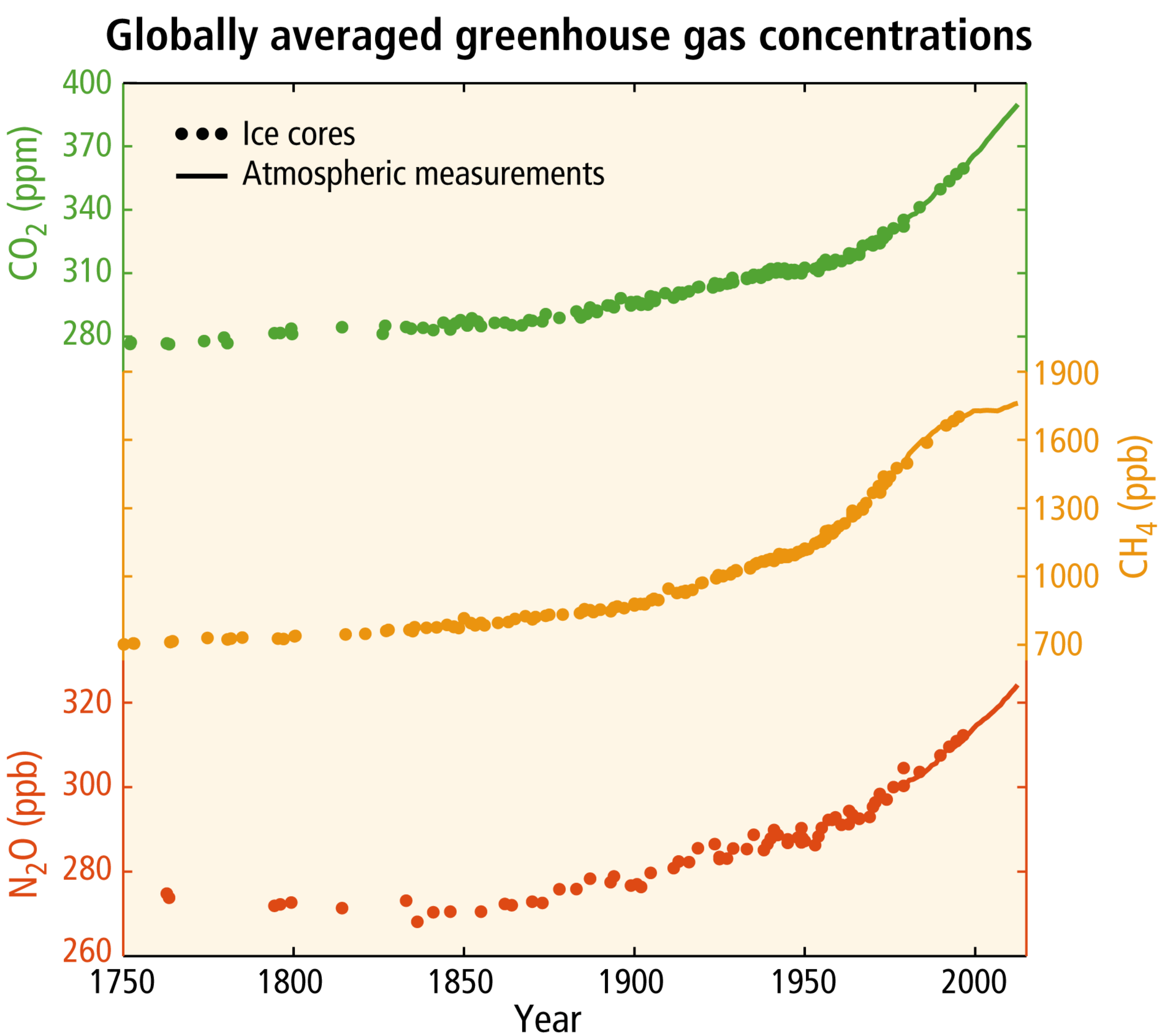
Climate change is real

Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years



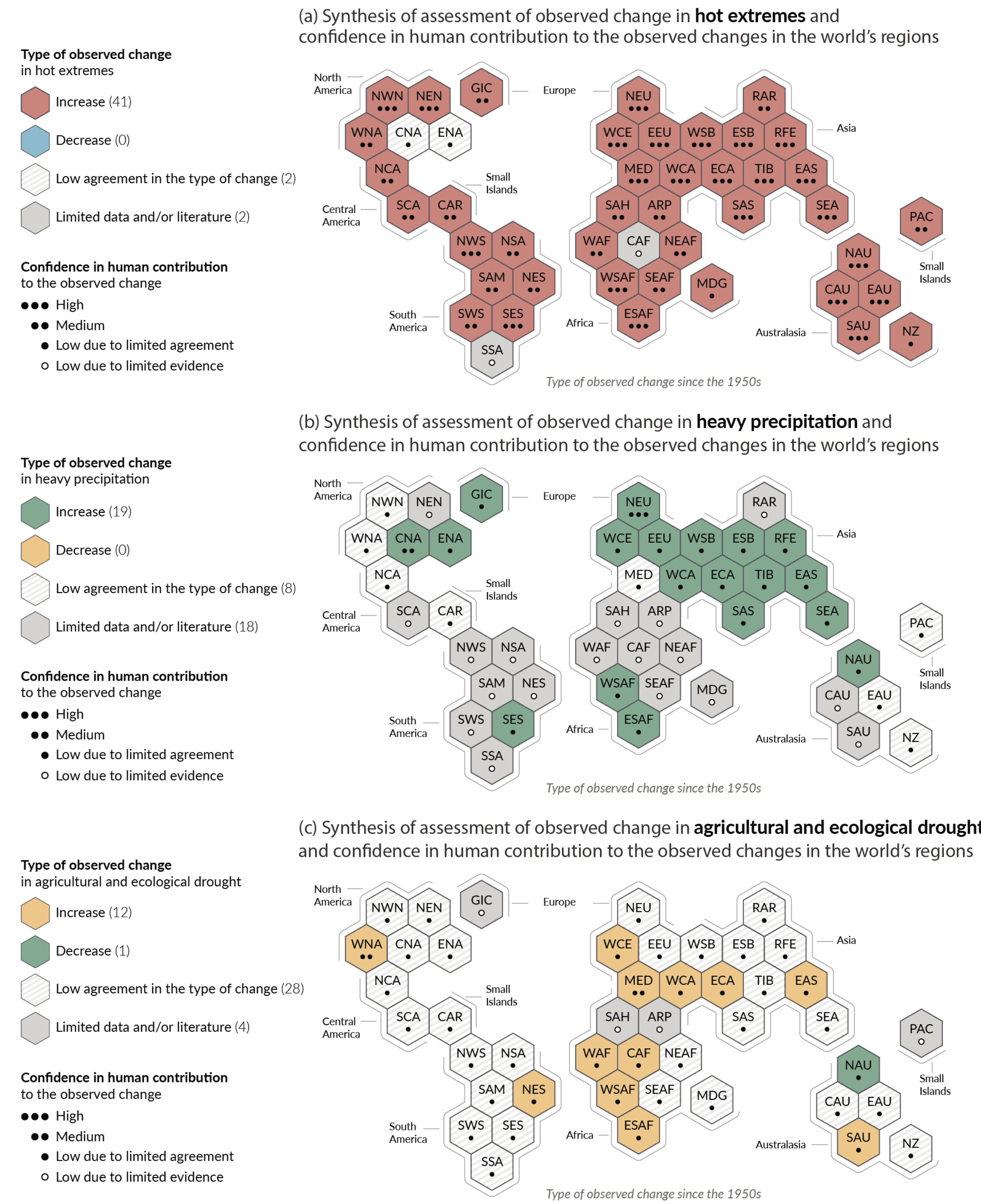
(IPCC AR6)

Climate change is real



(IPCC AR5)

Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes



(IPCC AR6)

Particle physics on a (carbon) budget

- Every 1000 gigaton of cumulative CO_2 emissions leads to 0.27-0.63 C increase in warming.
- To limit warming to < 1.5 C, emissions need to be limited to ~1 ton CO2e (CO_2 equivalent) per capita per year until 2050.
- Current per capita per year rate in U.S. ≃ 14.2 tCO2e, was ≃ 20 tCO2e in 2005, but still ~3x global average.
- Particle physics activities have the potential for scientists to have a carbon impact well above that of average citizens, so we must pay attention.
  - Moral reason: Responsibility for leaving behind a habitable planet.
  - Practical reason: Future major projects will have significant carbon impact and will be scrutinized for it.
- Particle physics is a world leader in international cooperation for common goals — can we do the same here?
- How can we pursue the science we love sustainably?

Astronomy impacts

nature astronomy
ARTICLES
https://doi.org/10.1038/s41550-022-01612-3

Check for updates

Estimate of the carbon footprint of astronomical research infrastructures

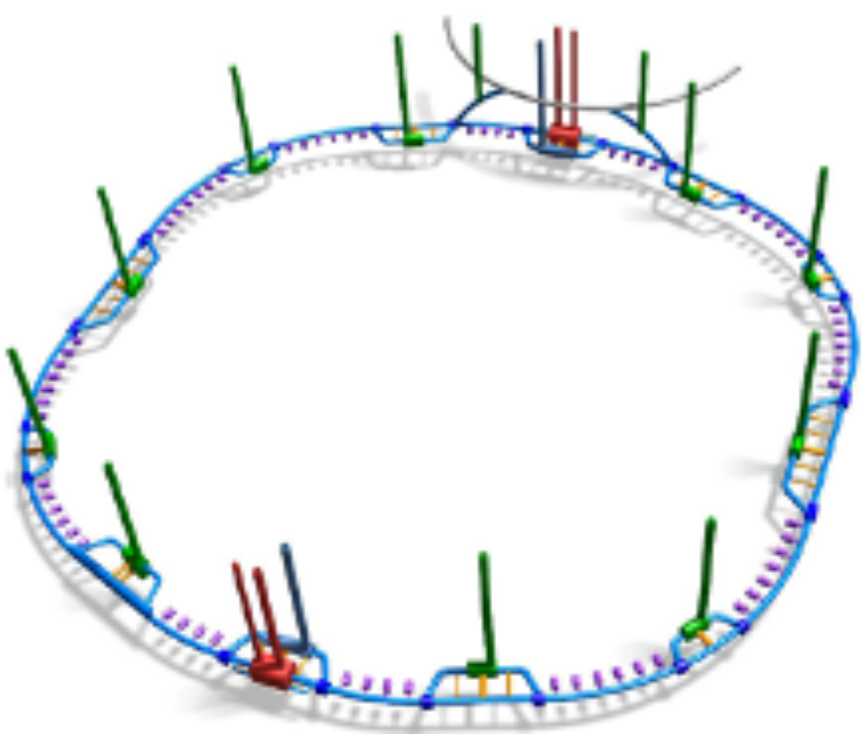
Jürgen Knödlseder ✉, Sylvie Brau-Nogué, Mickael Coriat, Philippe Garnier, Annie Hughes, Pierrick Martin and Luigi Tibaldo

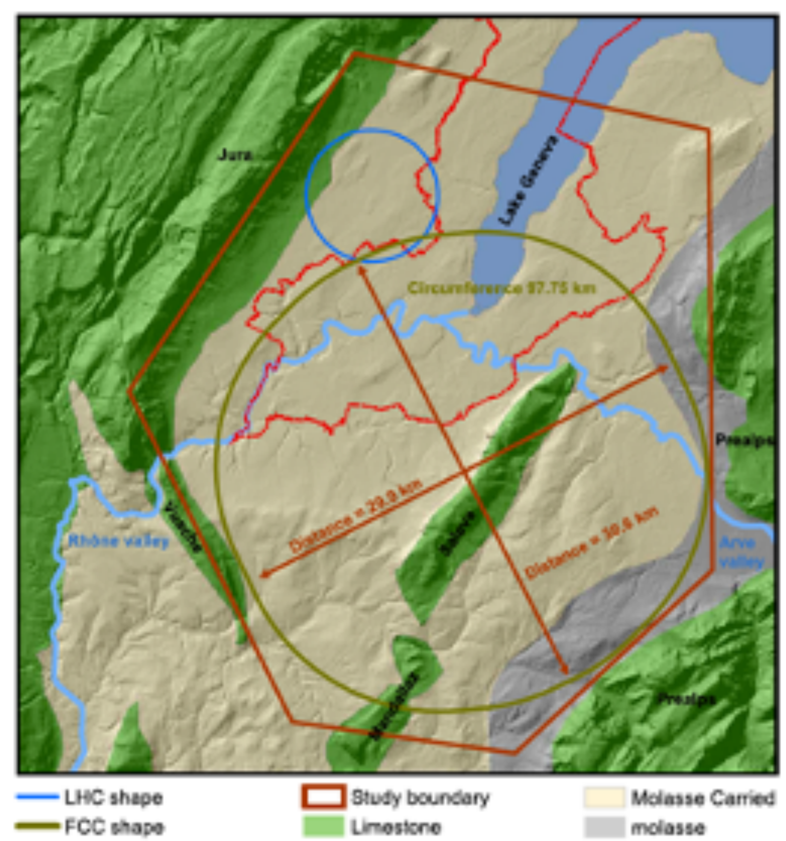
The carbon footprint of astronomical research is an increasingly topical issue with first estimates of research institute and national community footprints having recently been published. As these assessments have typically excluded the contribution of astronomical research infrastructures, we complement these studies by providing an estimate of the contribution of astronomical space missions and ground-based observatories using greenhouse gas emission factors that relates cost and payload mass to carbon footprint. We find that worldwide active astronomical research infrastructures currently have a carbon footprint of 20.3 ± 3.3 MtCO$_2$ equivalent (CO$_2$e) and an annual emission of 1,169 ± 249 ktCO$_2$e yr^{-1} corresponding to a footprint of 36.6 ± 14.0 tCO$_2$e per year per astronomer. Compared with contributions from other aspects of astronomy research activity, our results suggest that research infrastructures make the single largest contribution to the carbon footprint of an astronomer. We discuss the limitations and uncertainties of our method and explore measures that can bring greenhouse gas emissions from astronomical research infrastructures towards a sustainable level.

"Just to give you some perspective — 20 million tonnes of CO2 — this is the annual carbon footprint of countries like Estonia, Croatia, or Bulgaria," says Jürgen Knödlseder, an astronomer at IRAP, an astrophysics laboratory in France.

Emissions from construction

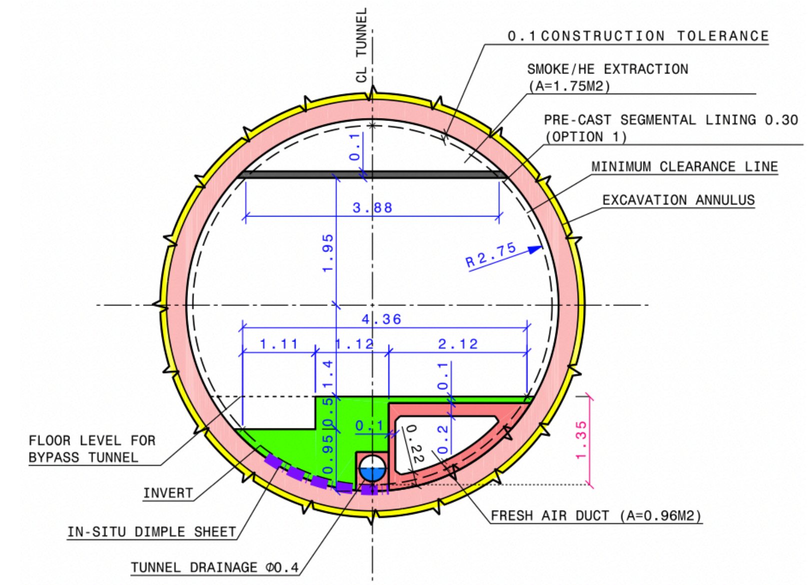
- Building construction industry contributes 10% of world's total carbon emissions.
  - Cement made via $CaCO_3$ + heat → CaO + CO_2, 1 ton CO_2 per 1 ton cement, hard to decarbonize.
- Assumption: the electric grid will be decarbonized by ~2040, so new HEP facilities will be operating on decarbonized energy.
  - Facility construction rather than operation could dominate carbon impacts!
- Example: FCC(-ee,-hh), 97.75 km tunnel would be one of the world's largest, plus many bypass tunnels, access shafts, experimental caverns, surface facilities….





Emissions from construction

- Carbon impact of main tunnel?
- Bottom up: calculate volume of tunnel walls, concrete is 15% cement → ~240 kt CO_2.
- Top down: studies of road tunnel construction give rule of thumb of 5,000-10,000 kg CO_2/km of tunnel → > ~500 kt CO_2.
- 6 million trees required for carbon offset!



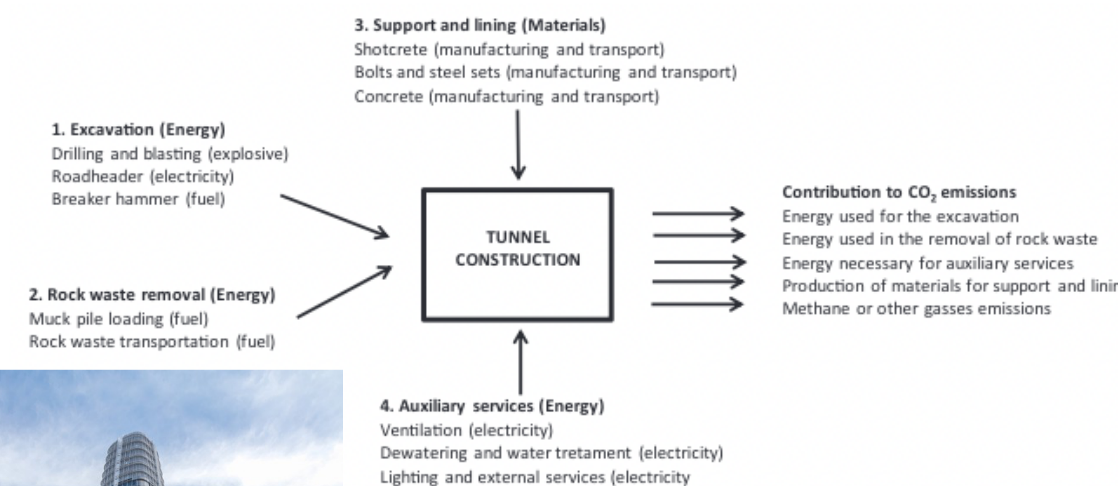
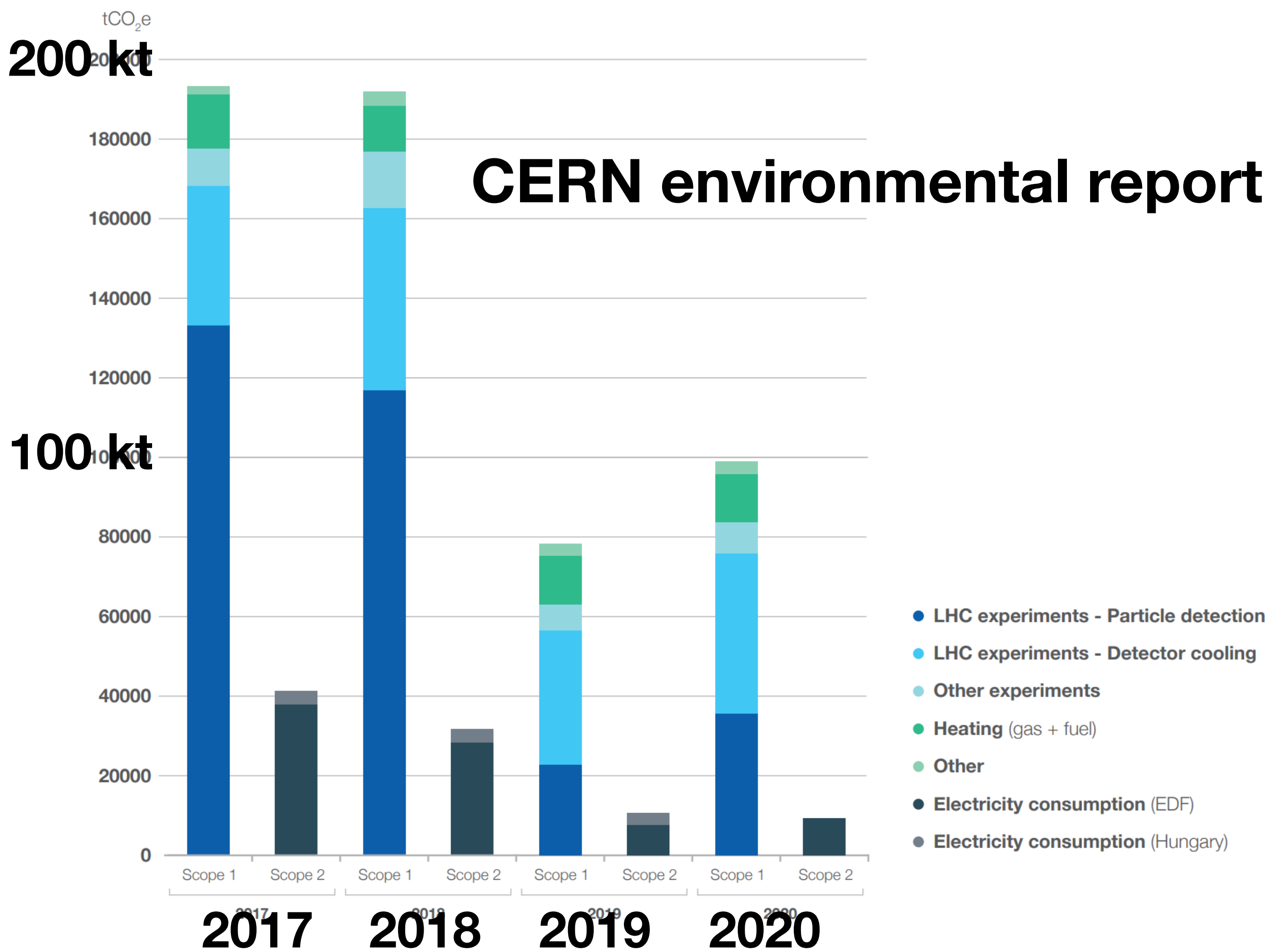


Fig. 1. Schematic overview of the system boundary.

- Salesforce Tower: 1.4M ft^2, ~550 kg embodied carbon/m^2 → ~79 kt CO2e.

Emissions from detectors

- CERN emissions are dominated by experiment gases!



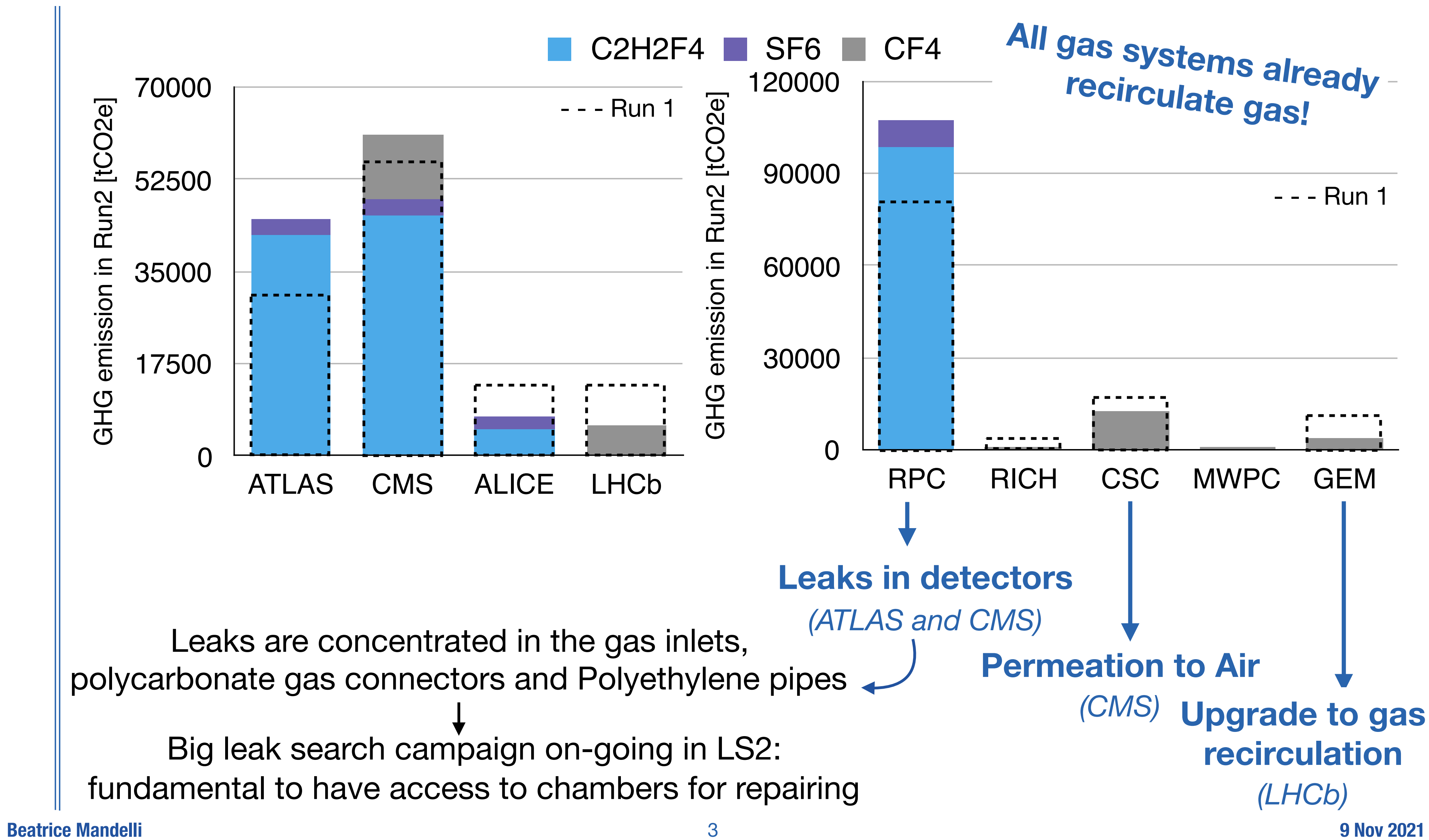
- Scope 1: direct emissions from organization
- Scope 2: indirect emissions from electricity, heating, etc.
- Scope 3: all other emissions upstream and downstream (business travel, commuting, catering etc.); harder to quantify

GROUP	GASES	tCO_2e 2017	tCO_2e 2018
PFC	CF_4, C_2F_6, C_3F_8, C_4F_{10}, C_6F_{14}	61 984	69 611
HFC	CHF_3 (HFC-23), $C_2H_2F_4$ (HFC-134a), HFC-404a, HFC-407c, HFC-410a, HFC R-422D, HFC-507	106 812	96 624
	SF_6	10 192	13 087
	CO_2	14 612	12 778
TOTAL SCOPE 1		193 600	192 100

Scope 1 emissions by gas type

- Gases used for particle detection, cooling, etc.
- $C_2H_2F_4$ (78% of detector emissions) has 1300x global warming potential (GWP) of CO_2.
- CF_4 (15%) has 6630x GWP, SF_6 (8%) has 23500x GWP!

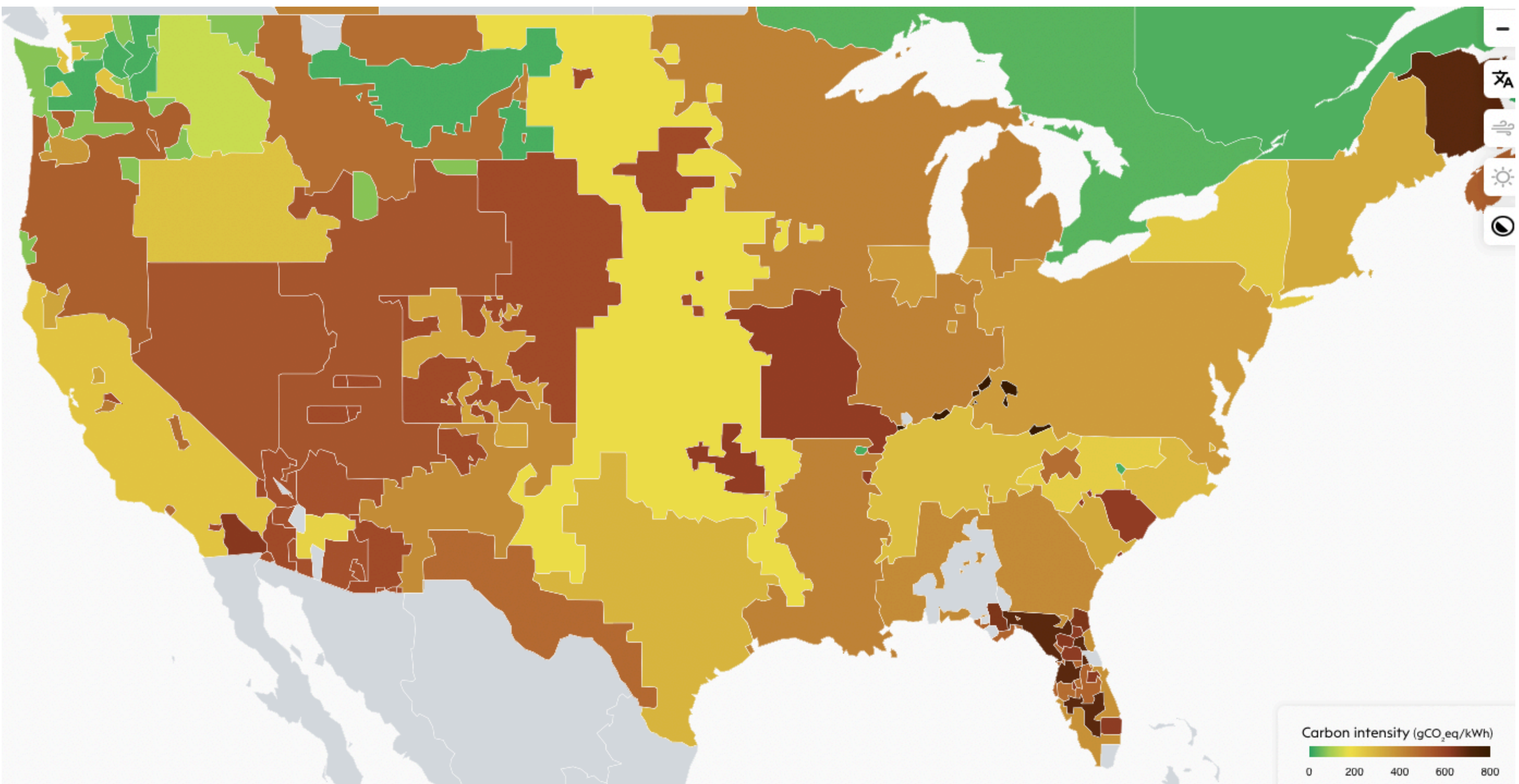
Emissions from detectors



- F-gases are good for detector operations, but highly regulated in the EU (phased-down sales → more expensive), mandatory reporting in the US.
- Procurement subject to availability and price increases → potential threat to long-term LHC program.
- New eco-friendly gases good for refrigerants, not so much for particle detection.

Emissions from computing

- Data centers and computing contribute 2-4% of global GHG emissions, only expected to grow.
- Up-front considerations: where do we place computing facilities and how are they powered? Electricity emissions vary significantly across regions.
- But if electric grid is decarbonized, electricity supply might be biggest concern.



electricitymap.org

Emissions from laboratories

- DOE requires yearly reports on environmental impacts.
- Fermilab 2021 sustainability report:

Scope 1 & 2 Greenhouse Gas Emissions

Goal: YOY scope 1 & 2 GHG emissions reduction from a FY 2008 baseline.
Interim Target (FY 2020): 0.0%

Current Performance: -72.2%

	FY 2008	FY 2019 (PY)	FY 2020	% Change from Baseline	% Change from Last Year
Facility Energy	343,366.8	161,122.7	120,825.4	-64.8%	-25.0%
Non-Fleet V&E Fuel	142.6	186.6	46.3	-67.5%	-75.2%
Fleet Fuel	691.6	27.9	0.0	-100.0%	-100.0%
Fugitive Emissions	40,165.1	139.1	708.3	-98.2%	409.2%
On-Site Landfills	0.0	0.0	0.0	N/A%	N/A%
On-Site WWT	0.0	0.0	0.0	N/A%	N/A%
Renewables	0.0	0.0	0.0	N/A%	N/A%
RECs	0.0	-17,435.4	-14,619.3	N/A	-16.2%
Total (MtCO2e)	**384,366.1**	**144,040.9**	**106,960.6**	**-72.2%**	**-25.7%**

renewable energy certificates

Scope 3 Greenhouse Gas Emissions

Goal: YOY scope 3 GHG emissions reduction from a FY 2008 baseline.
Interim Target (FY 2020): 0.0%

Current Performance: -77.9%

	FY 2008	FY 2019 (PY)	FY 2020	% Change from Baseline	% Change from Last Year
T&D Losses*	22,287.8	7,306.8	2,654.0	-88.1%	-63.7%
T&D RECs Credit	0.0	-1,148.5	-963.0	N/A	-16.2%
Air Travel	2,215.8	2,530.1	1,061.9	-52.1%	-58.0%
Ground Travel	168.9	128.5	78.7	-53.4%	-38.8%
Commute	4,633.3	5,392.5	3,493.0	-24.6%	-35.2%
Off-Site MSW	191.8	247.7	180.4	-5.9%	-27.2%
Off-Site WWT	4.8	11.0	10.8	125.0%	-1.8%
Total (MtCO2e)	**29,502.4**	**14,468.1**	**6,515.8**	**-77.9%**	**-55.0%**

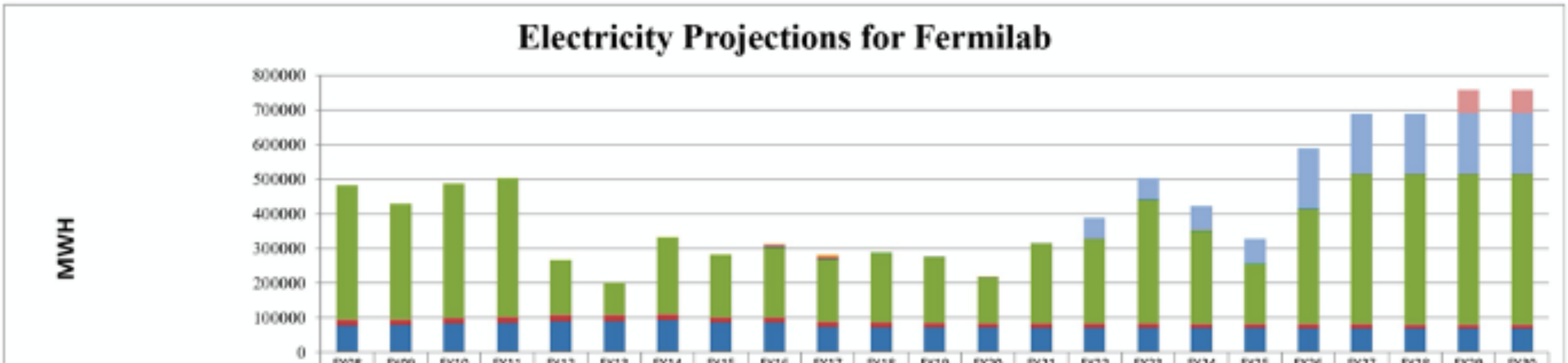
* Includes T&D losses for purchased renewable electricity

Emissions from laboratories

- More on Fermilab: electricity usage is expected to increase by 30% over historic peak levels due to PIP-II, LBNF operations.

	2008	2018	2019	2020	2021
Scope 1+2	384,666	128,304	144,013	106,961	163,818
Scope 3	29,503	16,495	14,468	6,516	17,456

Table 1. Summary of Fermilab GHG emission data from 2008 (reference year) and 2018 - 2021. Emissions are divided into the three scope areas and given in CO2e metric tons [42].



	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30
LBNF																						68328	68328
PIP-II															61320	61320	70956	70956	173448	173448	173448	173448	173448
SBN Near & Far Detectors									3942	8869.5	548.9508	521.6047	669.758	700.8	700.8	700.8	700.8	700.8	700.8	700.8	700.8	700.8	700.8
Mu2e (MC-2)											324.825	348.5065	471.1054	1752	1752	1752	1752	1752	1752	1752	1752	1752	1752
Muon G-2 (MC-1)									5080.8	5080.8	932.8659	947.4887	1057.261	1057.261	876	876	876	876	876	876	876	876	876
Existing Particle Accelerators HEMSF	391208.4	337149.6	390287.5	402903.2	160678.4	94728.3	224836.8	182507.3	203178.3	179476.8	200217.4	189303.5	133630	229464.3	242312.3	357463.3	267470.5	172838	332149.8	432510	432866.6	433220.6	433570.1
Existing High Performance Computing HEMSF	16548.45	17215.17	17230.22	19718.99	19542.3	18389.43	16574.14	14742.82	14742.82	15904	15321	14334	13131.06	13131.06	13131.06	13131.06	13131.06	13131.06	13131.06	13131.06	13131.06	13131.06	13131.06
Site Base	74689.13	75595.25	80021.26	80555.85	85979.34	86723.26	90333.26	83857.44	83617.98	70310.85	69309.95	68919.64	68533.19	68150.6	67771.85	67396.85	67025.65	66658.15	66294.35	65934.12	65577.52	65224.5	64875

Emissions from campuses

- What is your campus doing about reducing carbon emissions?
- Good place to check: The Association for the Advancement of Sustainability in Higher Education.
  - They produce ratings of campuses that submit information about their sustainability activities.
  - But a lot of the points are awarded on the basis of teaching/research activities, not so much on sustainability of campus operations.
- Many campuses have dashboards showing progress on reducing emissions — does yours have one? If not, are you asking why not?

Why am I here?

Places I have flown to give this seminar

Rethinking travel

- Particle physicists are famous for their travel!
- Air travel is "only" 2.4% of global emissions (2018), but rising rapidly (up 32% in 5 years) and hard to de-carbonize.
- The pandemic has taught us a lot about what can be done remotely…and what *can't* be done remotely.
- Optimizing experiment work: remote control rooms, improved meeting technology, rely more on regional centers.
- What about conferences? Is in-person appearance necessary for career development, or just for fun?
  - Estimate 1 ton CO2e per conference participant!
  - Improvements: accessible venues, virtual attendance, reduce frequency, multiple regional hubs
- Judicious choices can have an impact.

What to do?

- Be prepared!
  - Expect more stringent review of environmental impacts.
  - Set concrete emissions reduction goals and define pathways to meet them.
  - Consider the evolving context, e.g. a decarbonized electric grid by 2040.
- Invest for a zero-carbon future by letting particle physicists spend some of their research time on directly tackling challenges related to climate change in the context in particle physics.
  - Less carbon-intensive construction materials, better gases for particle detection, energy-efficient accelerators and computing, improved remote meeting technology.
- Addressing climate change requires a societal response, but particle physics should be leaders in sustainable science.
- It’s not too late, if we start acting now.