Exploring The Benefits of Carbon-Aware Routing

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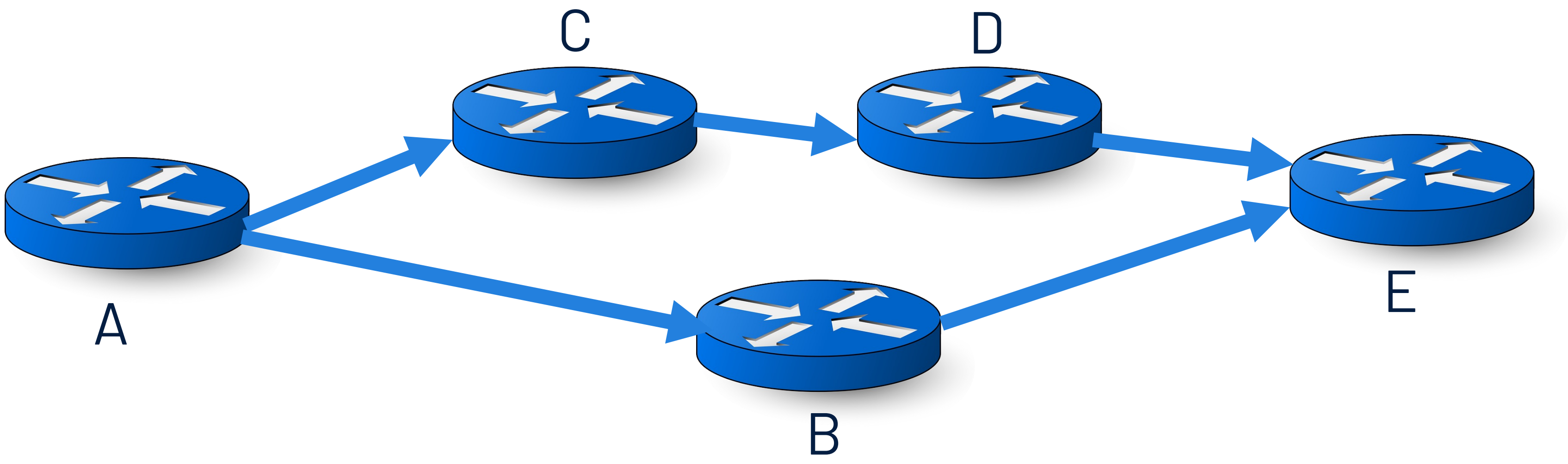
Toward Net Zero Internet

- Net zero by 2050!
- A large hyperscaler consumes 10-20 TWh/year
- A large ISP consumes 3-6TWh/year
- But there are a lot more ISPs...
- **The carbon emissions of the network are not negligible!**

Motivation

- Previous work focused on **energy** efficiency
- **Carbon** efficiency is a new optimization problem



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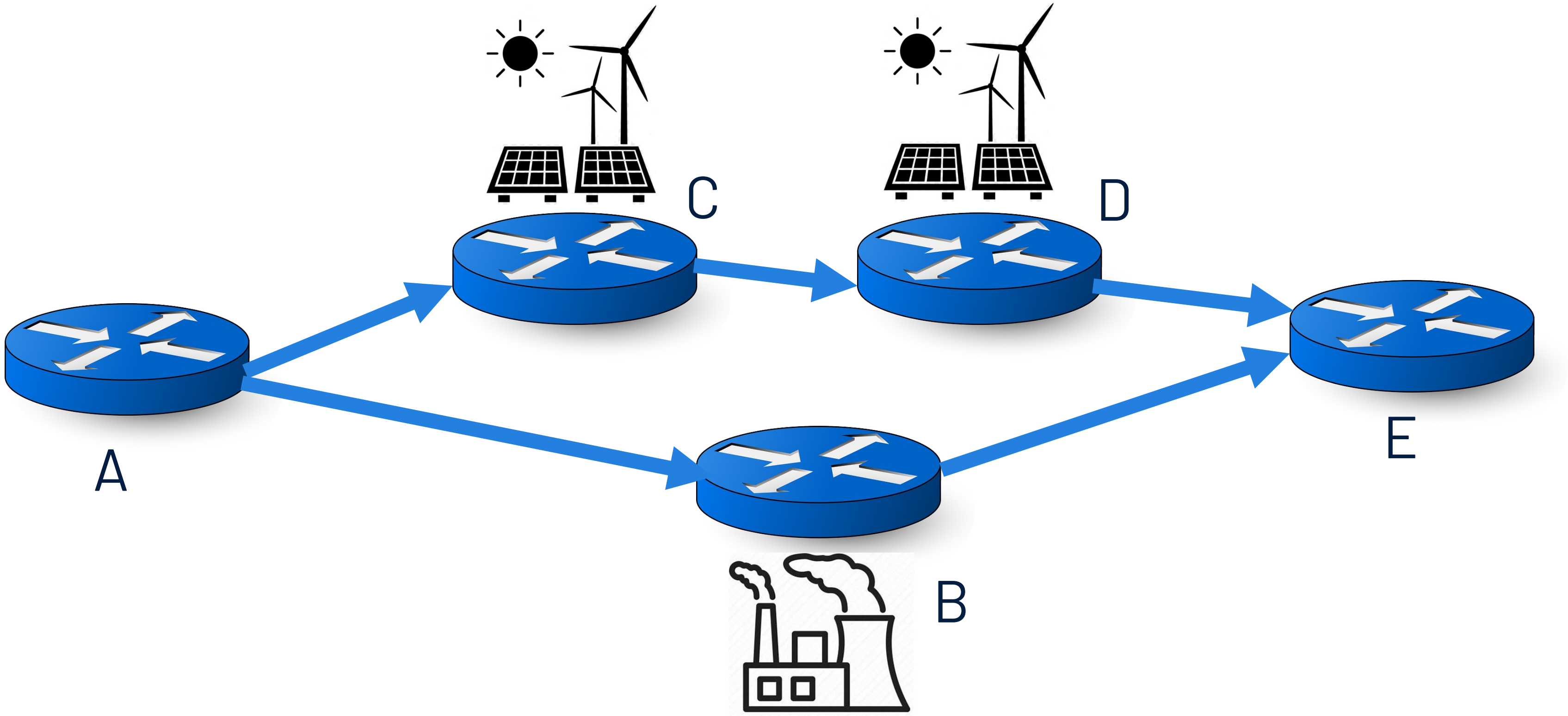
- Adds the energy mix variation per region to the routing



Motivation

- Previous work focused on **energy** efficiency
- **Carbon** efficiency is a new optimization problem
- Adds the energy mix variation per region to the routing
- **Opportunity:** energy mix of the grid is predictable per region

- **Goal: quantify the potential benefits of carbon-aware routing**
- **Scope: routing, operational carbon emissions of routers**

Carbon Footprint

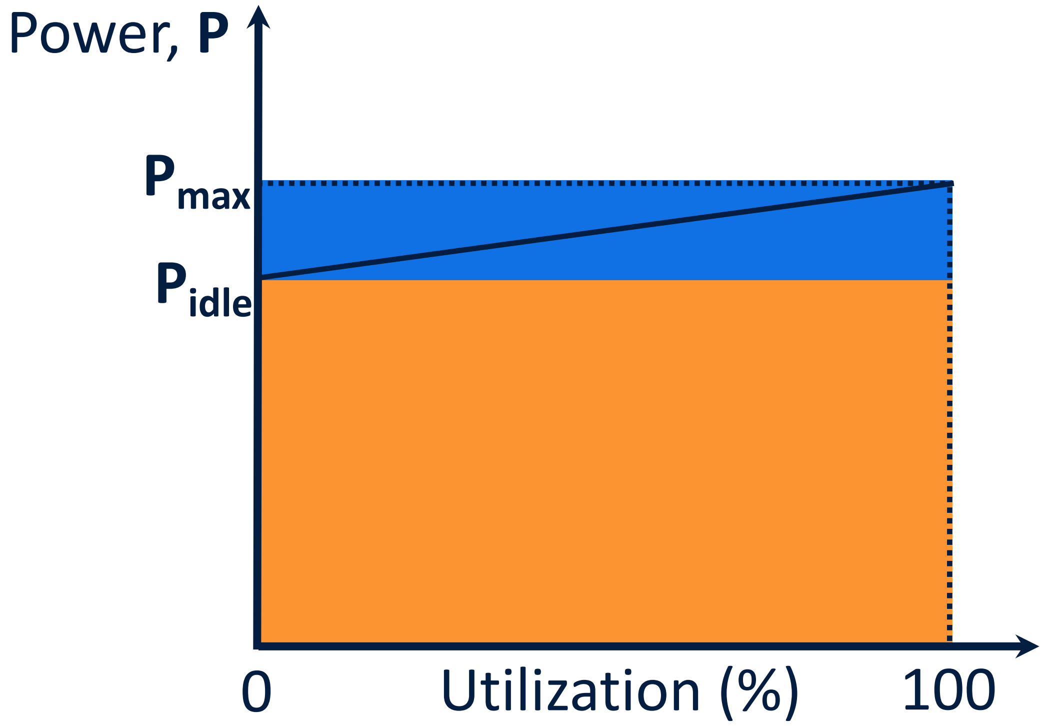
- Carbon emissions relate to:
  - Amount of energy consumed
  - Source of energy
  - Weighted carbon emissions associated with the source

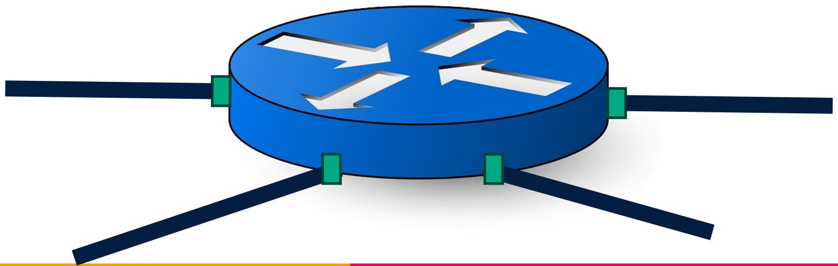
Carbon Footprint

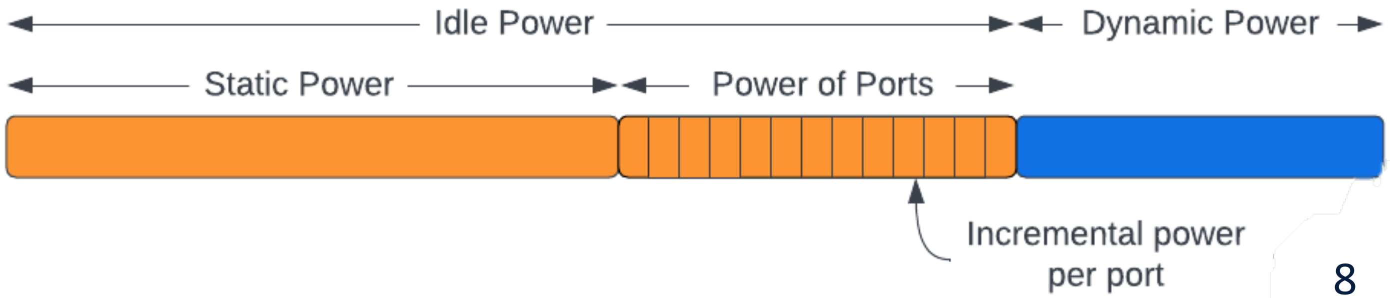
- Carbon emissions relate to:
  - Amount of energy consumed
  - Carbon Intensity

Energy Consumption

- Dynamic Power: proportional to the utilization
- Idle Power is composed of:
  - Static Power
  - Power of Ports

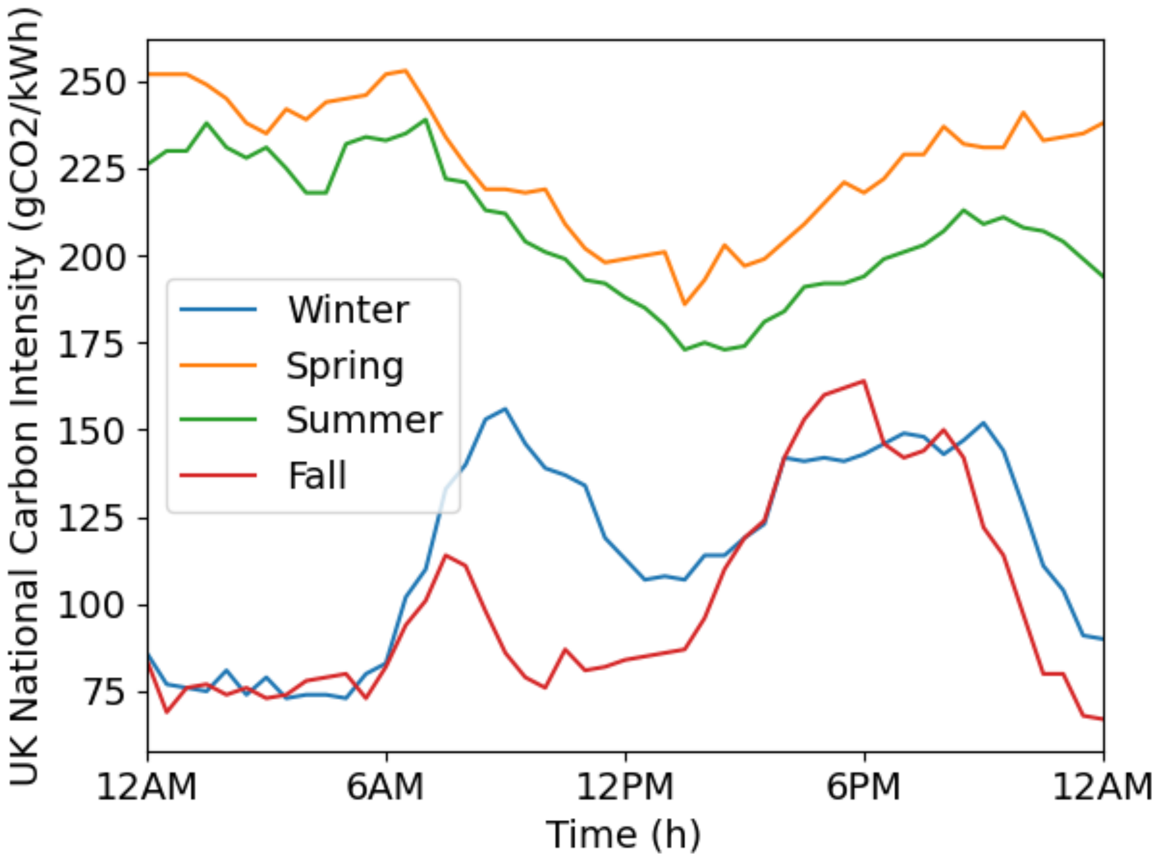






Carbon Intensity

- Unit: gCO_2/kWh
- Carbon intensity varies:
  - per day
  - per season
  - per region
- Can noticeably change within a few hours
- Can be forecasted up to 24-48 hrs beforehand



Carbon Intensity API

Potential Metrics

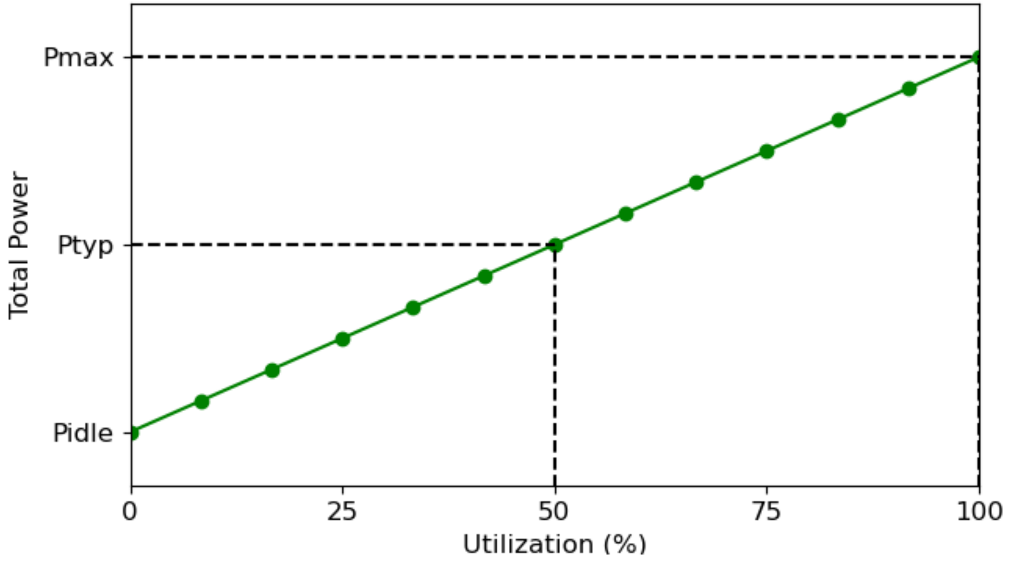
Energy-related Metrics

Carbon-related Metrics

Potential Metrics

Energy-related Metrics

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

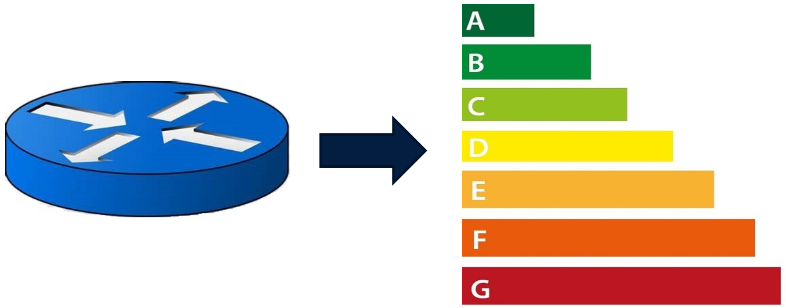


Carbon-related Metrics

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

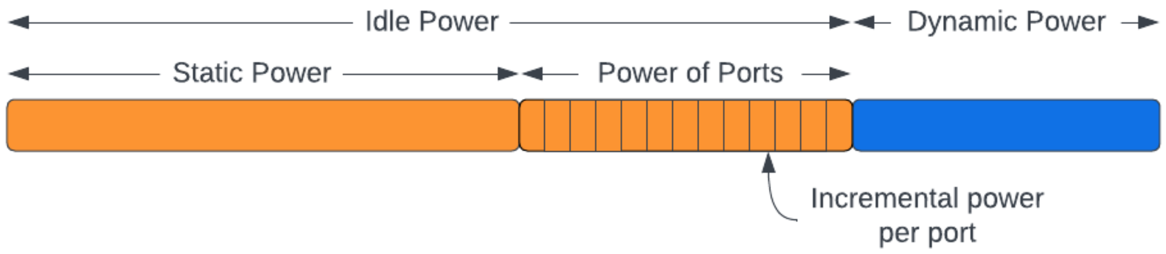


Carbon-related Metrics

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
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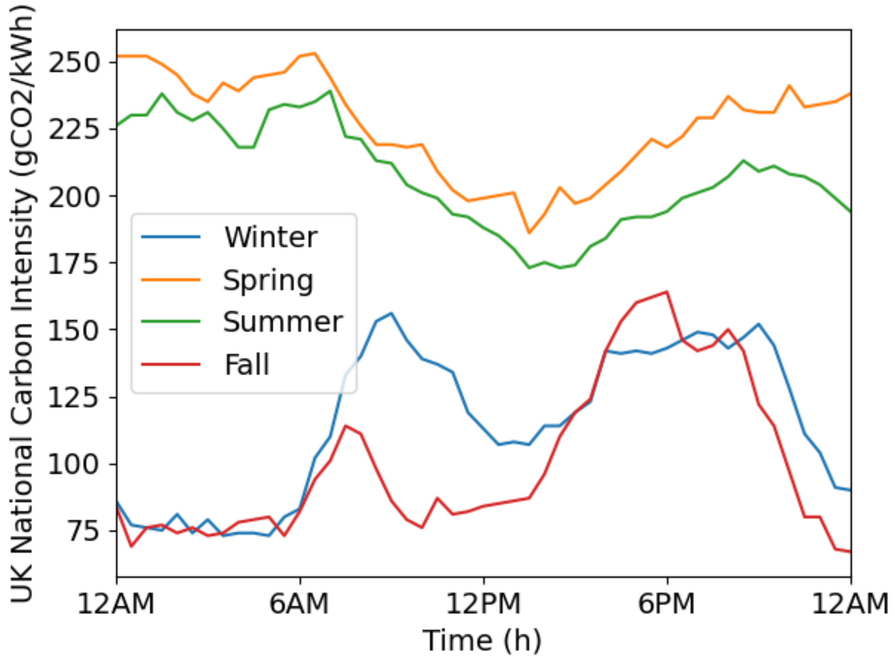
- Incremental Dynamic Power per Unit of Traffic

Carbon-related Metrics

- Carbon Intensity



Potential Metrics

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

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

Potential Metrics

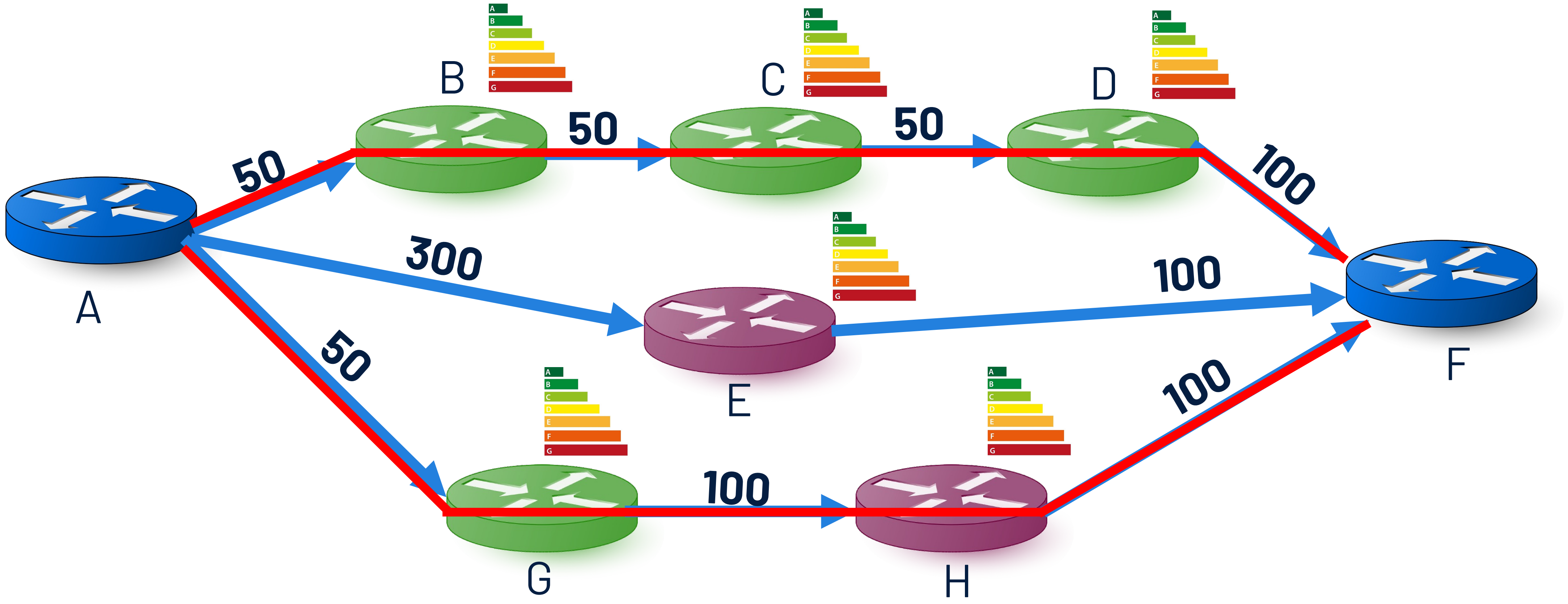
Energy-related Metrics
- Typical Power
- Energy Rating
- Incremental Dynamic Power per Unit of Traffic

Carbon-related Metrics
- Carbon Intensity
- Carbon Emissions

→ Combinations of different metrics are also possible

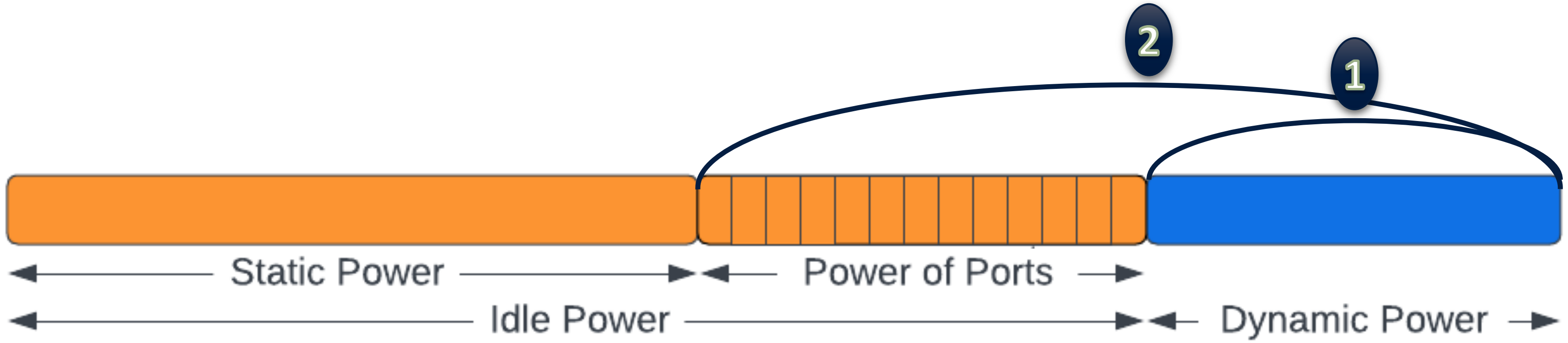
Approach

1. Change link costs based on the previous metrics



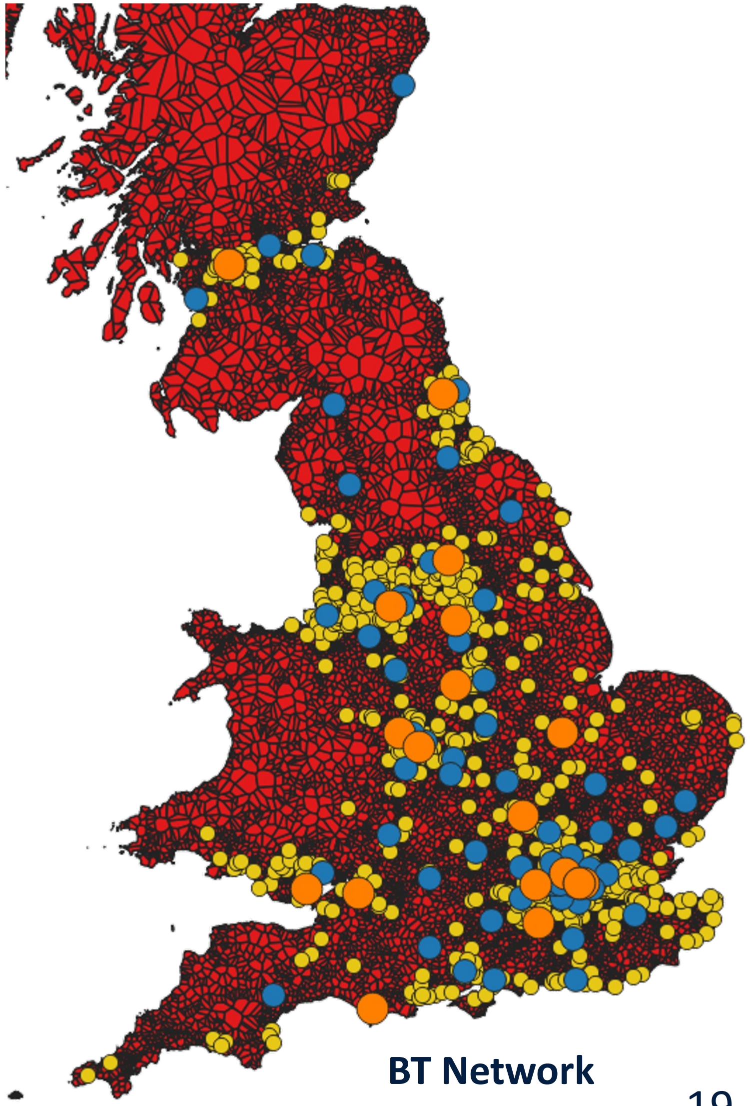
Approach: CATE

2. CATE: Carbon-Aware Traffic Engineering
   - Shut down links with least utilization and highest carbon emissions
   - Check if graph is still connected (+redundancy)
   - Check the improvement introduced



Approach

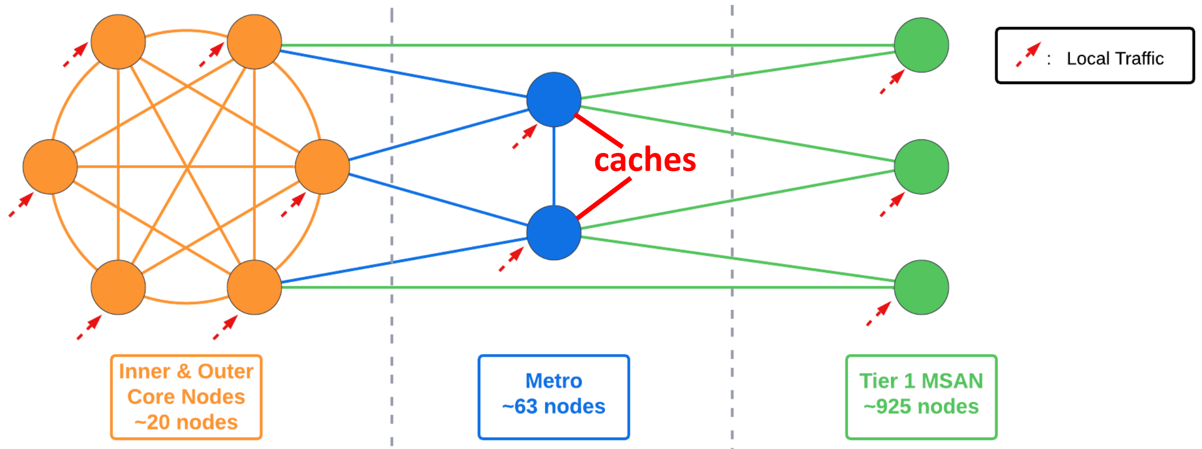
- Simulation-based study using ns-3 simulator
- Network topologies:
  - British Telecom (BT) in the UK
  - GEANT in Europe



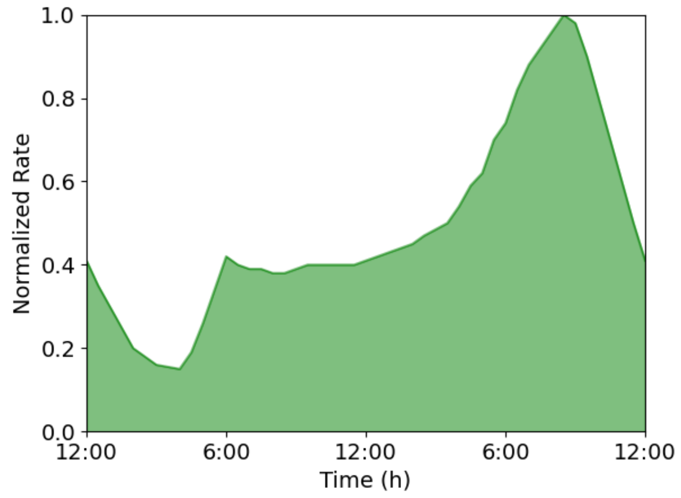
BT Network

Traffic Patterns

- Day Traffic:
  - Business customers during working hours [9AM - 5PM]
  - Mostly symmetric (any-to-any)
  - Overall throughput is almost constant



BT Network Topology

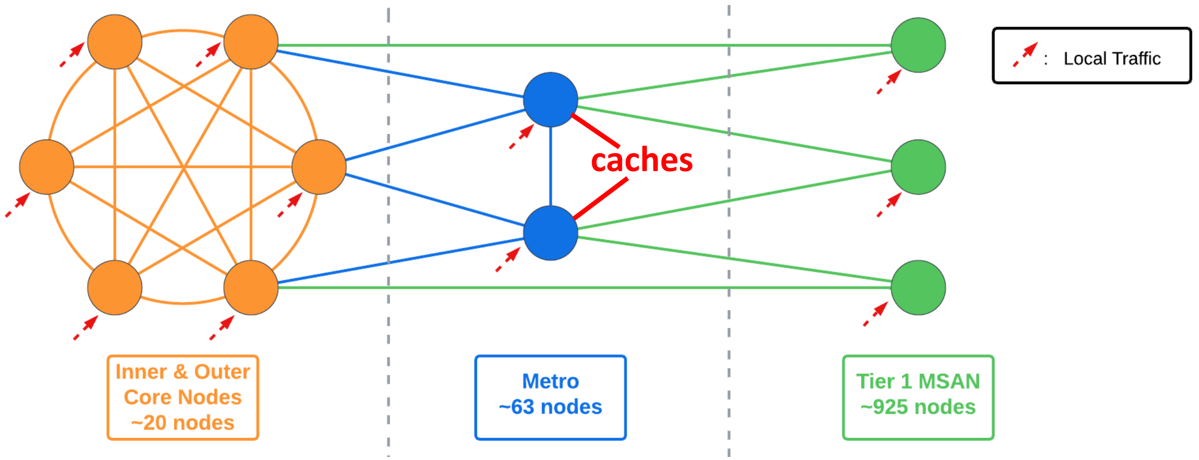


Normalized Network Traffic

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

Traffic Patterns

- Evening Traffic:
  - Residential customer traffic dominates
  - Predominantly downstream of content (90%) from content caches co-located within metro-nodes (for BT)
  - Peak between 7PM and 8PM



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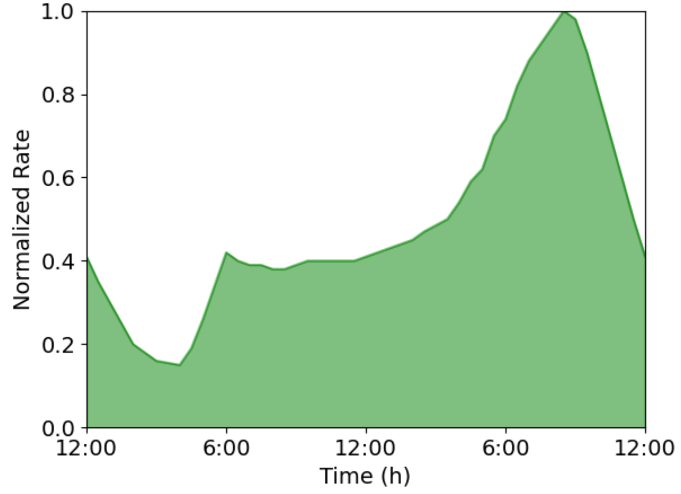

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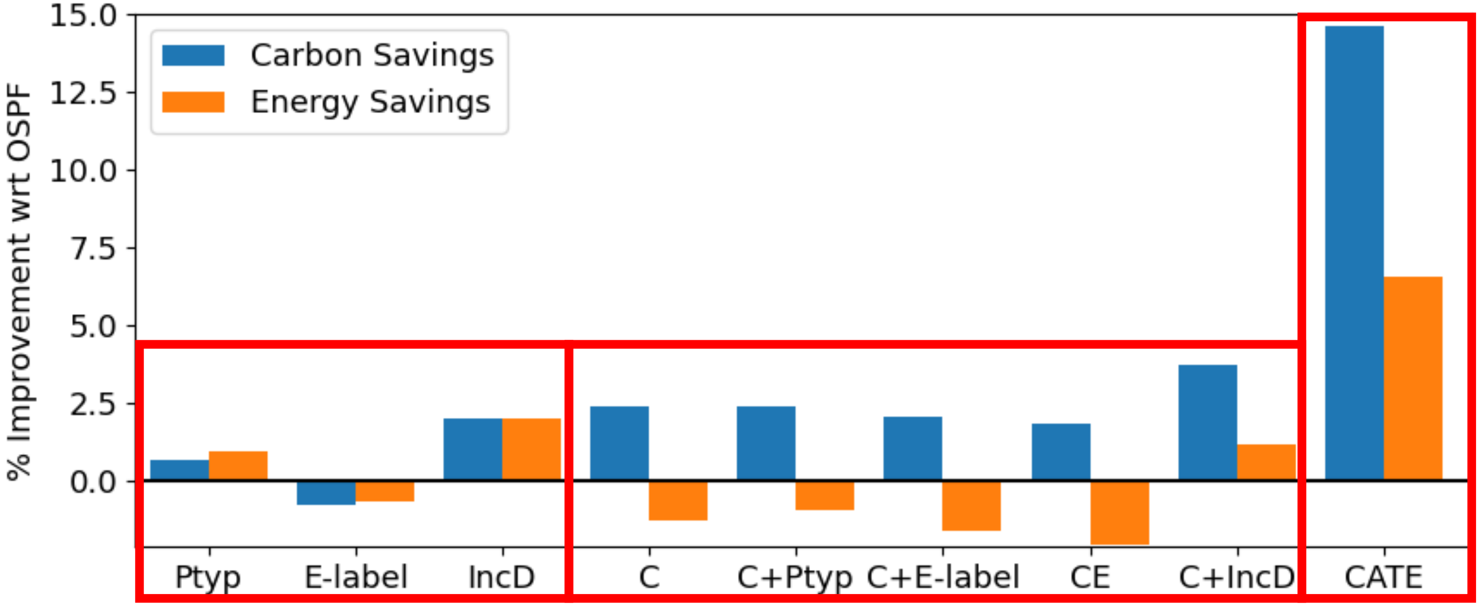
Results: Carbon & Energy (BT)

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



Carbon & Energy Savings for Day-Traffic

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

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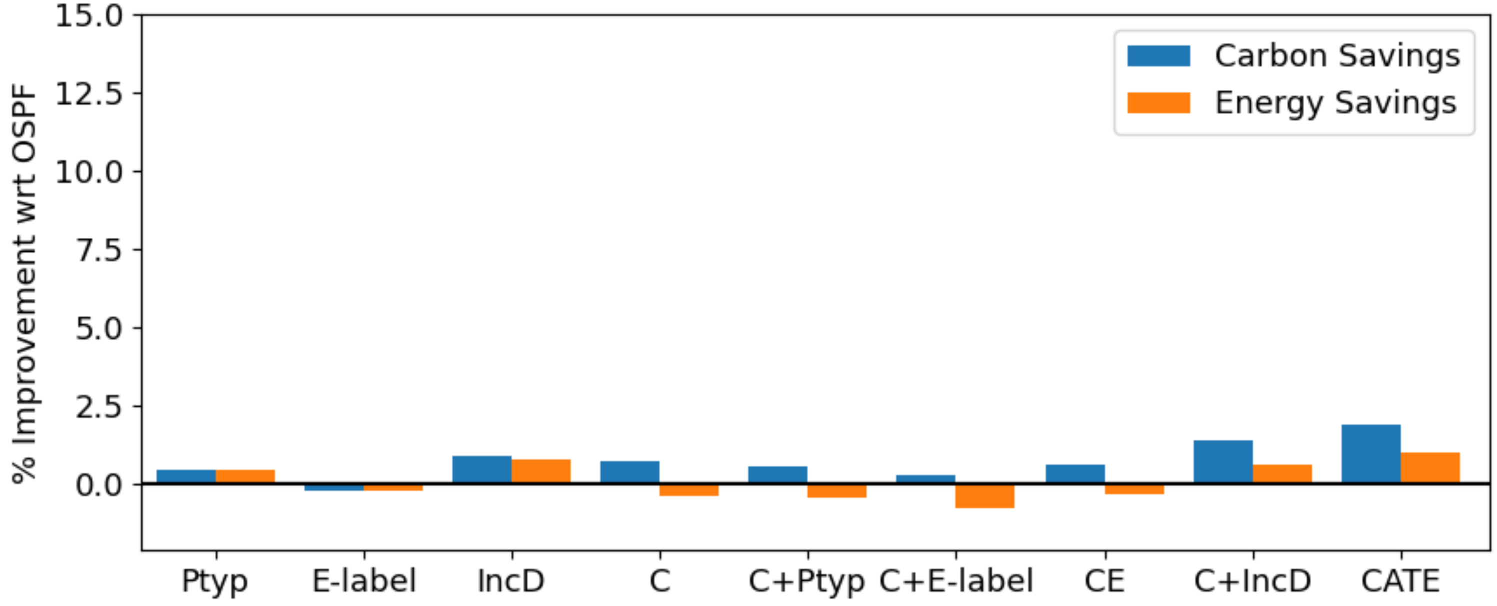

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Results: Flow Intensity (BT)

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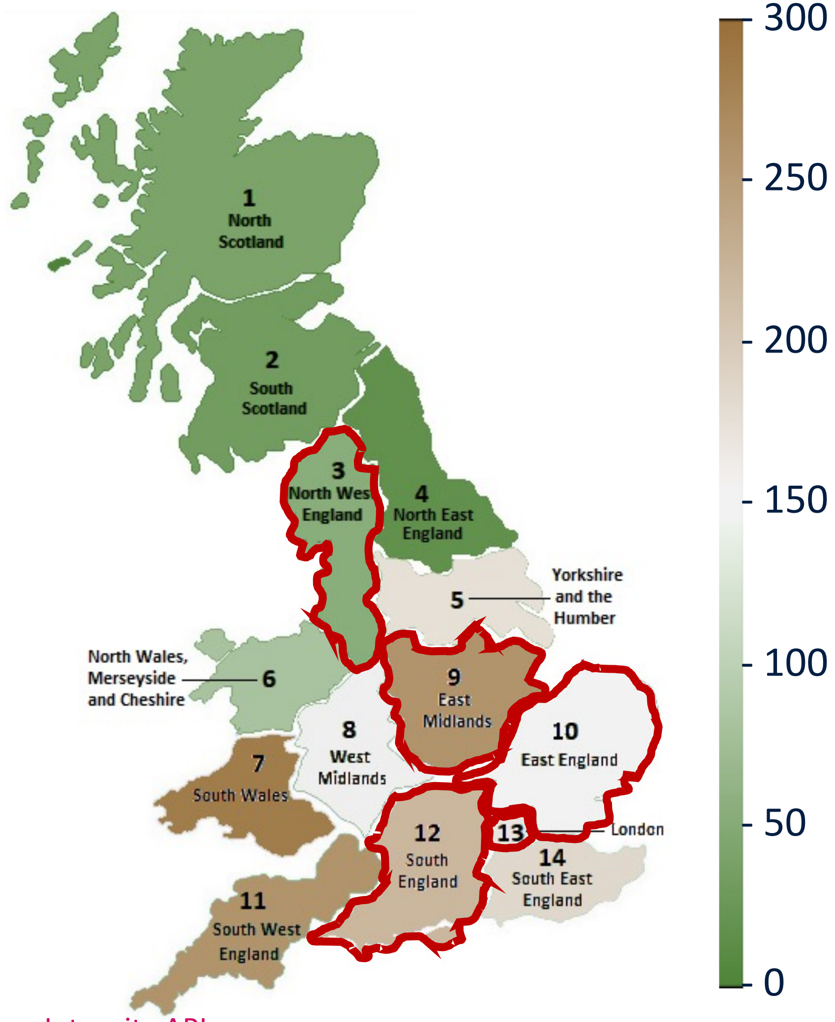
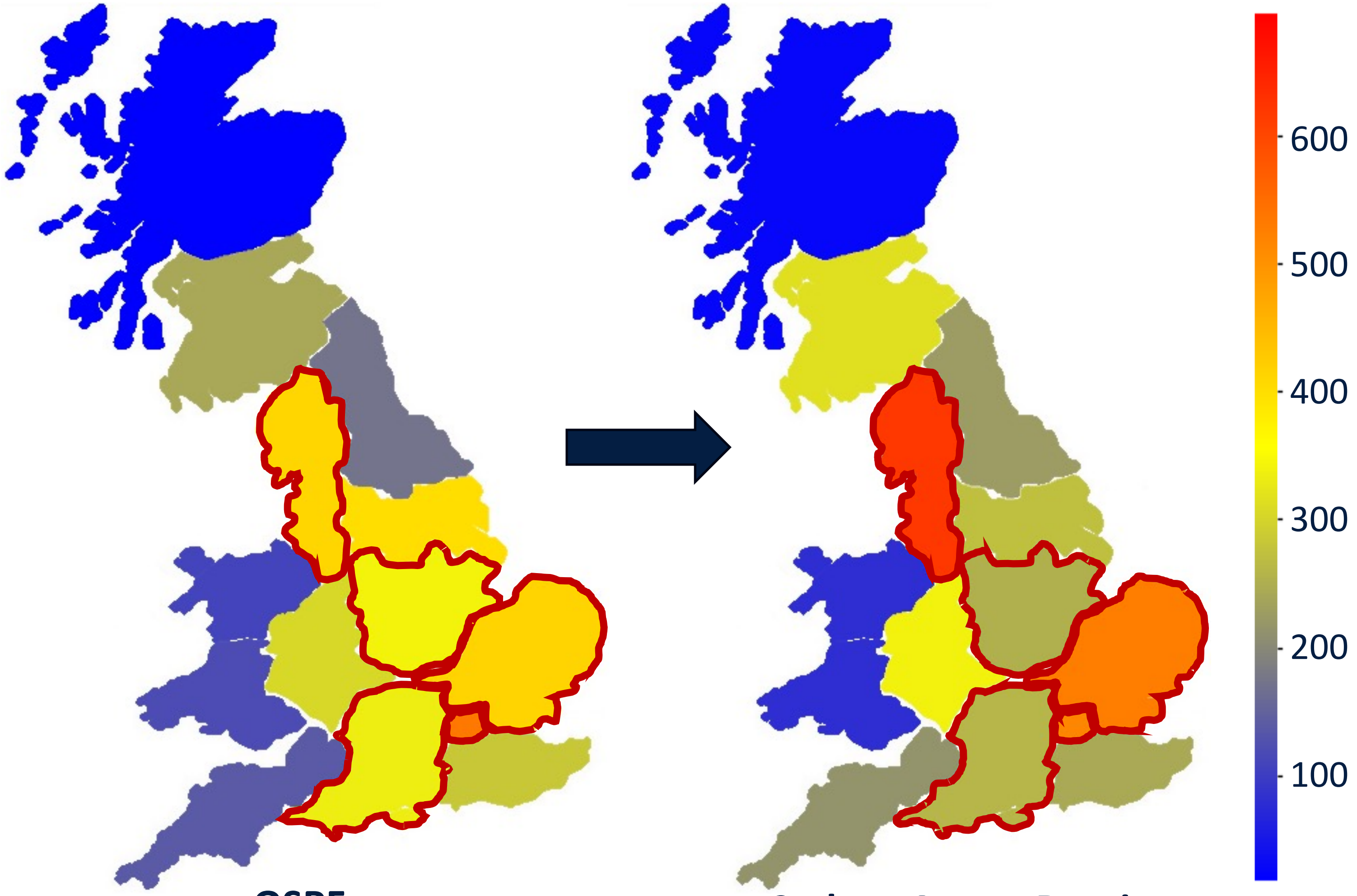
Carbon Intensity in gCO2/kWh



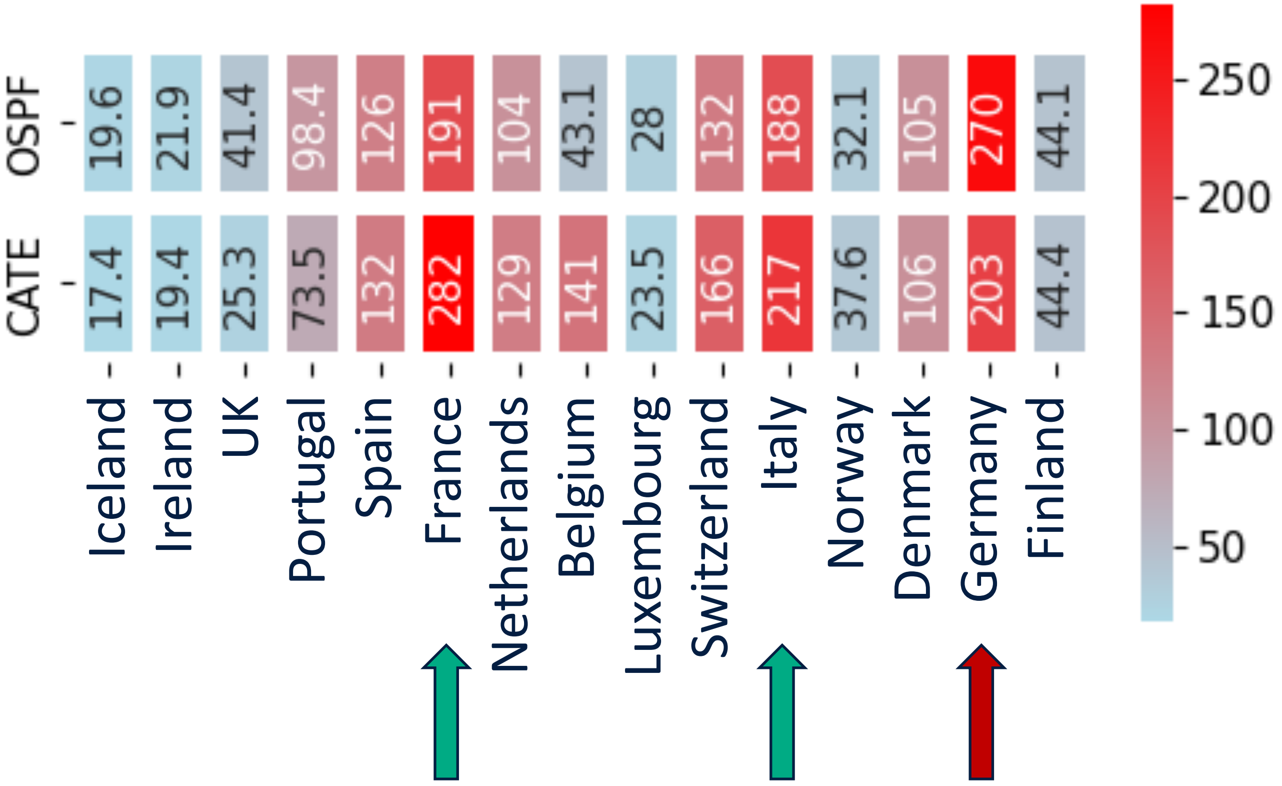
Flow Intensity in Gbps

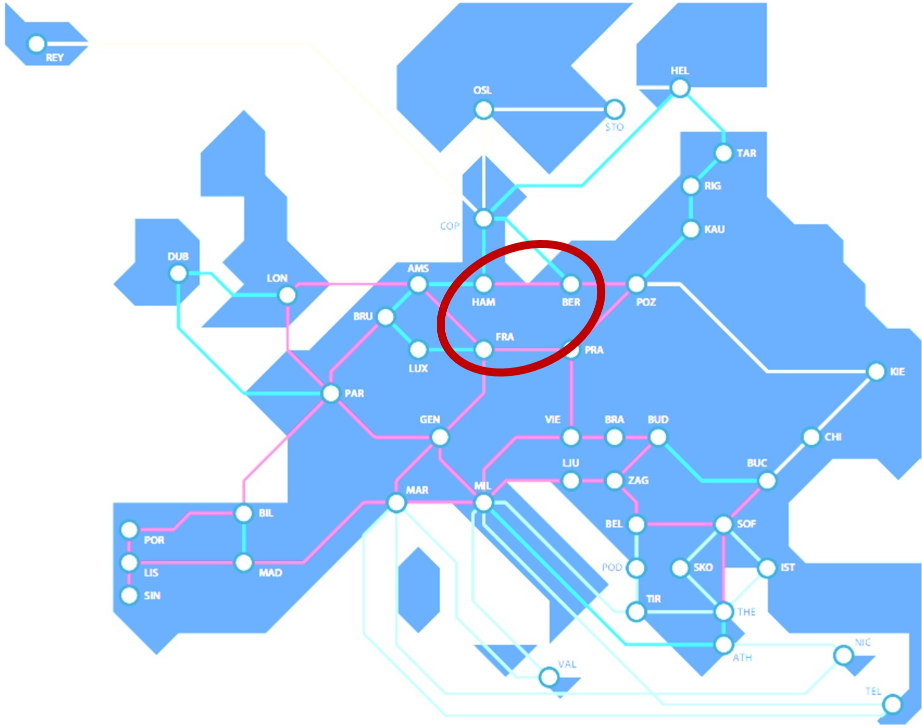


OSPF **Carbon-Aware Routing**

Carbon Intensity API

Results: Flow Intensity (GEANT)



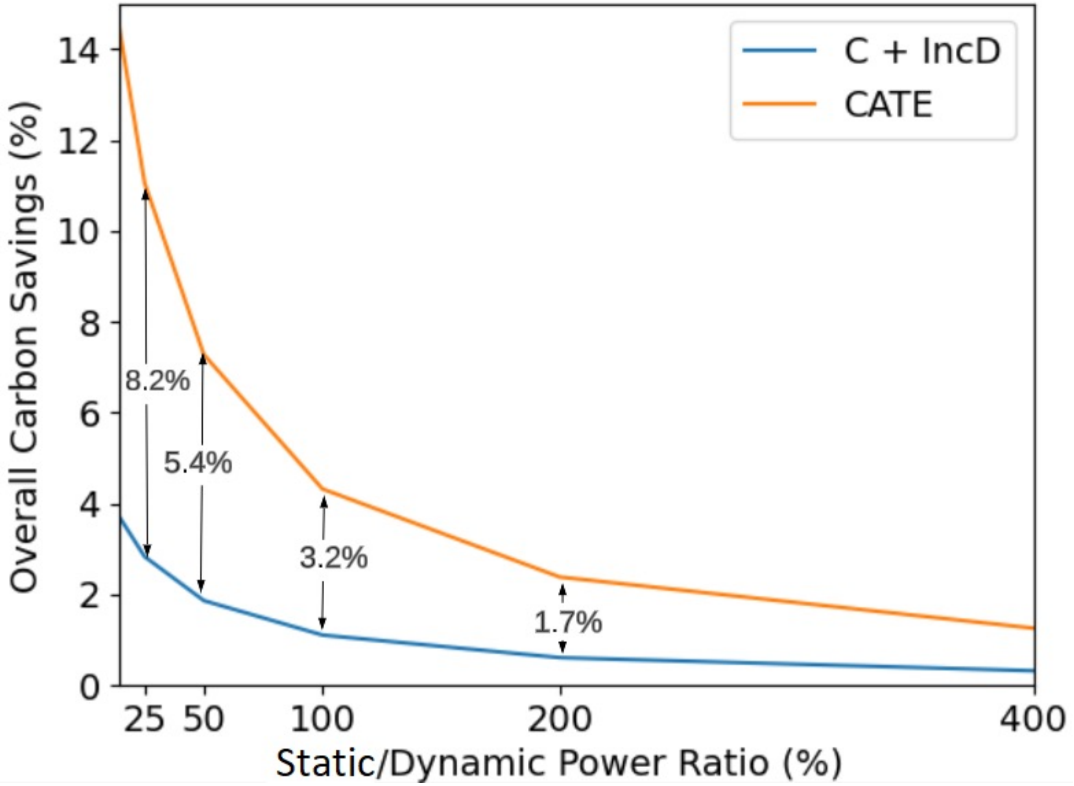


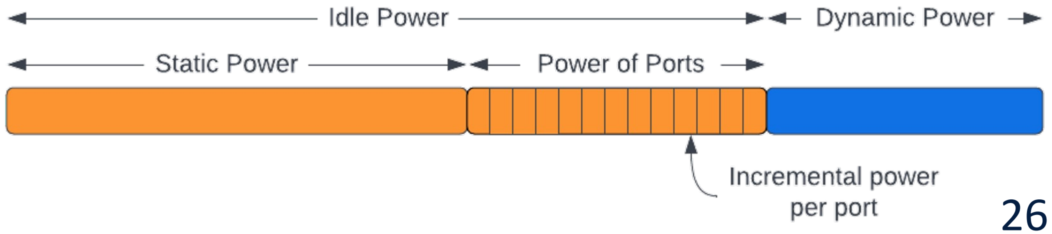
GEANT Network Map
source: geant.org

Results: Static/Dynamic Ratio

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

→ Invest in replacing equipment with **lower static power** routers





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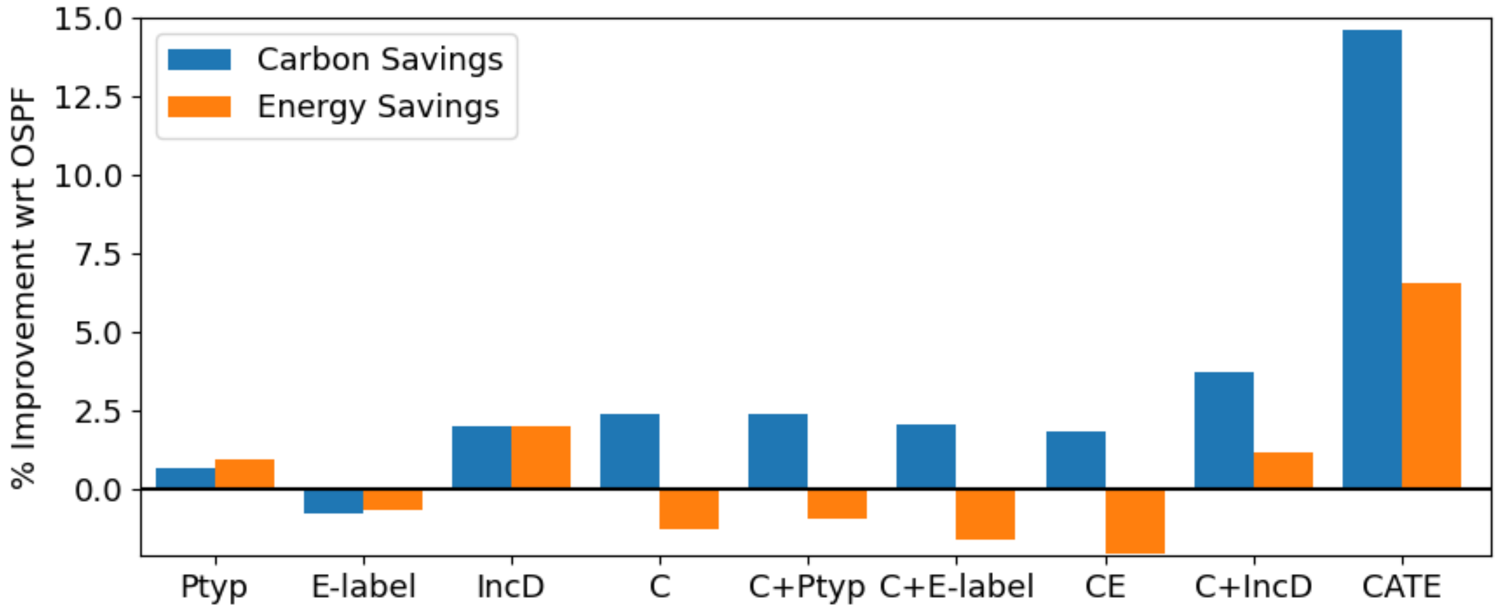
1. Carbon intensity + Incremental dynamic power are the best combination of metrics



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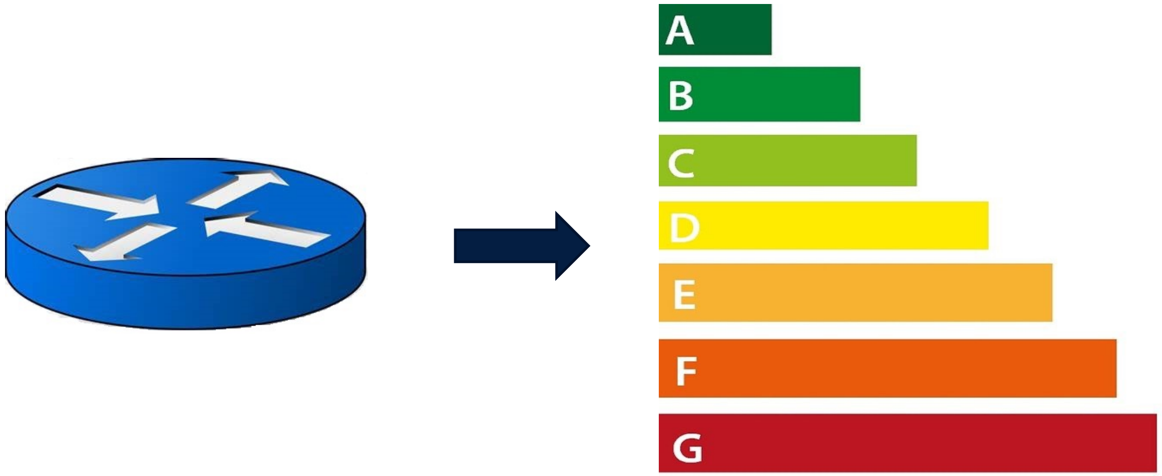

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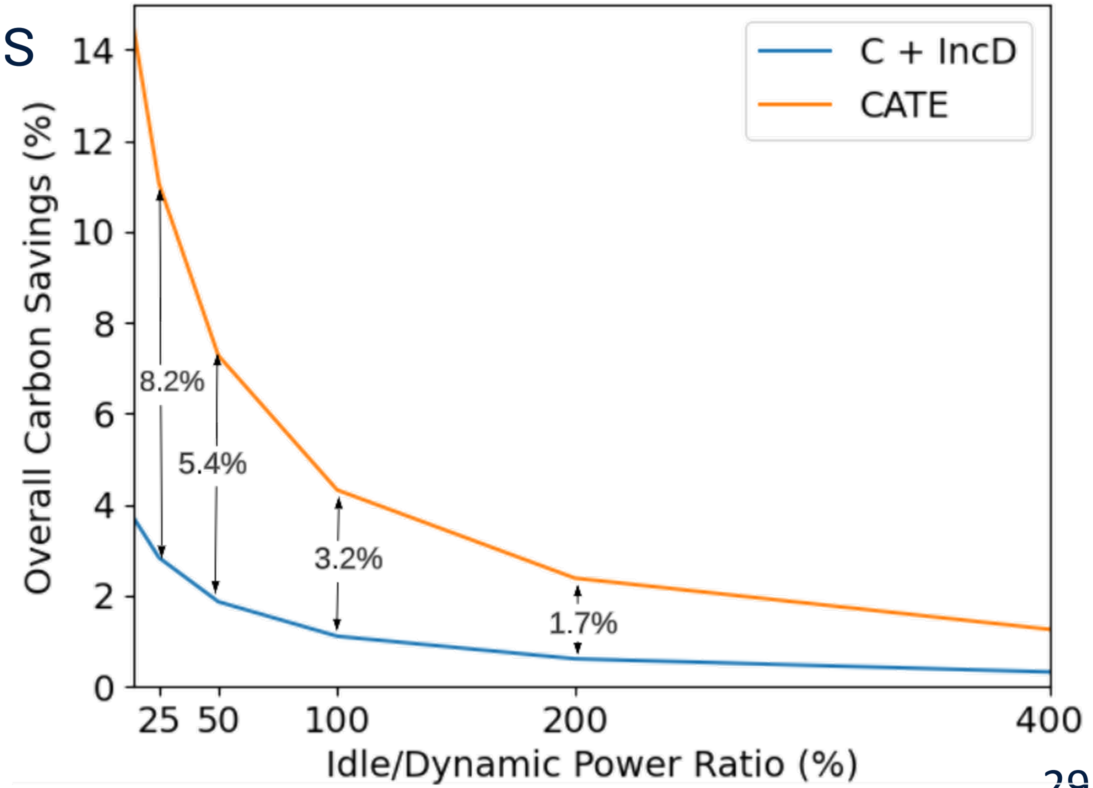

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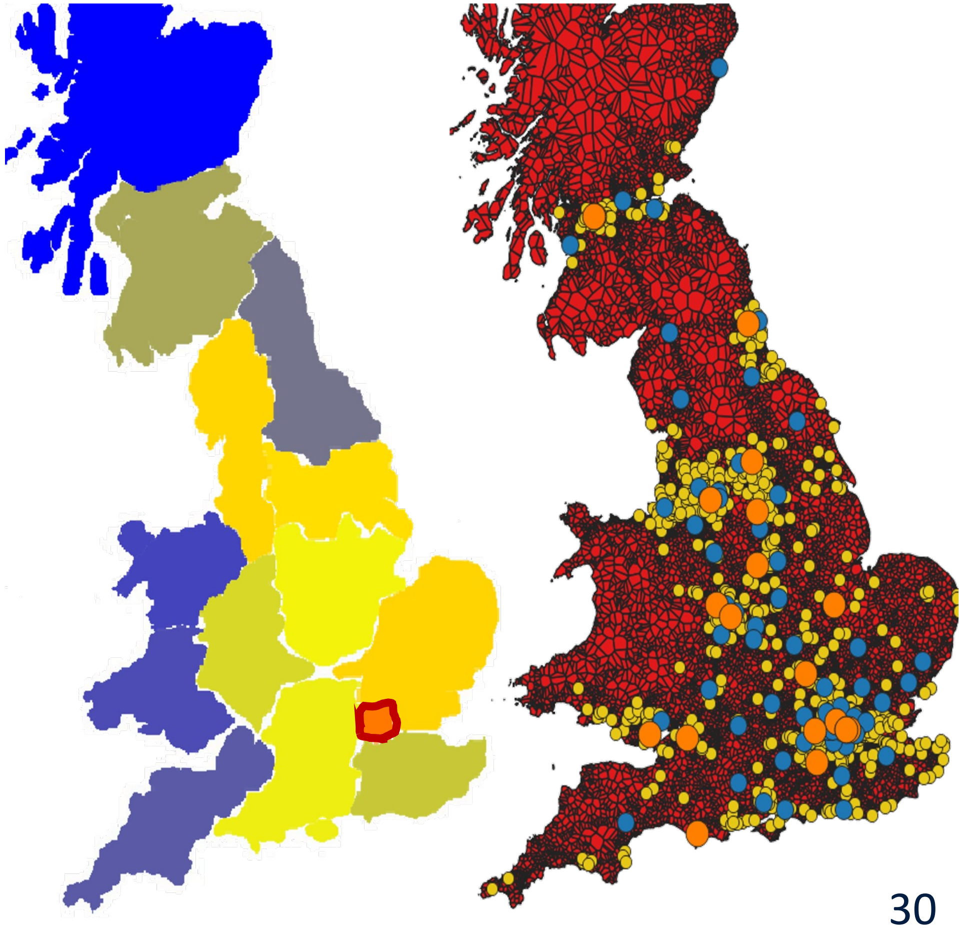

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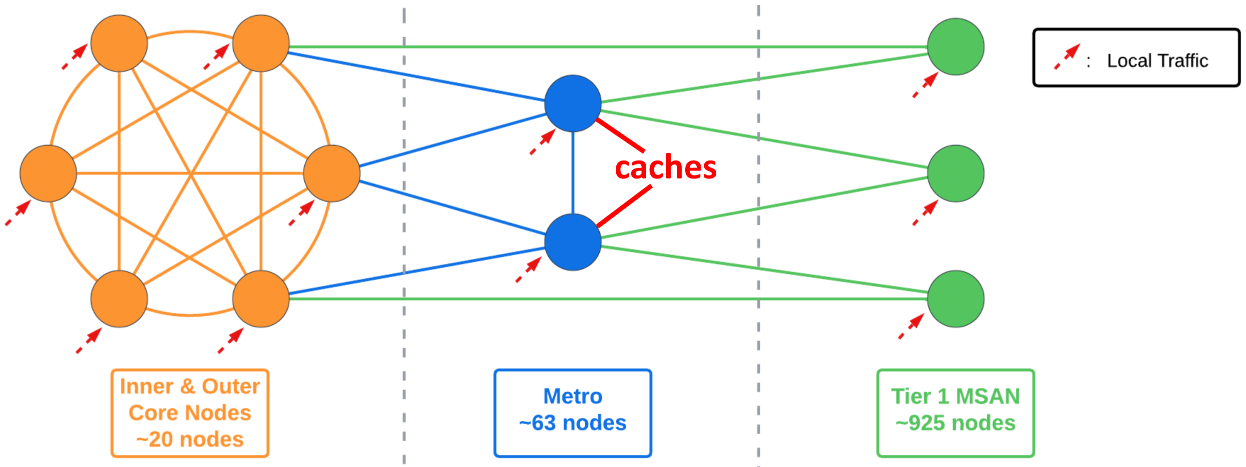
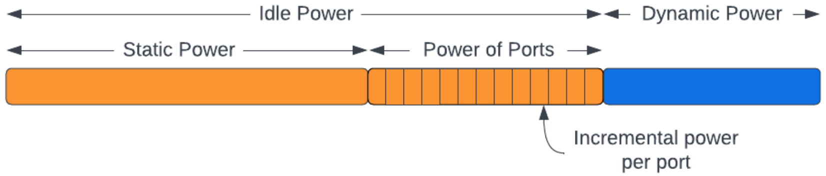
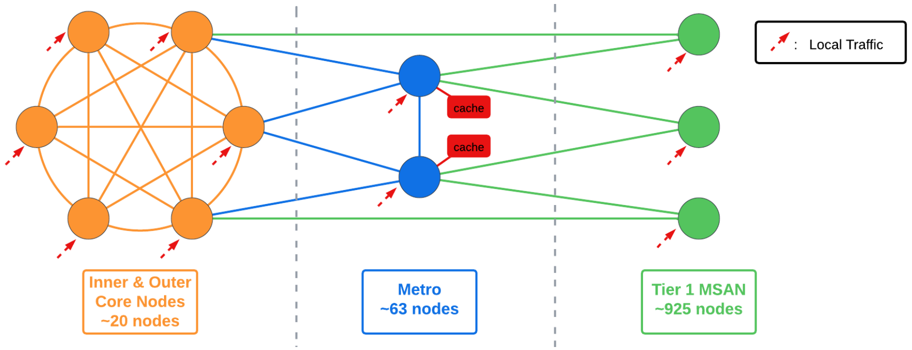
3. High idle power limits carbon savings
4. Routing bottlenecks limit carbon savings
5. Carbon optimization is application-specific

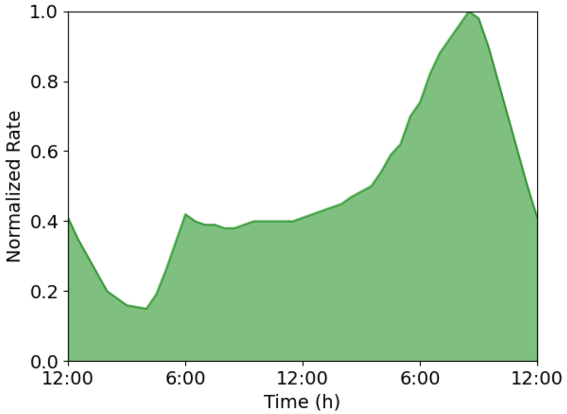


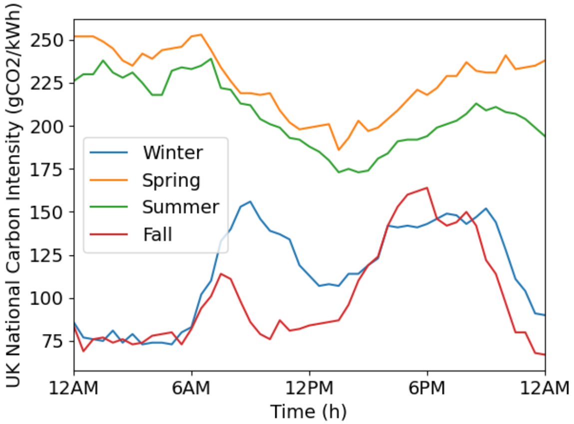
Questions?

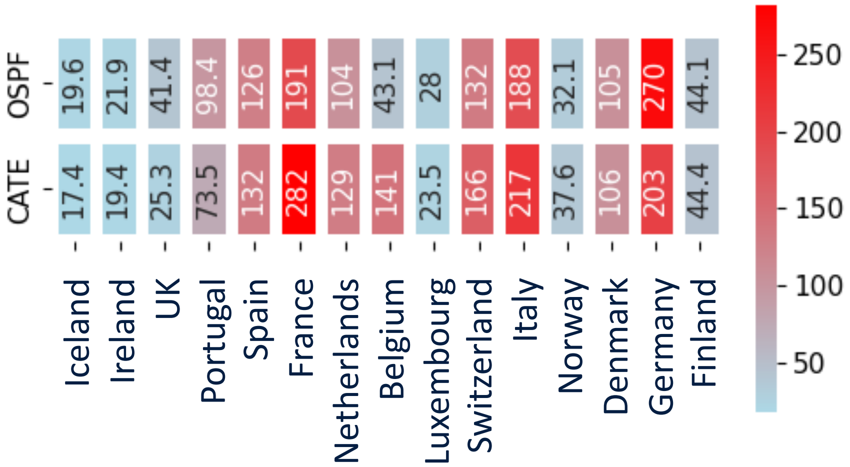


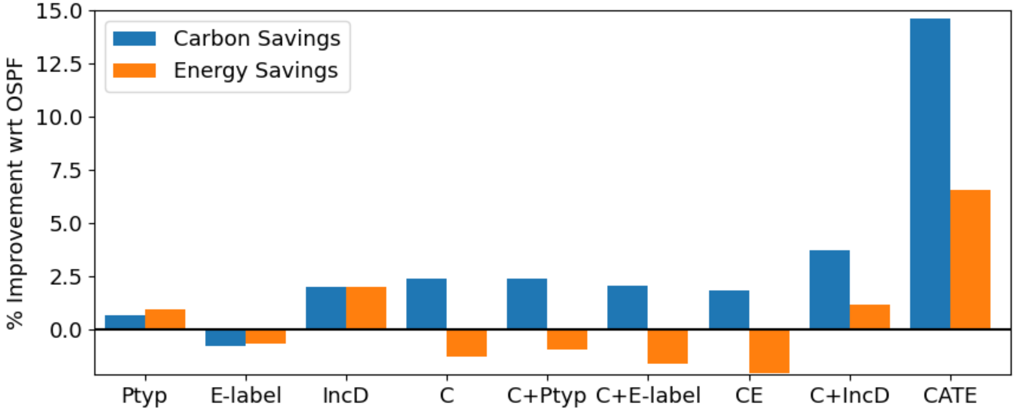
Code is available! https://github.com/ox-computing/CATE



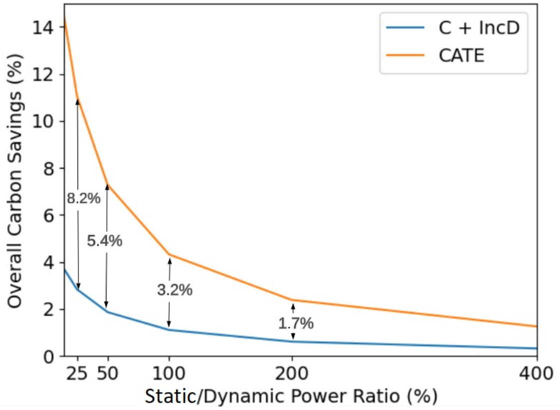








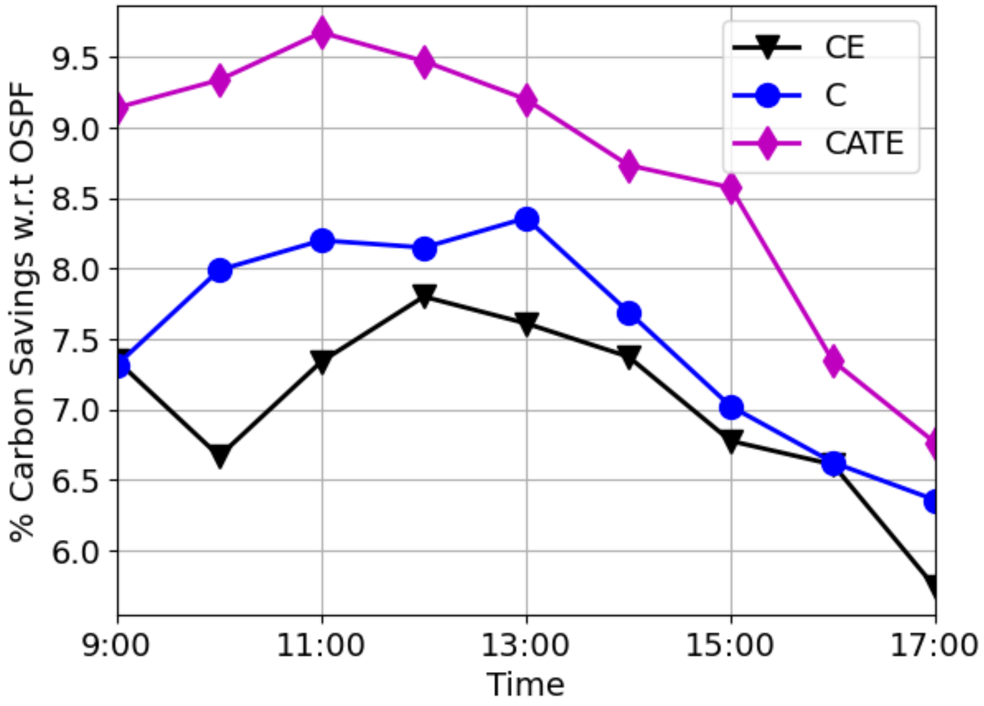
Carbon & Energy Savings for Day-Traffic



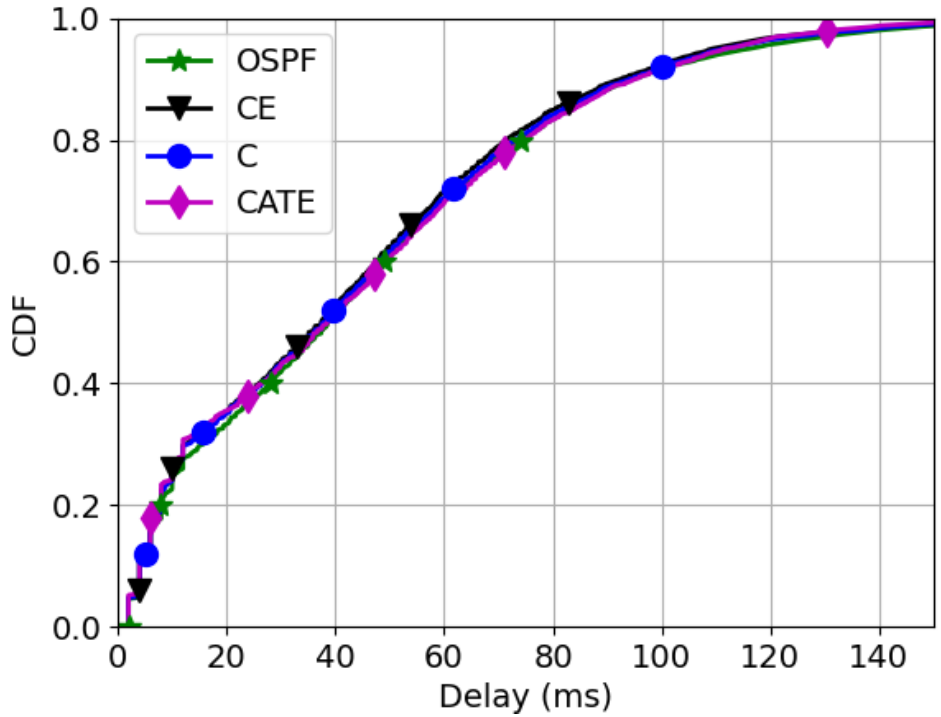
Backup Slides

Results: Carbon & Energy (GEANT)

- All nodes have the same energy parameters
- CATE: highest savings, with around 8% links disabled
- Delay is similar for all 4 scenarios



Carbon Savings Relative to OSPF



End-to-End Path Delay