Carbon Lifecycle Analysis for Scientific Computing

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NORDIC E-INFRASTRUCTURE COLLABORATION

Overview

- Question
- Methodology
- Assumptions
- Calculations
- Conclusions

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Question

- What is the optimal replacement cycle for scientific computing hardware?
  - From a total CO2e emissions point of view
- Requires us to make a carbon lifecycle analysis
  - Manufacture
  - Transport
  - Operations
  - Scrapping
- Is changing to modern more efficient computers good to minimize emissions?

Methodology

- For a given capcity over time t, without any hardware replacement:
  - total_emissions(t) = embodied_carbon + pue*energy_consumption*carbon_intensity(t)*t
- With hardware replacement
  - Assuming Koomey's law for energy efficiency gains, current slope is 1.88 times over four years. Also assuming less embedded carbon per computing iteration:
    - total_emissions(1) = embodied_carbon + pue*energy_consumption*carbon_intensity(1)
    - total_emissions(t) = total_emissions(t-1)+ pue*energy_consumption*carbon_intensity(t)/eff_gain_step+ embodied_carbon(t)*(t_step(t)-t_step(t-1))
    - t_step = ceil(t/t_lifetime)
    - embodied_carbon(t)=embodied_carbon(1)*correction(t)
    - correction(1) = (1-a)^(t-1)
    - eff_gain_step(t) = t_step(t)==t_step(t-1) ? eff_gain_step(t-1) : eff_gain(t)

Assumptions

- The data on equipment comes from vendors
  - Dell, HPE, Lenovo all have published impact of a few select models
  - Covering: Manufacture, transport, recycling
  - Totally dominated by manufacturing!
  - Of this chip manufacturing (CPU, RAM, SSD) is 80+%
  - Some assumptions needed to map general purpose servers to HPC
- The vendor documents also have ops numbers
  - But these are not very applicable to scientific computing
  - Assuming low CPU load, low efficiency compute rooms, dirty power
- We can find real load and facility numbers!

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Compute node assupmtions

- Current best in class AMD Bergamo CPU nodes
- 2x128 cores, 4GB ram/core
- Benchmark load: HEPScore23
  - Known to scale well with LHC computing
  - Node score 7500
  - Average node power draw during benchmark: 1200 W
  - Or, 160 W/kHS23
  - Numbers from D. Britton, HEPiX Fall 2023
- Assuming 80% of the benchmark as lifetime usage
  - Batch system fill over time, downtimes, IO bottlenecks, etc

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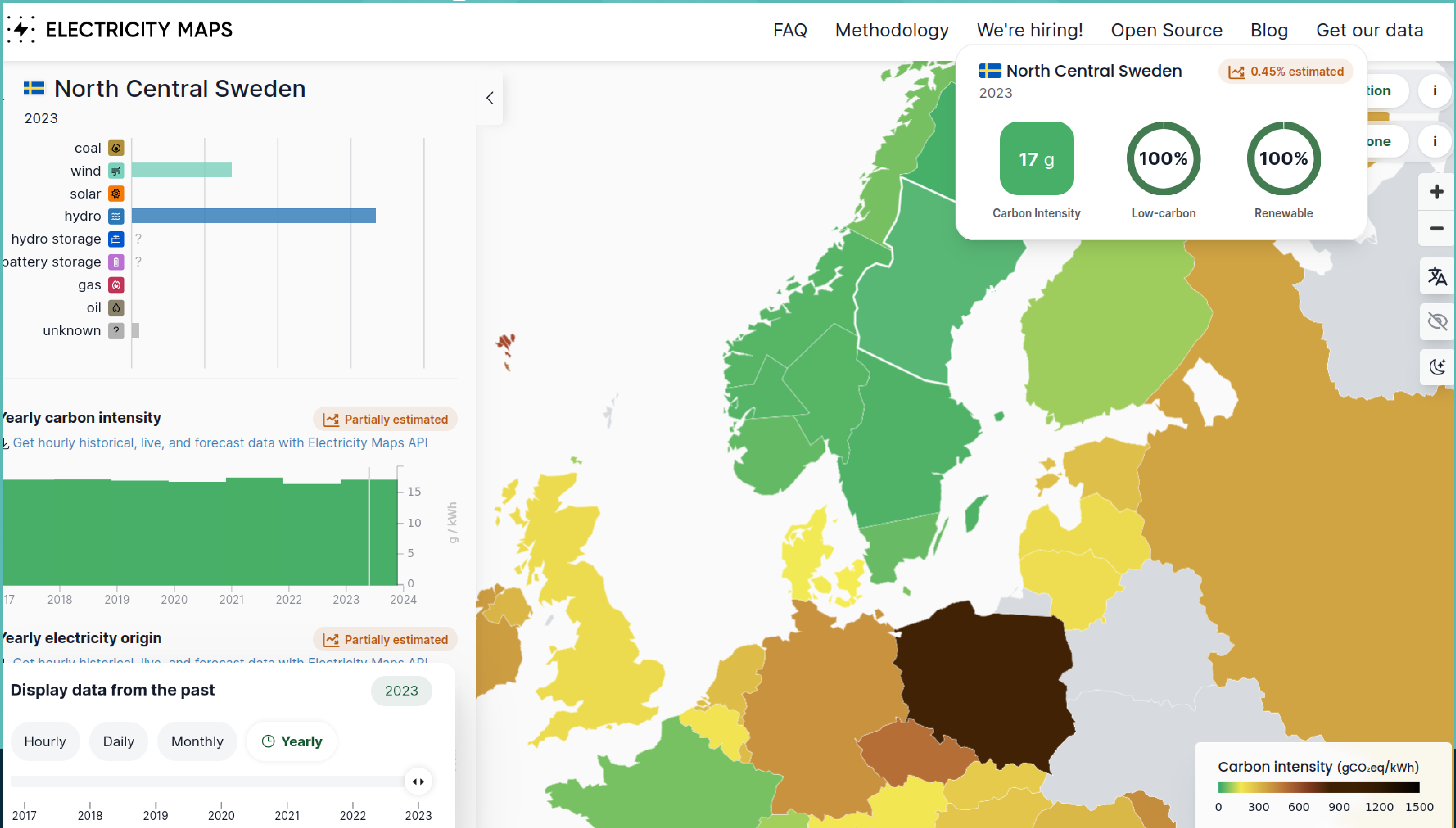
Power generation emissions



North Central Sweden

2023

early carbon intensity

Partially estimated

Get hourly historical, live, and forecast data with Electricity Maps API

early electricity origin

Partially estimated

Display data from the past 2023

Hourly Daily Monthly **Yearly**

North Central Sweden

0.45% estimated

2023

17 g	100%	100%
Carbon Intensity	Low-carbon	Renewable

Power generation emissisons

- Data from: app.electricitymaps.com
- Looking at 2023 average for electricity production and imports in that area
- Does not reflect green power purchasing
  - Facilities buying green power look a bit worse here than what they are paying for
- Does not reflect marginal generation or exports

Marginal power consumption

- If HPC2N in North Central Sweden draws 1 kWh more from the grid, what's the impact?
  - 1 kWh more generated in the same power mix
  - 1 kWh more generated with different power mix
  - 1 kWh less exported to other power areas
- Range:
  - 1 g/kWh (non-fossil production, as per contract)
  - 11 g/kWh (margin power likely hydro, CO2e mostly land use effect)
  - **17 g/kWh (long-term average) ← this is what this paper uses**
  - 460 g/kWh (more gas burned in Denmark)
  - 1100 g/kWh (more coal burned in Poland)

Facility cooling

- Mostly additional electricity to drive fans, pumps, and compressors, measured as PUE
- One facility has explicit CO2e/kWh from use of district cooling
- Heat reuse in cold locations explored in one scenario

Facility numbers – real world

- HPC2N, Sweden
  - 17 gCO2e/kWh electricity
  - PUE 1.03 + 3.6 gCO2e/kWh district cooling
- Vega, Slovenia
  - 242 gCO2e/kWh electricity
  - PUE 1.13
- BNL, USA
  - 282 gCO2e/kWh electricity
  - PUE 1.35
- ASGC, Taiwan
  - 535 gCO2e/kWh electricity
  - PUE 1.62

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Facility numbers - hypothetical

- HPC2N, Sweden – heat reuse
  - Assuming we run heat pumps to heat the university campus for the cold months of the year
  - Higher PUE (compressors drawing electricity): 1.33
  - Leading to estimated reduction of 40gCO2e/kWh yearly average emissions due to offsetting district heating
- French Vega
  - Assuming identical computer facility as Vega
  - But running on the French power mix of mostly nuclear power
  - 53 gCO2e/kWh

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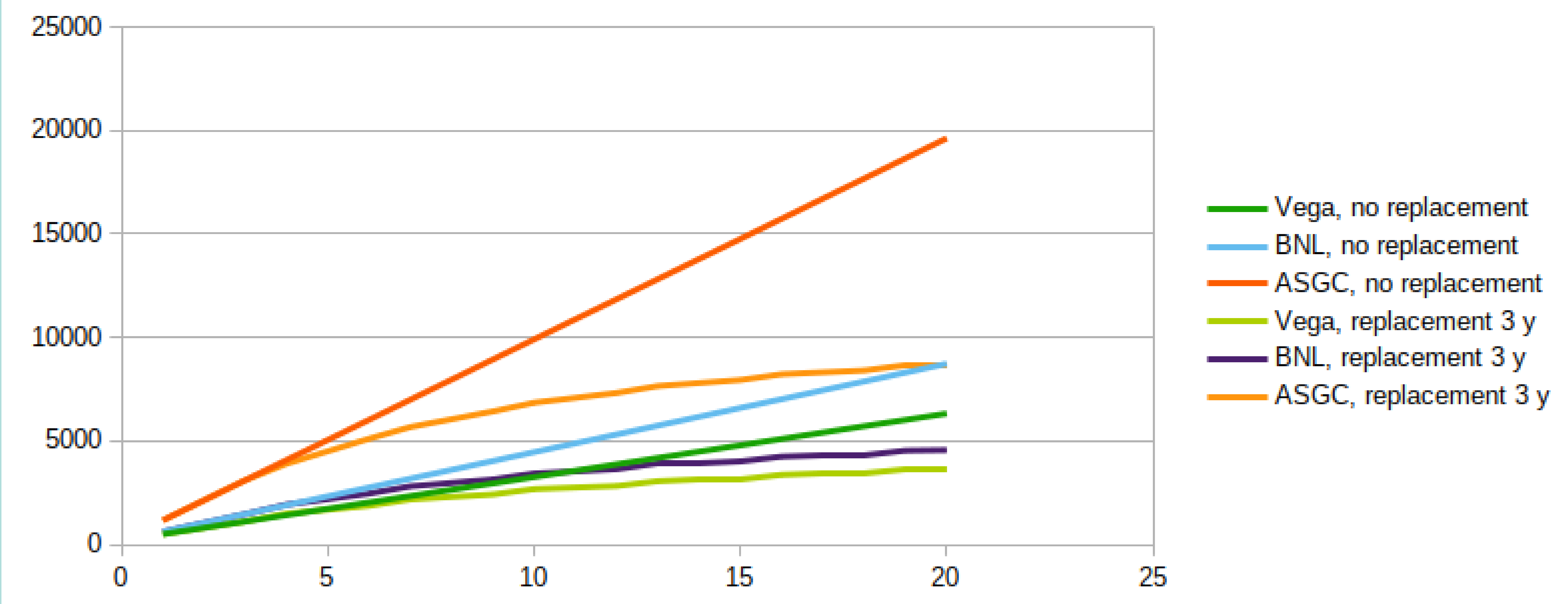
Calculations

- Exploring replacement cycles of 3, 5, 10 years vs no replacement, over a period of 20 years
- Graphs split in high and low emission plots with different scales
  - Otherwise the “HPC2N” lines are just flat lines at the bottom
- The unit is kgCO2e/kHS23

3 year replacement cycle



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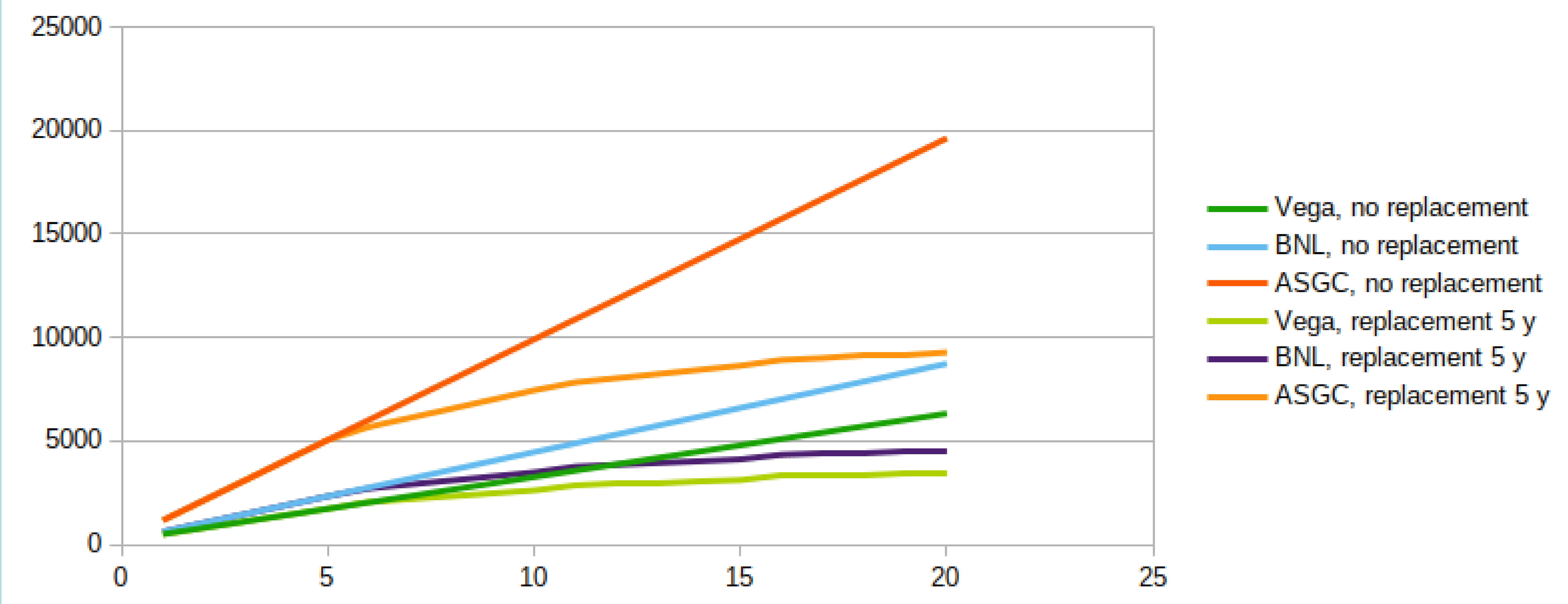
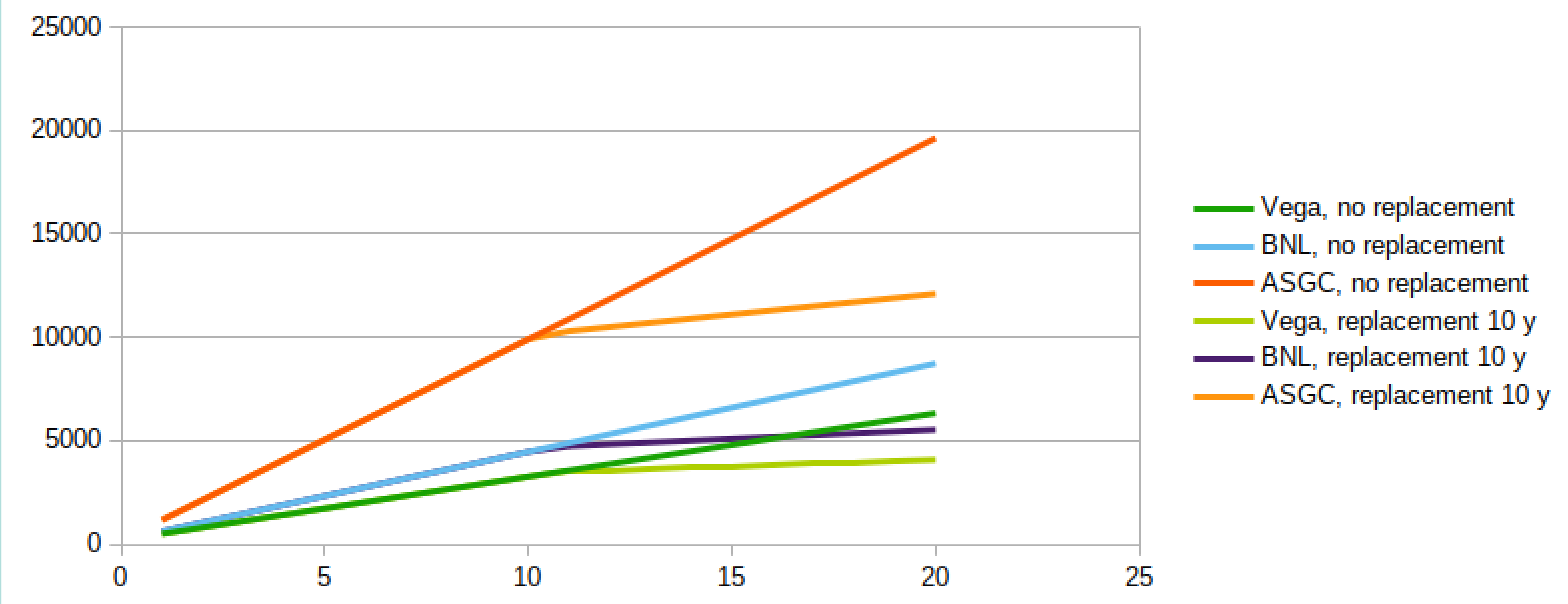
5 year replacement cycle



10 year replacement cycle



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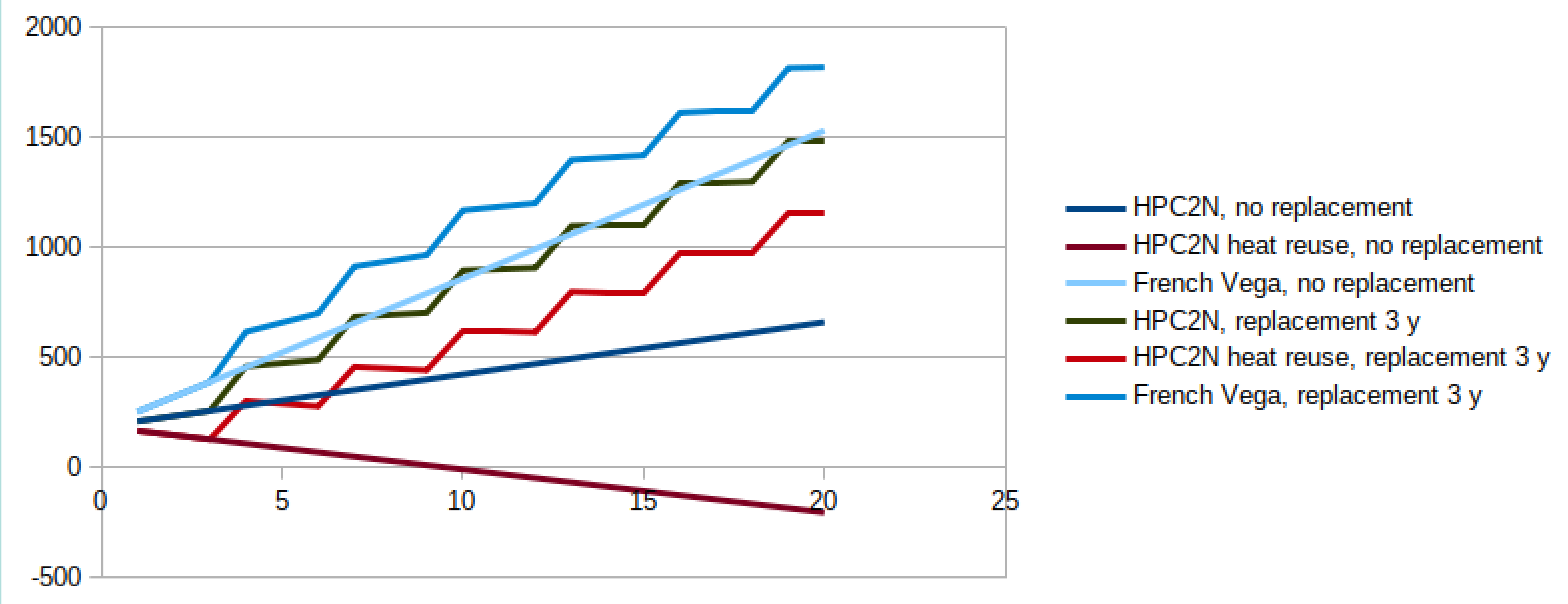
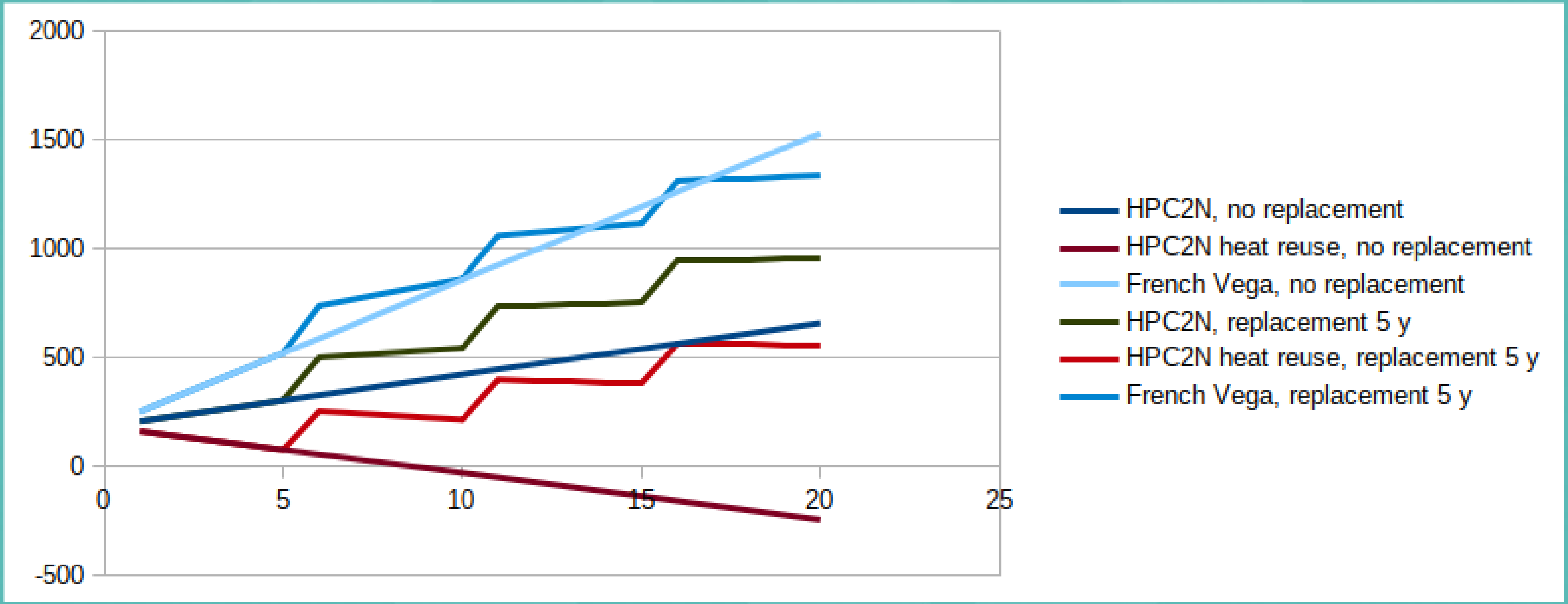
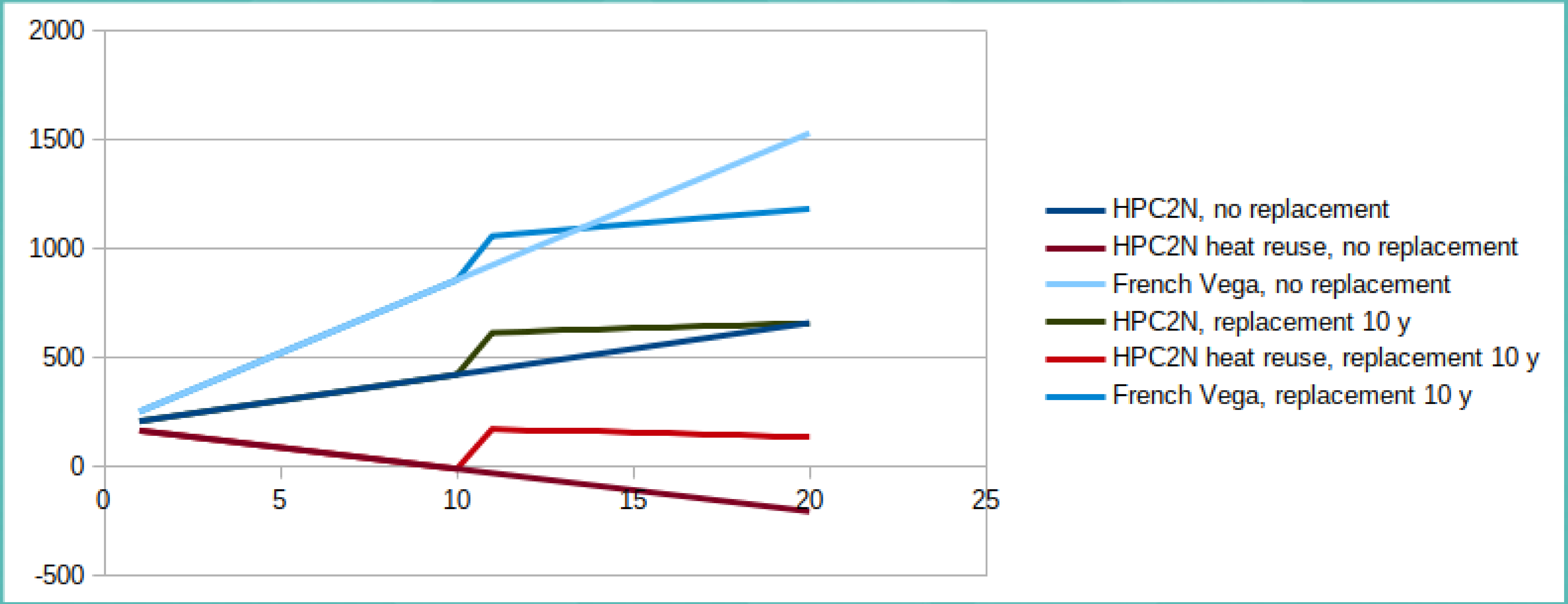


5 year replacement cycle



10 year replacement cycle



Conclusions

- In high emission locations: replace old servers by new as soon as financially viable
  - For heavily loaded scientific computing nodes
  - For general purpose servers or desktops this is less obvious
- In low emission locations: Running old servers for a long time might be better
  - The tradeoffs are emissions vs operating costs (power, staff, parts)

Conclusions

- Reducing embedded carbon in servers?
  - Don’t buy more SSD or RAM than needed for the workloads
    - 4-8TB SSD could be half node manufacturing emissions
  - Convince Taiwan to switch to greener electricity so TSMC chips will have less embedded carbon from manufacturing
- Heat reuse can be a big impact
  - Cold regions with low emission power can even reach negative emissions, depending on what the alternative heat is
  - Comes at a significant financial cost, both investment and running

Questions?

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