Candidate Metrics for Carbon-Efficient Routing

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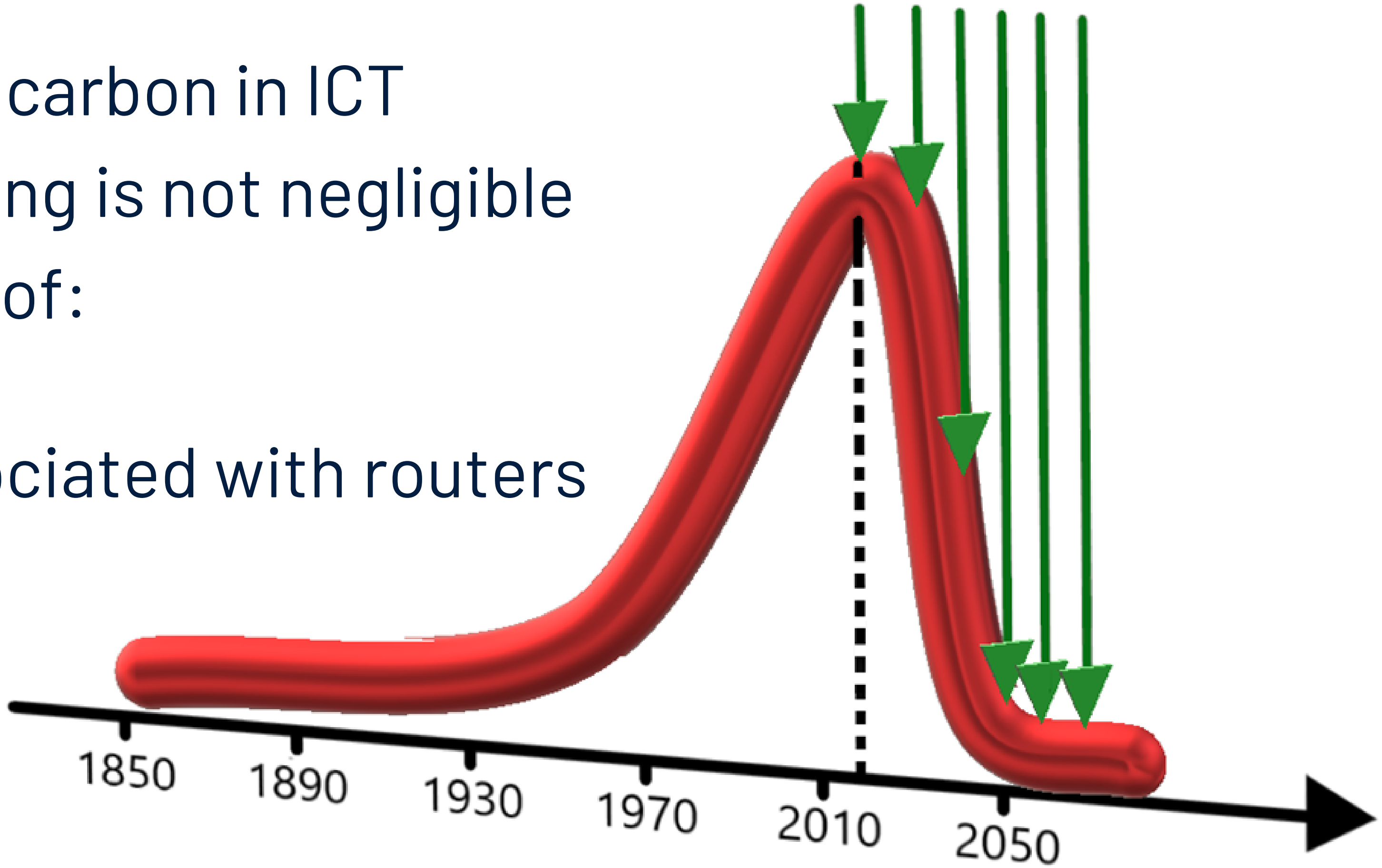
Joint work with Paul Gunning (BT) and Noa Zilberman

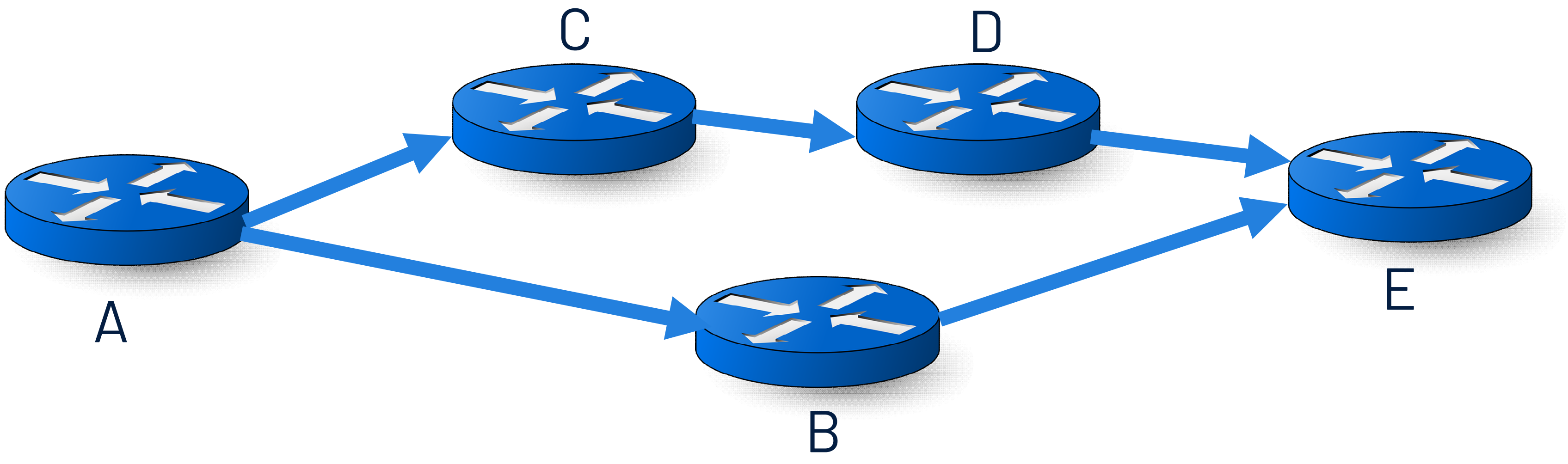
Problem

- Net zero goals by 2050
- Computing is one driver of carbon in ICT
- Carbon related to networking is not negligible
- This work is in the context of:
  - Routing (network layer)
  - Scope 2 emissions associated with routers



Motivation

- Previous work focuses on **power** efficiency.
- **Carbon** efficiency is a new optimization problem.



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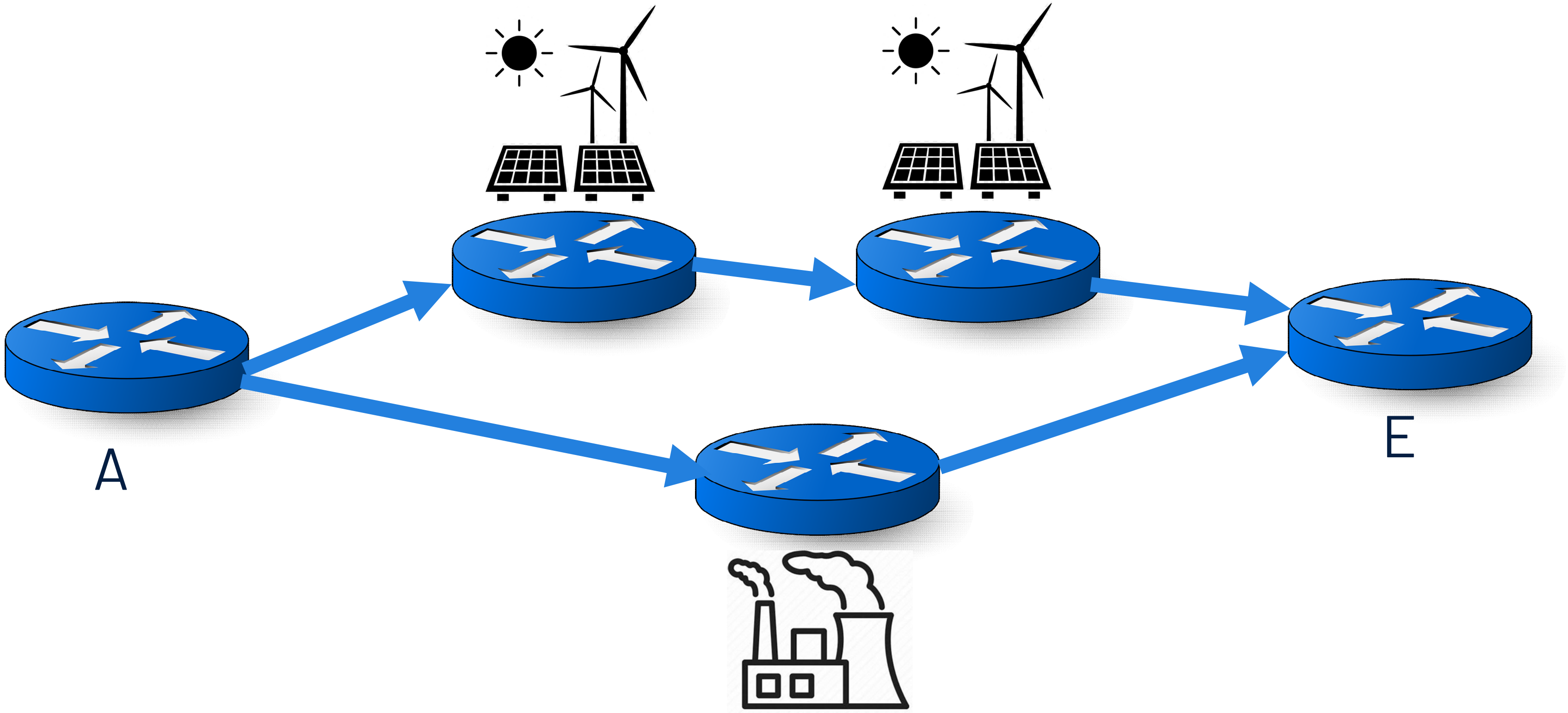
- Adds the geographical dimension to the routing.



Motivation

- Previous work focuses on **power** efficiency.
- **Carbon** efficiency is a new optimization problem.
- Adds the geographical dimension to the routing.
- **Opportunity:** carbon intensity is predictable per region.
- **Goal:** Quantify the potential carbon emissions benefits of carbon-aware routing.

Carbon Footprint

- "You can't improve what you don't measure."

- Carbon emissions relate to:
  - Amount of energy consumed
  - Source of energy
  - Weighted carbon emissions associated with the source

Carbon Footprint

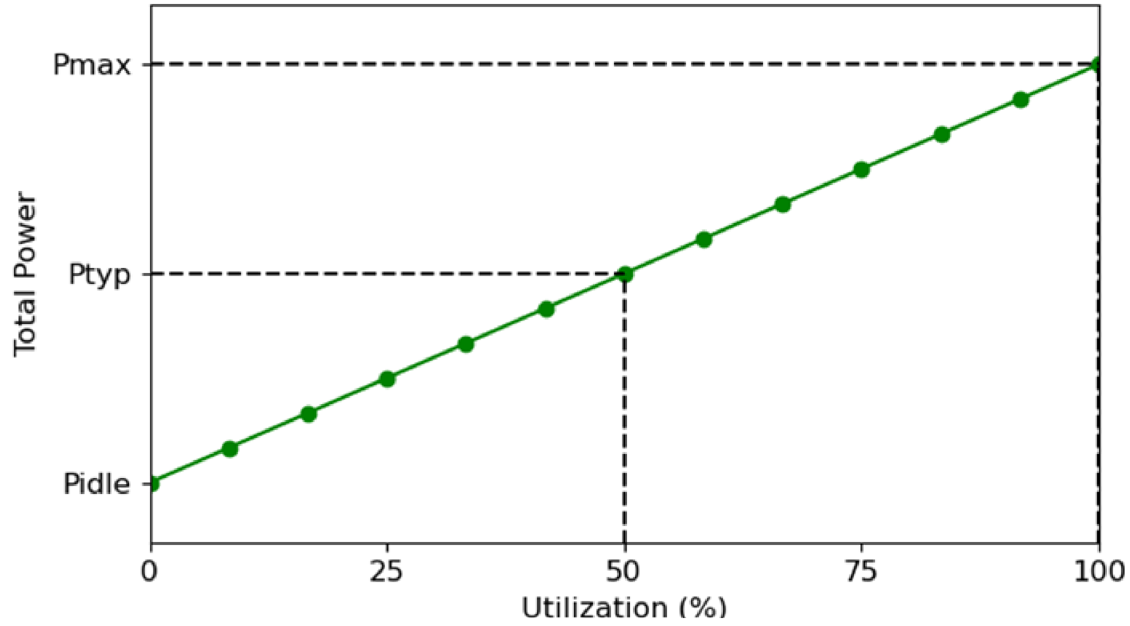
- "You can't improve what you don't measure."

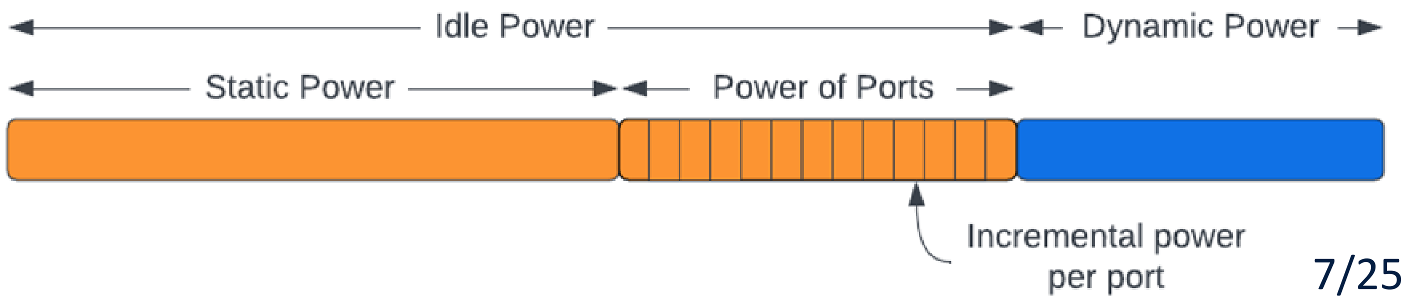
- Carbon emissions relate to:
  - Amount of energy consumed
  - Carbon Intensity

Energy Consumption

- Dynamic Power: proportional to the utilization

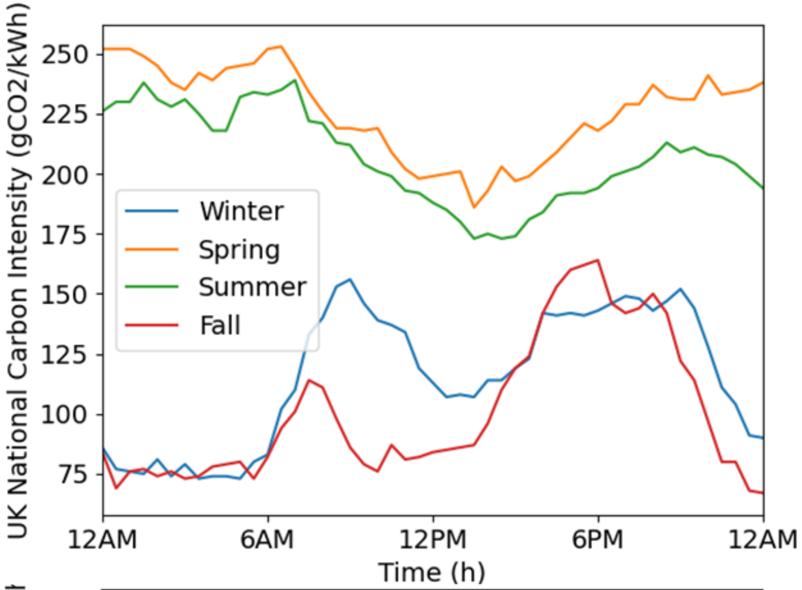
- Idle Power is composed of:
  - Static Power
  - Power of Ports

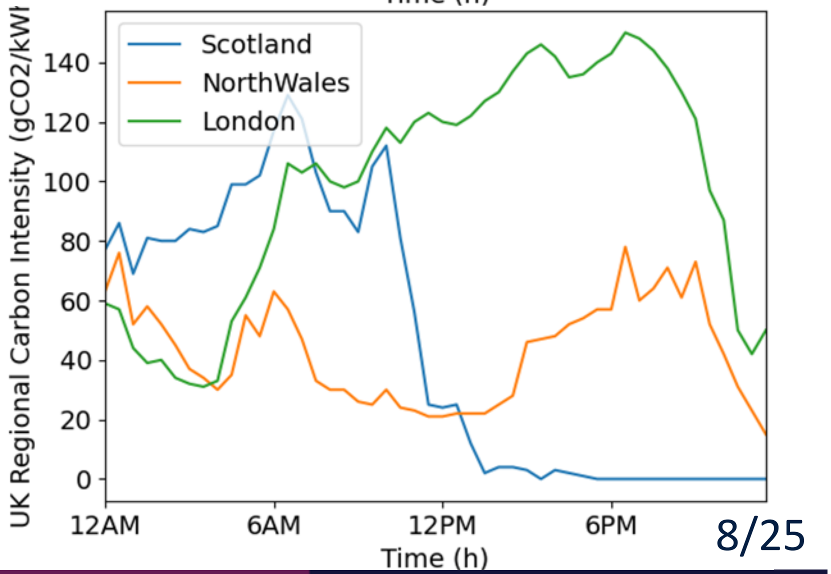




Carbon Intensity

- Unit: gCO2/kWh
- Carbon intensity varies:
  - per day
  - per season
  - per region
- Noticeable change can be seen within few hrs.
- Can be forecasted up to 24-48 hrs beforehand.
- Main motivation: Adapt the routing of traffic to greener paths.





Carbon Intensity API

Potential Metrics

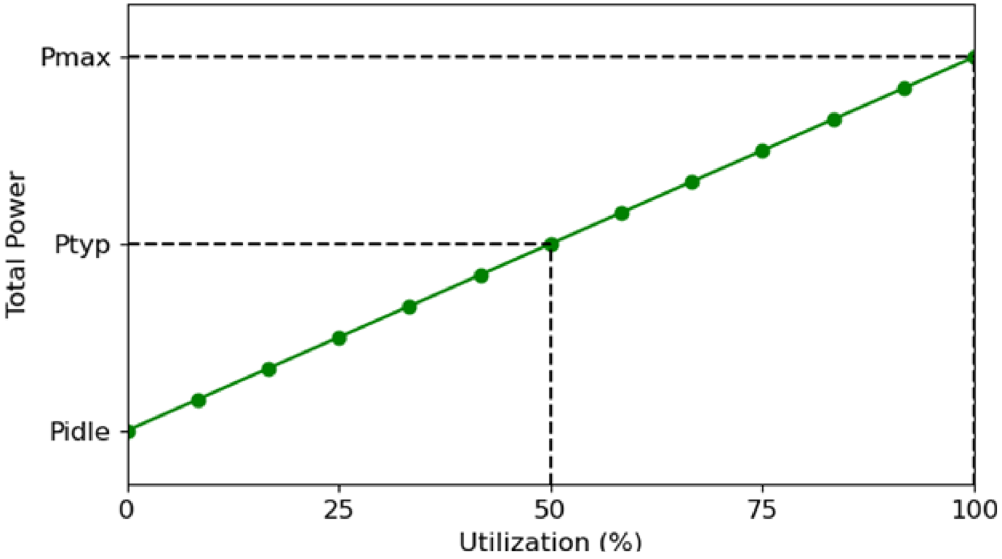
Energy-related Metrics

Carbon-related Metrics

Potential Metrics

Energy-related Metrics

- Typical Power
  - power at 50% utilization
  - Extracted from datasheet

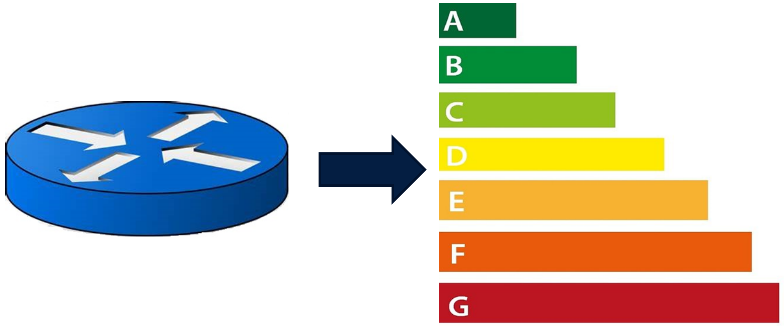


Carbon-related Metrics

Potential Metrics

Energy-related Metrics

- Typical Power
- Energy Rating
  - Not standardized yet
  - Ratio of typical power and maximum packet rate
  - Divided into a 7-star scale

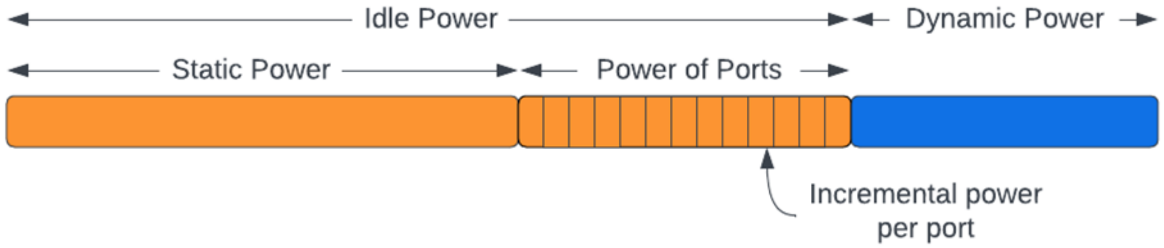


Carbon-related Metrics

Potential Metrics

Energy-related Metrics

- Typical Power
- Energy Rating
- Incremental Dynamic Power per Unit of Traffic
    - Ratio of **dynamic** power and maximum capacity (W/Mbps)

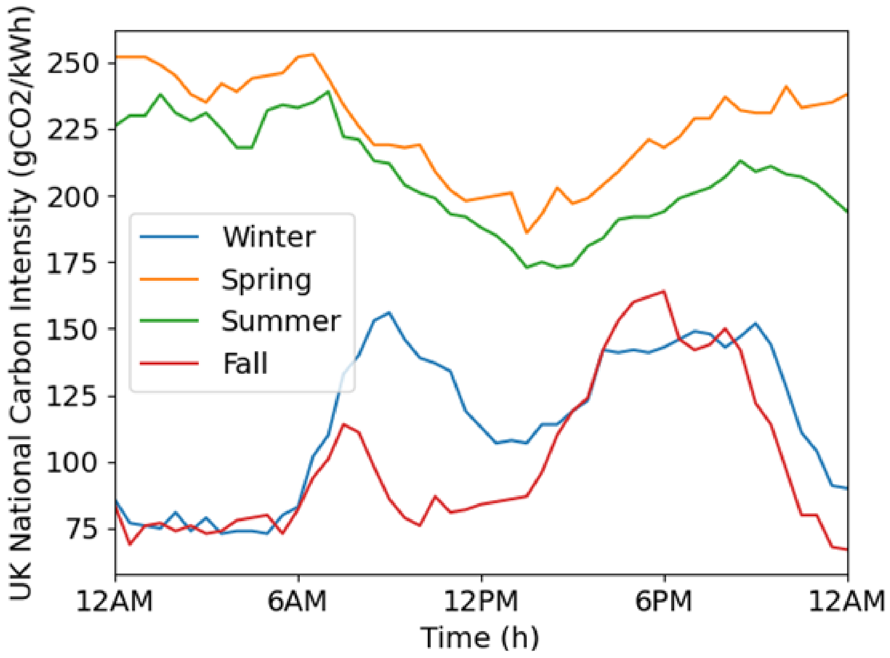


Carbon-related Metrics

Potential Metrics

Energy-related Metrics
- Typical Power
- Energy Rating
- Incremental Dynamic Power per Unit of Traffic

Carbon-related Metrics
- Carbon Intensity



Potential Metrics

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Energy-related Metrics
- Typical Power
- Energy Rating
- Incremental Dynamic Power per Unit of Traffic

Carbon-related Metrics
- Carbon Intensity
- Carbon Emissions
  - Product of energy consumption and carbon intensity
  - Energy consumption weighted over the previous interval of time (30 min or 1 hour)

Potential Metrics

Energy-related Metrics
- Typical Power
- Energy Rating
- Incremental Dynamic Power per Unit of Traffic

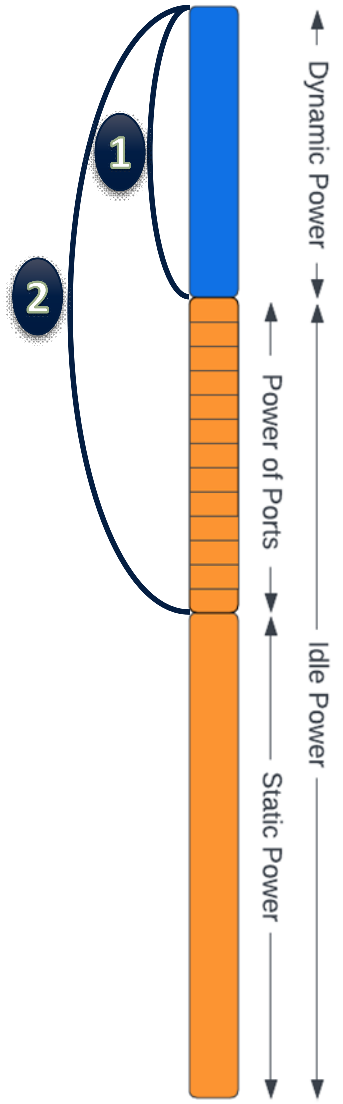
Carbon-related Metrics
- Carbon Intensity
- Carbon Emissions

→ Combinations of different metrics are also possible.

Approach

1. Change link costs based on the previous metrics

2. CATE: Carbon-Aware Traffic Engineering:
   - Pick the links with least utilization and highest carbon emissions, and shut them down
   - Check if graph is still connected
   - Check the improvement introduced

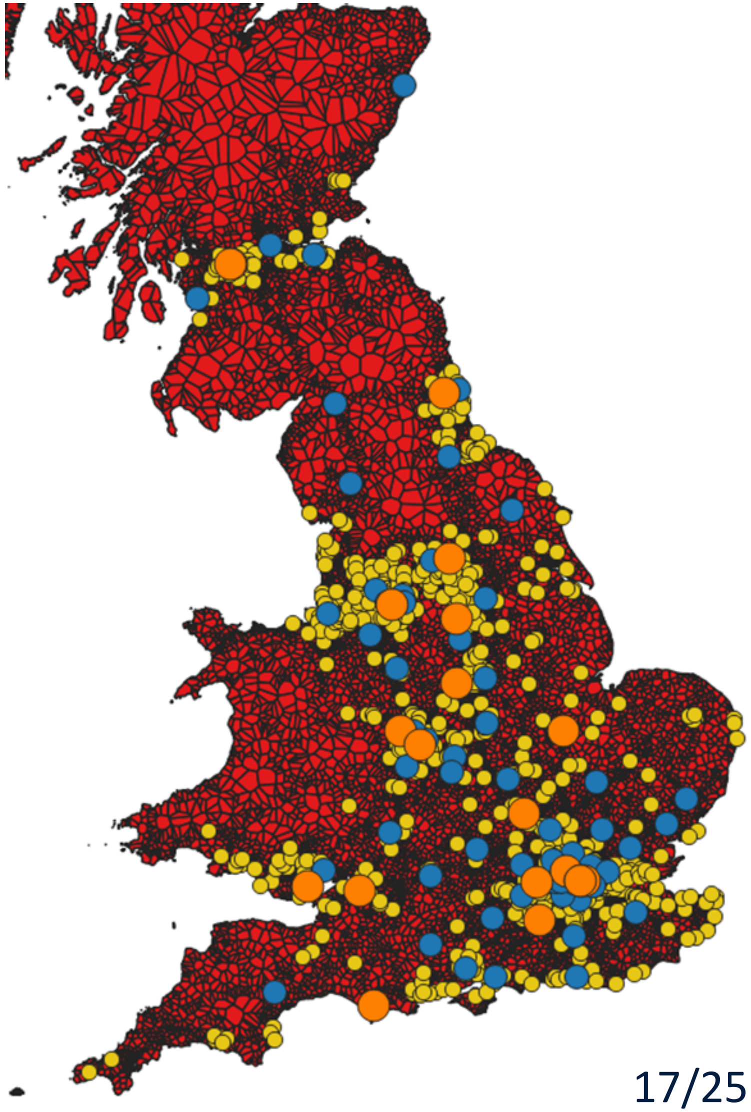


Approach

✓Simulation-based study using NS3 simulator

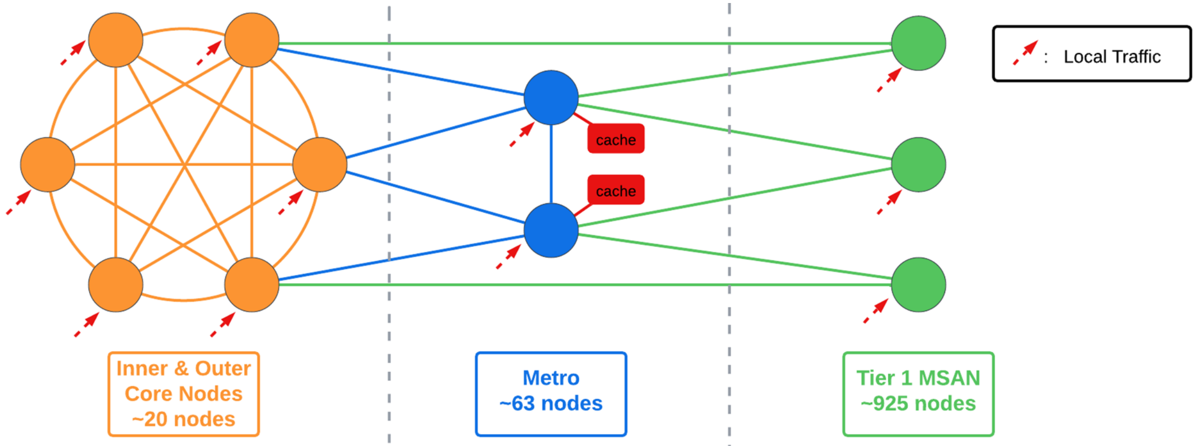
✓Real network topologies:

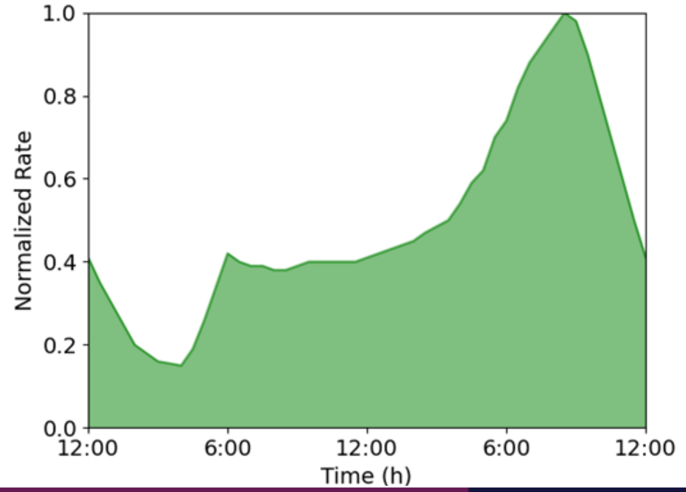
- BT in the UK
- GEANT in Europe



Traffic Patterns

- Day Traffic:
  - Business customers during working hours [9AM - 5PM]
  - Mostly symmetric (any-to-any)
- Evening Traffic:
  - Residential customer traffic dominates, peak between 7PM and 8PM
  - Predominantly downstream of content (90%) from content caches co-located within metro-nodes

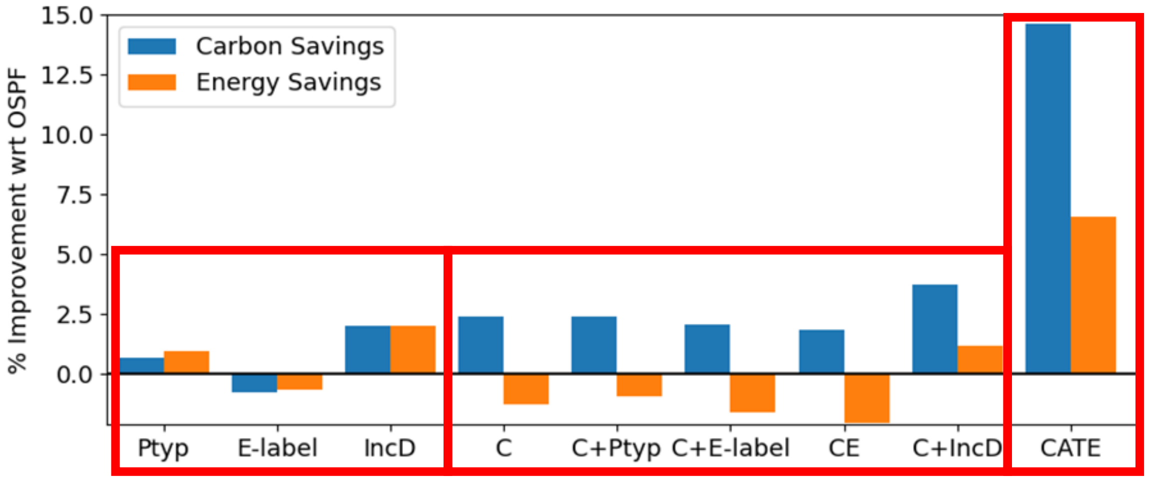




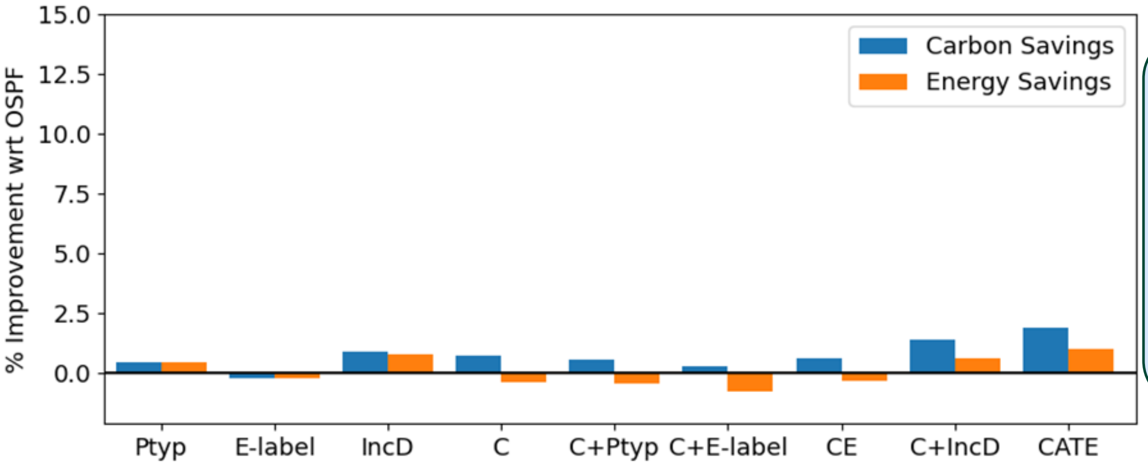
[Broadband ISP BT Sees UK Network Traffic Peak at 28Tbps - ISPreview UK]

Results: Carbon, Energy & Delay

- Carbon intensity-based metrics save carbon at the expense of path stretching of 5%
- Carbon intensity + Incremental dynamic power per unit traffic are the best combination
- CATE has the highest savings (shutting down unnecessary ports)
- Savings are negligible for evening-traffic (very short paths)



Carbon & Energy Savings for Day-Traffic



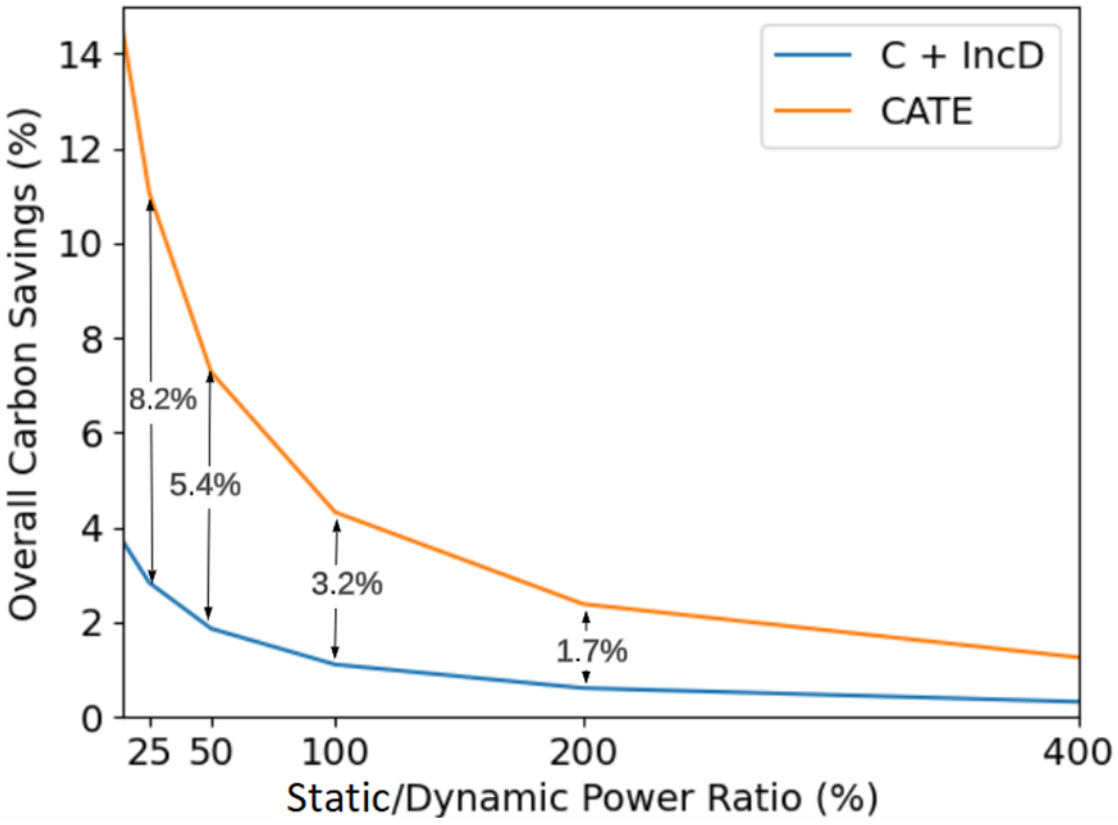
Carbon & Energy Savings for Evening-Traffic

Legend:
Ptyp: Typical Power
E-label: Energy Label
IncD: Incremental Dynamic Power per Unit Traffic
C: Carbon Intensity
CATE: Carbon-Aware Traffic Engineering

Results: Static/Dynamic Ratio

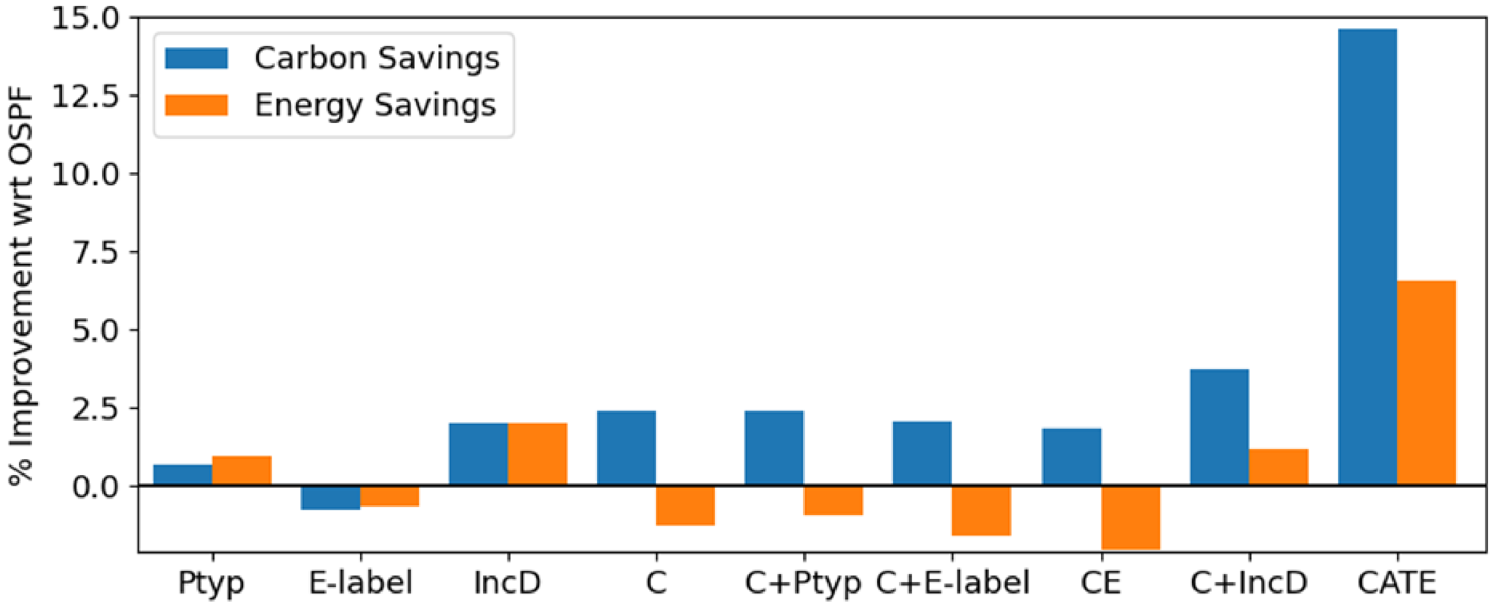
- Different routers have different ratios of static/dynamic power
  - Architecture and design decisions
  - Increased efficiency over time
- Example: chassis-based routers have a high static power for the chassis
- Improvement of carbon-aware routing diminishes as the static/dynamic ratio increases

→ Invest in replacing equipment with ones of **low static power** and **higher dynamic power ratio**



Summary

1. Carbon intensity + Incremental dynamic power per unit traffic are the best combination of metrics



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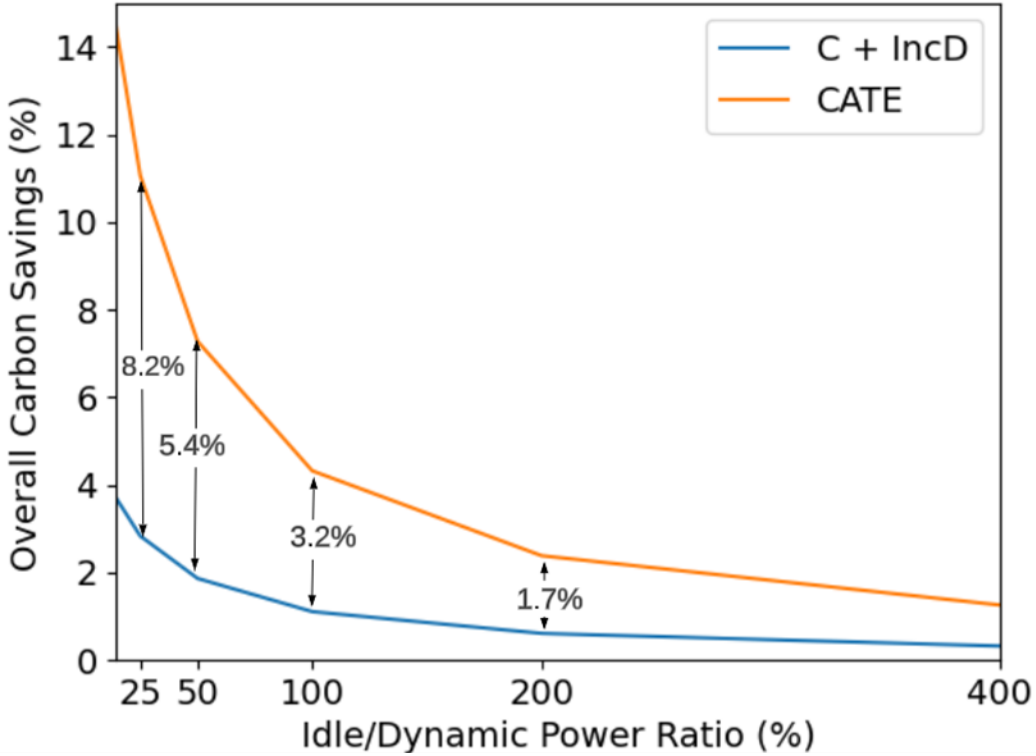
1. Carbon intensity + Incremental dynamic power per unit traffic are the best combination of metrics
2. High idle power limits carbon savings



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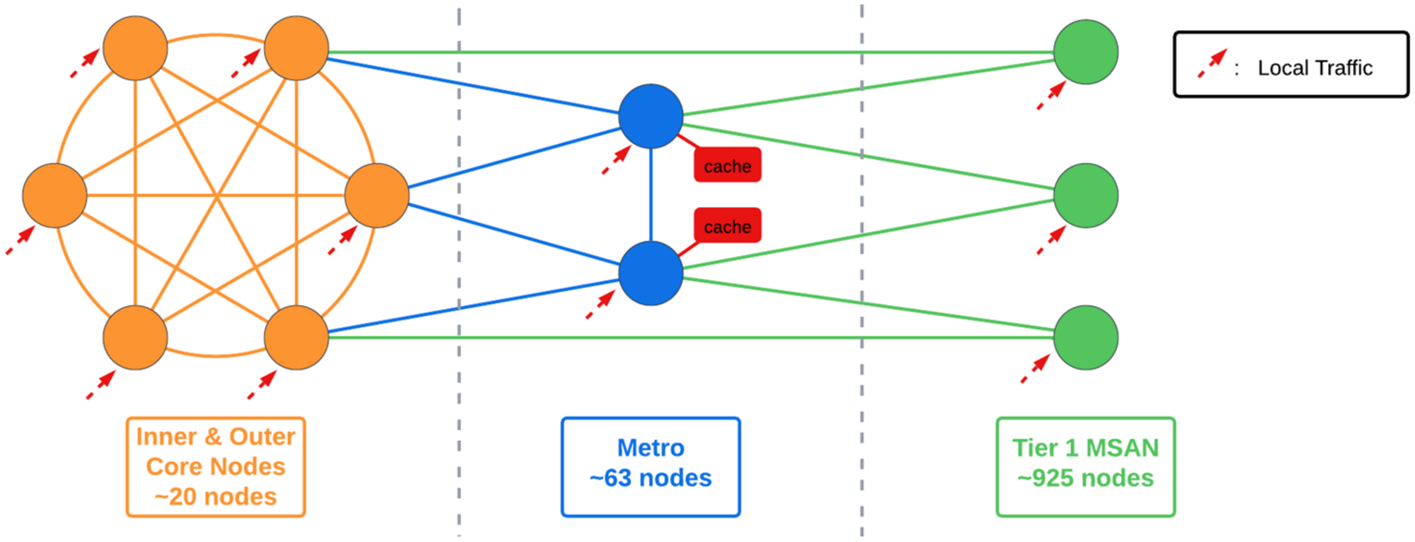
3. Carbon optimization is application-specific



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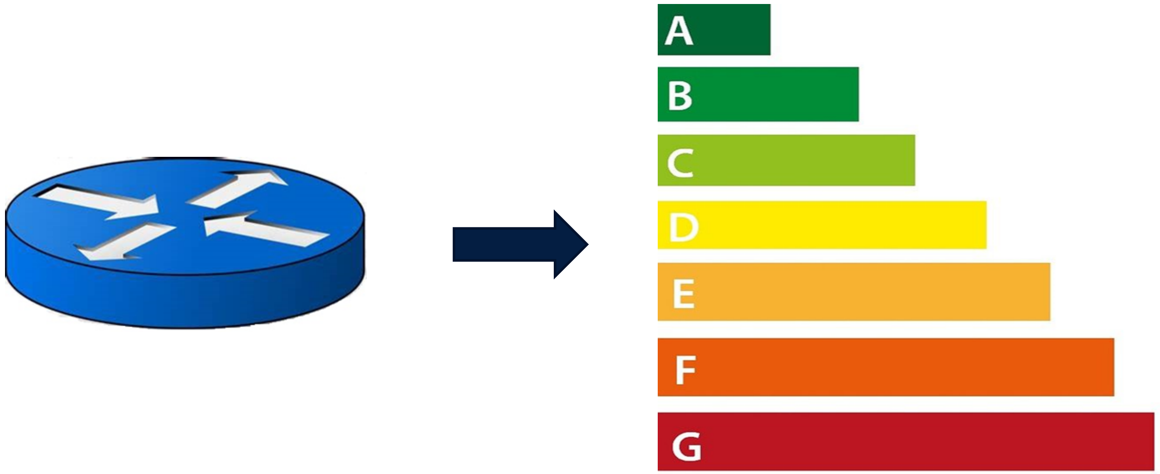
2. High idle power limits carbon savings
3. Carbon optimization is application-specific
4. Energy labels: good for purchasing, limited routing benefits



Thank you