Blackouts & Byteouts

Assessing Internet Infrastructure Resilience under Power Grid Failures

Presented By: Tanya Shreedhar

Collaborators: Kevin Vermeulen, Amreesh Phokeer, Ítalo Cunha and Fernando Kuipers

Postdoctoral Researcher at Networked Systems group at TU Delft

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Tanya Shreedhar

Postdoctoral Researcher, TU Delft, The Netherlands

Room B28.2.E.060
Van Mourik
Broekmanweg 6
2628 XE, Delft
The Netherlands

I am a postdoctoral researcher with Prof. Fernando A. Kuipers at the Networked Systems group of Delft University of Technology (TU Delft). I received my PhD from Wireless Systems Lab IIIT-Delhi, India in 2022. Previously, I was working as a postdoctoral researcher at NetSys group, University of Edinburgh. I was also a visiting researcher at the Chair of Connected Mobility at the Technical University of Munich (TUM). Before joining my PhD, I did my Bachelor in Engineering and received an academic gold medal from Panjab University, Chandigarh, India.

My research interests lie broadly in the area of networks and systems. I work in the area of next-generation transport protocols, specifically but not limited to Multipath TCP, QUIC and Age Control Protocol. My current research includes working on wireless and mobile systems with a focus on data-driven networking. Additionally, I enjoy working on problems in edge/cloud computing, satellite networking, Internet measurements and emerging Internet applications.

I am always looking for collaborations (and students) so if you are interested, please reach out to me via email.

News

Nov 2024 — I am invited to attend the Falling Walls Science Summit 2024 in Berlin, Germany. Thank you Klaus Tschira Stiftung for giving me this amazing opportunity!

Oct 2024 — I am invited to attend and present my work at the annual Alice & Eve event at Lieden!

Sep 2024 — I am invited to attend the Heidelberg Laureate Forum 2024 as an Alumni. I am also featured in the HLFF Spotlight Series!

HLFF SPOTLIGHT
Tanya Shreedhar
HEIDELBERG LAUREATE FORUM FOUNDATION
TANYA SHREEDHAR
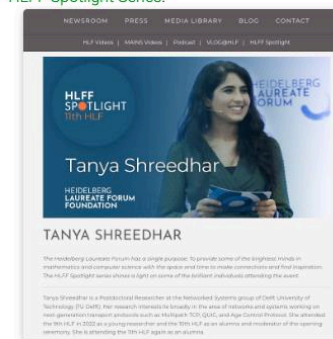
Edit: See my memories and reflections from HLF 2024

Mar 2024 — Our paper ACP+: An Age Control Protocol for the Internet is accepted in IEEE/ACM Transactions on Networking (TNET).

Mar 2024 — I am serving as the graduate forum chair and publicity chair for the COMSNETS 2025.

Feb 2024 — I am serving as the workshop and tutorial chair for the ACM IoT Conference 2024. Please see the open call here and submit for workshop/tutorial ideas. Deadline in May 2024!

Recently….
Power Outage in Spain and Portugal

On April 28, Spain was hit by a widespread power outage lasting several hours

This resulted in cascaded failures also impacting Portugal

Sport, page 36

'I wish I'd never written it'
Rust director Joel Souza

The making of Arne Slot

Tuesday
29 April 2025
£3.20
From £2.30 for subscribers

The Guardian

Spain declares state of emergency after power blackout causes chaos

Portugal also hit by huge outage that takes down ATMs, trains and phones

**Jon Henley
Ashifa Kassam and
Sam Jones** *Madrid*

Spain declared a state of emergency last night after tens of millions of people across the Iberian peninsula were plunged into a huge power blackout, leaving them without trains, metros, traffic lights, cash machines, phone connections and internet access.

People were trapped in lifts, stuck on trains, stalled in traffic and abandoned in airports. Hundreds stumbled along pitch-black metro tunnels using their phone torches; others scrambled for basics in supermarkets that could only take cash, or began long trudges home from work.

Mobile networks went down and internet access was cut as power failed at 12.33pm (1.33pm UK time). Hospitals postponed routine operations but used generators to attend to critical cases, and while electronic banking was able to function on backup systems, most cash machine screens were blank.

The mayor of Madrid, José Luis Martínez-Almeida, urged residents to limit their journeys and stay where they were, adding: "It is essential that the emergency services can circulate." Play at the ❶ ❶ ❶

▲ *Passengers wait outside Atocha railway station in Madrid after the power cut brought trains to a standstill across Spain* PHOTOGRAPH: THOMAS COEX/AFP/GETTY

⭘ NEWS FLASH

Spain and Portugal in darkness: blackout or cyberattack? The shocking truth behind the chaos

An unprecedented blackout shakes the Iberian Peninsula, amid hacker claims and critical infrastructure disruptions.

EUROPEAN COUNCIL ON FOREIGN RELATIONS ecfr.eu

PROGRAMMES ▾ ANALYSIS ▾ TOPICS ▾ EVENTS EXPERTS ABOUT ▾

🟡 European Power

Lights out: Why Iberia's power cut is a warning for EU energy security

In April, millions of people across Spain and Portugal were left without power—some for almost a day. The EU must now address weaknesses in its energy infrastructure to ensure the lights stay on

Szymon Kardaś ✖
Senior Policy Fellow

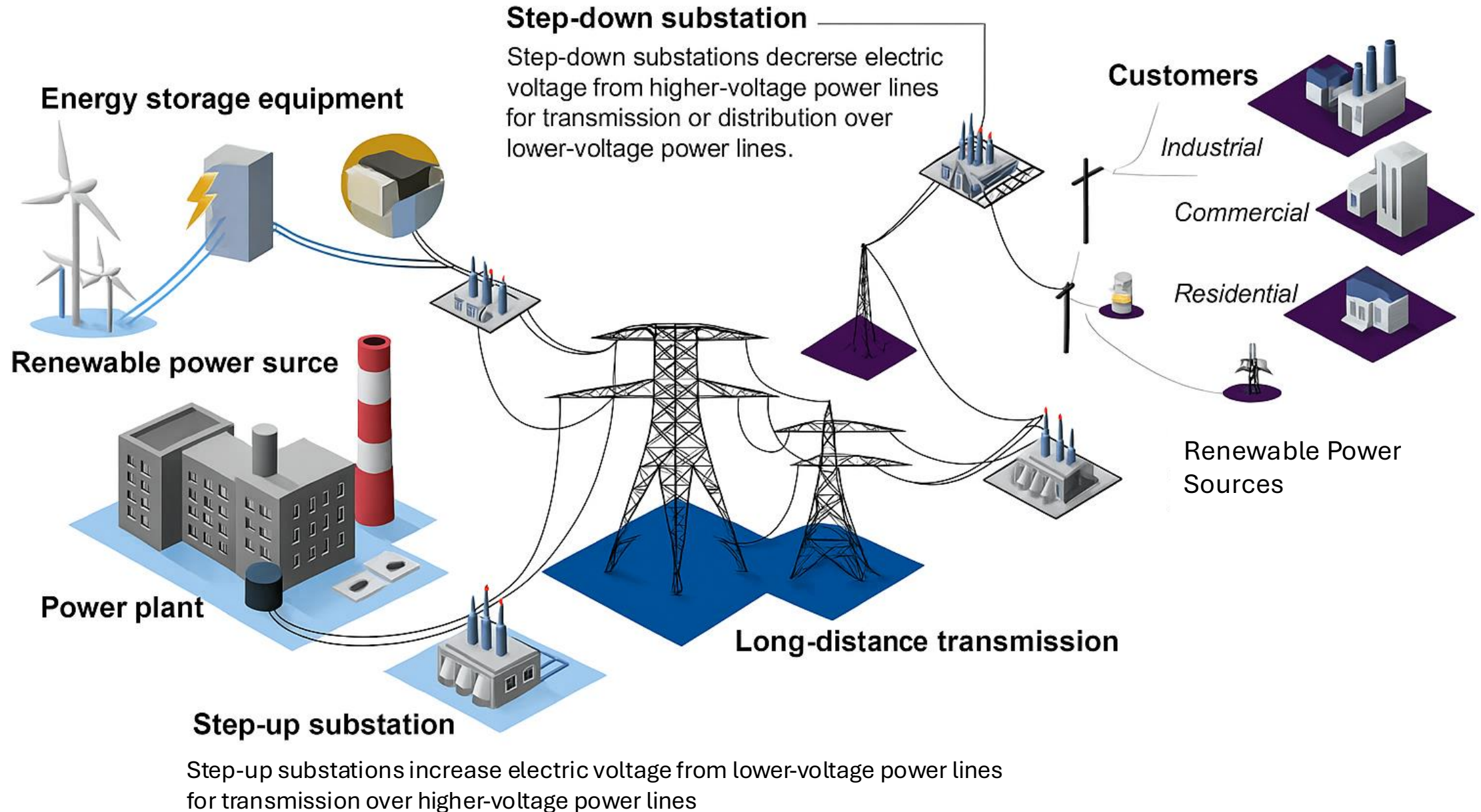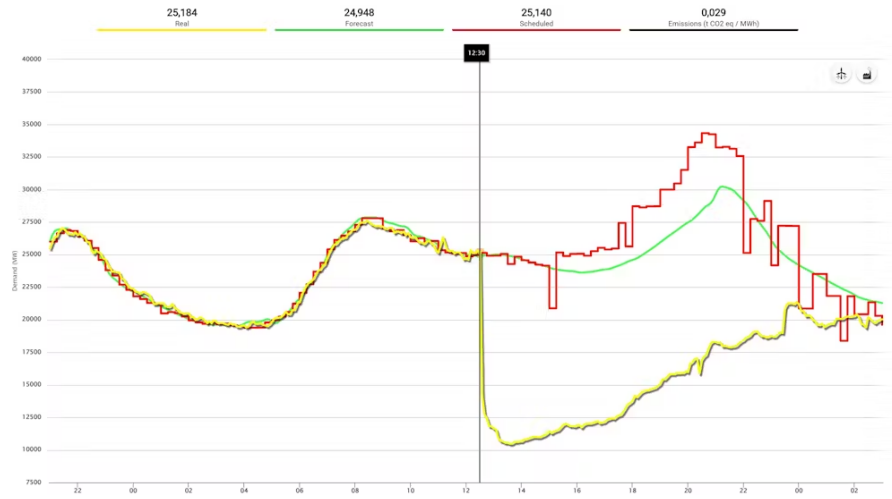Policy Alert · 7 May 2025 · 2 minute read

Editorial cartoon from the August 20, 2003, edition of the Ottawa Citizen

Generation and Storage

Transmission

Distribution

Energy storage equipment

Step-down substation

Step-down substations decrerse electric voltage from higher-voltage power lines for transmission or distribution over lower-voltage power lines.

Customers

Industrial

Commercial

Residential

Renewable power surce

Renewable Power Sources

Power plant

Long-distance transmission

Step-up substation

Step-up substations increase electric voltage from lower-voltage power lines for transmission over higher-voltage power lines

Demand Surge & Overload (extreme heat/cold spikes, overdrawn lines)

Equipment Failures & Aging (transformer faults, substation issues)

Human/Operational Errors (misconfiguration, procedural mistakes)

Cybersecurity & Malicious Acts (attacks on SCADA, grid intrusion)

EARTHQUAKE WILDFIRE SANDSTORM TORNADO TYPHOON

FLOOD ABNORMAL HEAT STORM AVALANCHE ERUPTION

Natural Disasters (storms, weather extremes, earthquakes)

"I currently don't have any internet service and just €15 in my wallet - I can't withdraw any money from the ATM"

Power outage also resulted in complete communication blackout.

- Almost no cellular services in impacted regions for hours

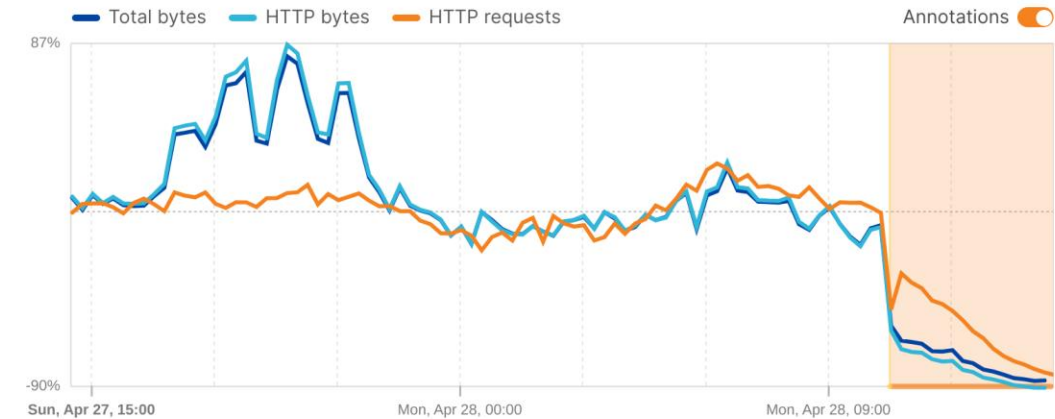**Iberian Outage Hits Telcos: Traffic Falls by 90%**

- Country-wide Internet impacted severely with significant reduction in traffic, 10x higher latencies and WhatsApp call overload

- Also resulted in cascaded Internet blackouts In Morocco and France

Traffic volume in Portugal
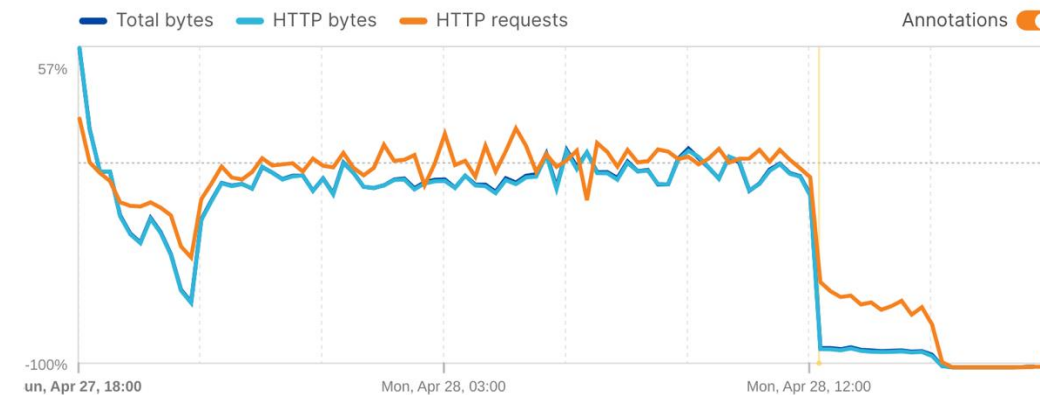Relative change from previous period

Traffic volume from AS36925
ASMedi — Orange Morocco
Relative change from previous period

Protecting Network Operations

Similarly, Internet cyberattacks can cause widescale power disruption

Several ongoing policies and regulations discussions on making energy and Internet resilient

United Nations

Cybersecurity in the United Nations system organizations

European Commission

Energy, Climate change, Environment

Energy

| Home | Topics | Strategy | Data and analysis | Energy explained | Studies | Publications | Consultations | Events | News |

Home > Topics > Energy security > Critical infrastructure and cybersecurity

Critical infrastructure and cybersecurity

Cybersecurity and the challenges related to it are rapidly evolving and the Commission is taking a series of measures to protect critical energy infrastructure, particularly against cyberattacks.

Botnets that can create power surges

Internet

Electric Grid

Cyberattacks on Power Distribution using Internet

Internet Resiliency Index

- The Internet plays a critical role in society.
- A resilient Internet connection is one that maintains an acceptable level of service in the face of faults and challenges.
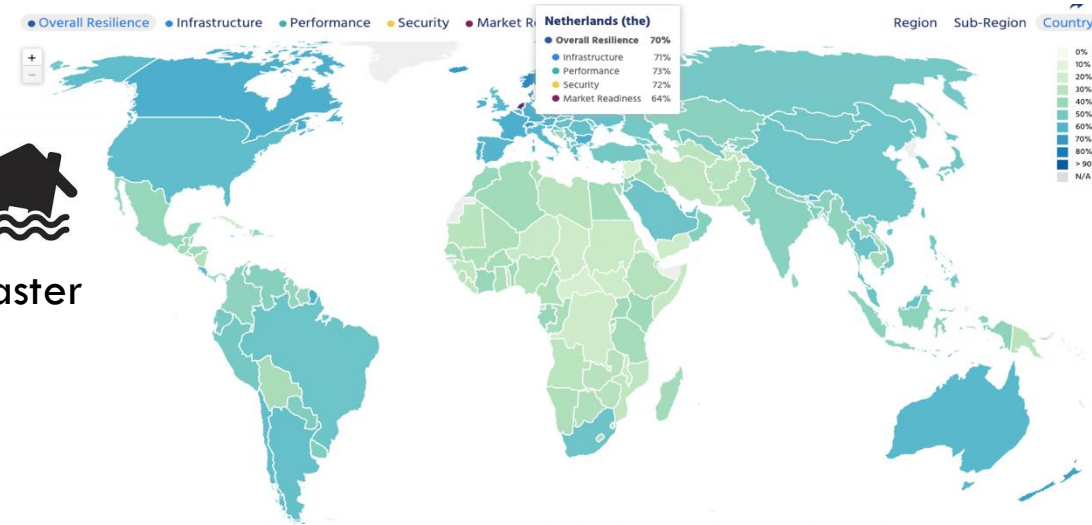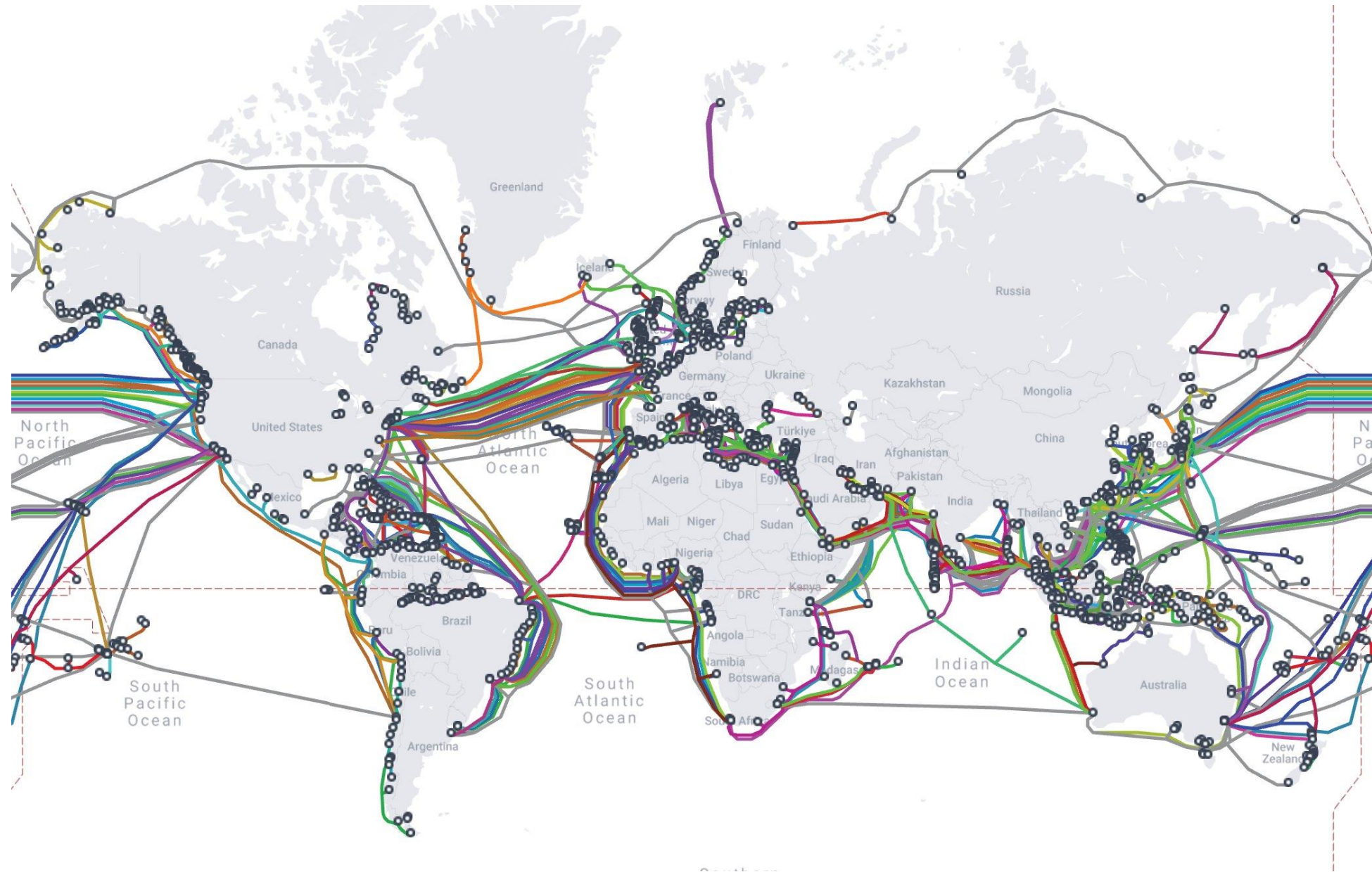
Infrastructure   Security   Performance   Market Readiness   Disaster

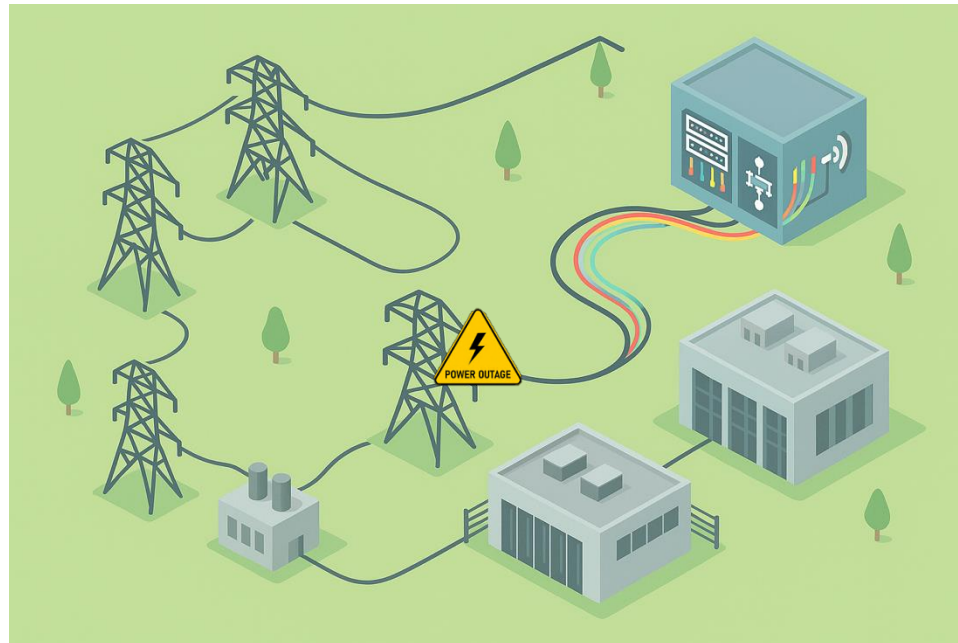# Internet is a complex network of cables

Internet is a complex network of cables

& physical equipments and facilities

© IXP map

Key Research Question

How much of our Internet operations is susceptible to failures in power distribution network?

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How much of our Internet operations is susceptible to failures in power distribution network?
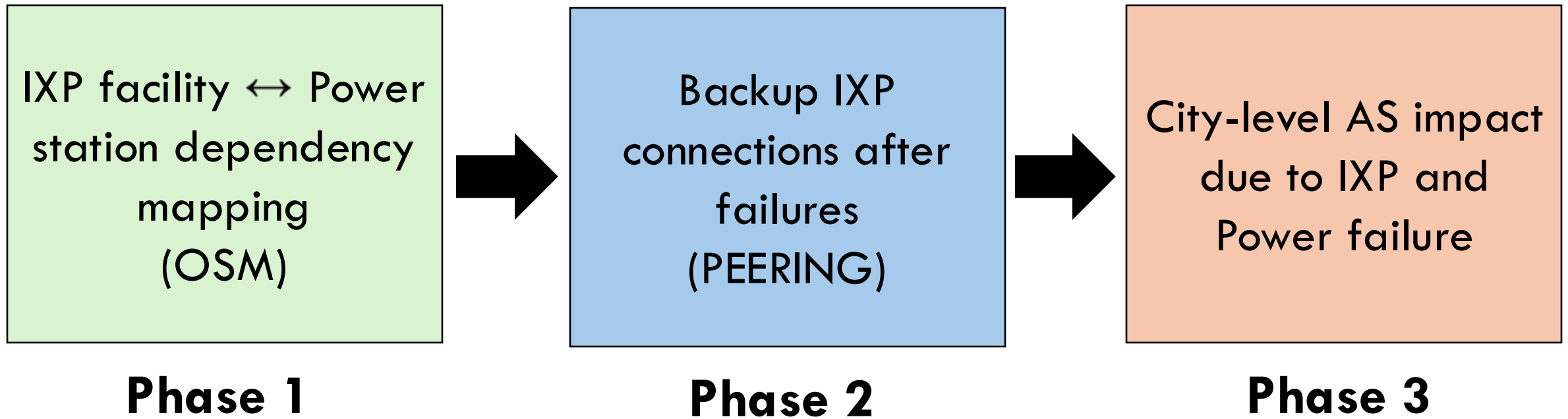
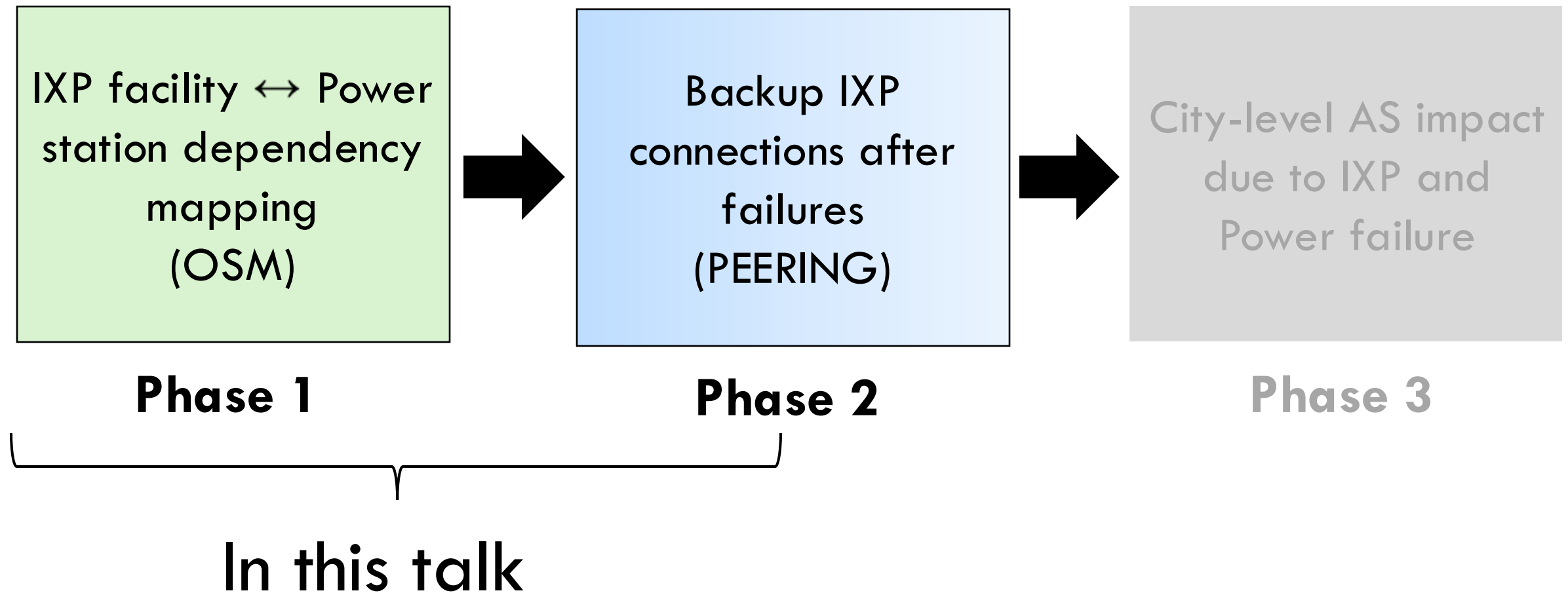at zonal/country level   +   at city/local level

Key Research Question

How much of our Internet operations is susceptible to failures in power distribution network?

- Investigate the dependence of IXP infrastructure on local power stations

- Characterize the backup IXP peerings in case of failures

- Uncover the impact on local ASes due to failures

Approach

IXP facility ↔ Power station dependency mapping (OSM)	Backup IXP connections after failures (PEERING)	City-level AS impact due to IXP and Power failure
Phase 1	**Phase 2**	**Phase 3**

Approach

| IXP facility ↔ Power station dependency mapping (OSM)	Backup IXP connections after failures (PEERING)	City-level AS impact due to IXP and Power failure
Phase 1	**Phase 2**	**Phase 3**

In this talk

Datasets and Challenges

- IXP facility data is publicly available on PeeringDB

- Power station locations are not standardized and released on a common platform
  - Richer data available in EU
  - Shared in different formats

- No clear indication which IXP facilities are powered by which power stations


IXPs

?
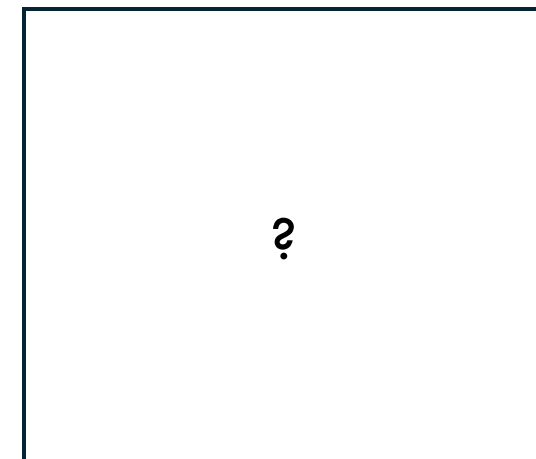
Power stations

Methodology - Data Collection (Power Grid)

- OpenStreetMap (OSM) Dataset
  - detailed geospatial information
  - raw OSM is extremely noisy
  - Inconsistent/missing voltage tags
  - raw OSM is not consistent with operator views (TSO/DSO)

- Transmission System Operator (TSO) Dataset
  - patchy availability
  - inconsistent formats, years, abstractions, schematics (planning)
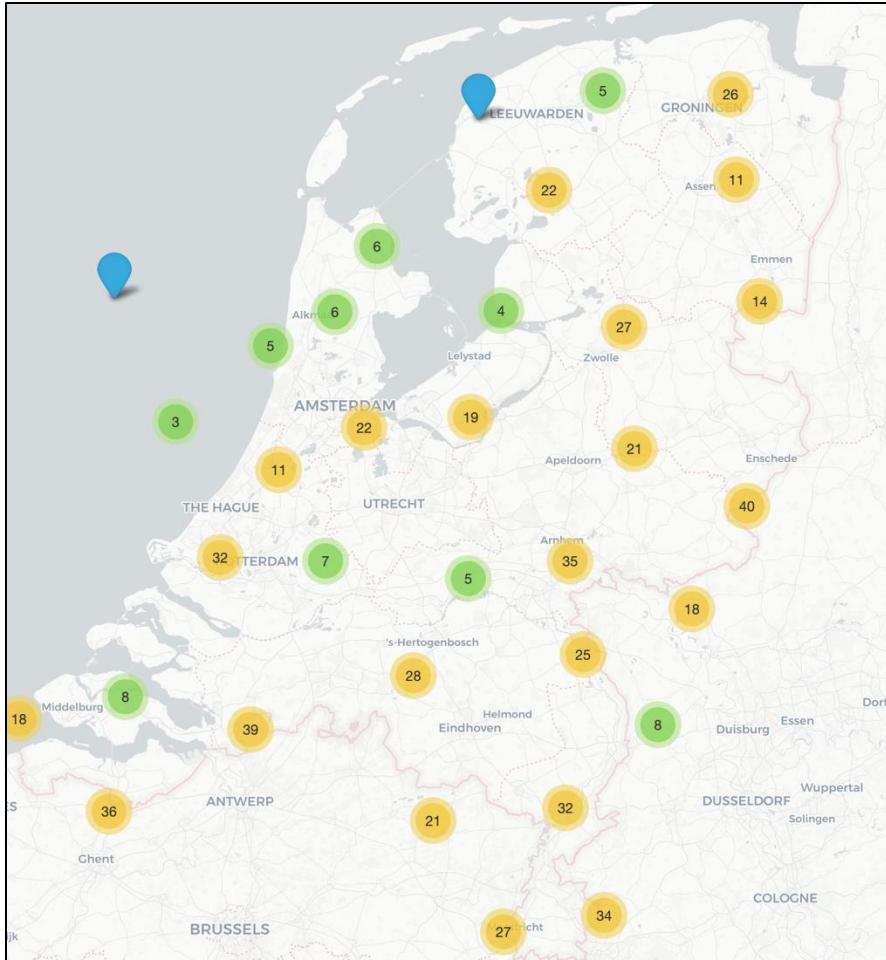 - country specific -- not global view

Validation of OSM Inferred Grid against TSO
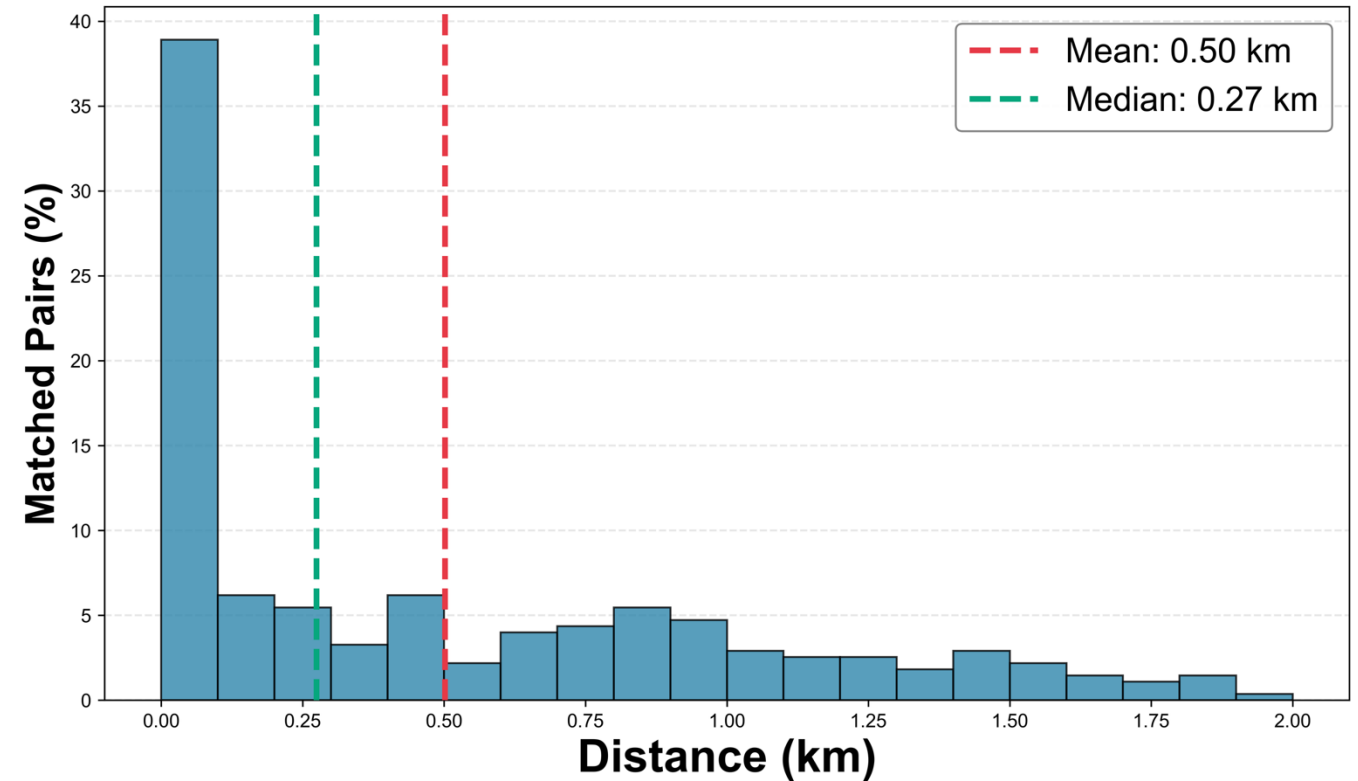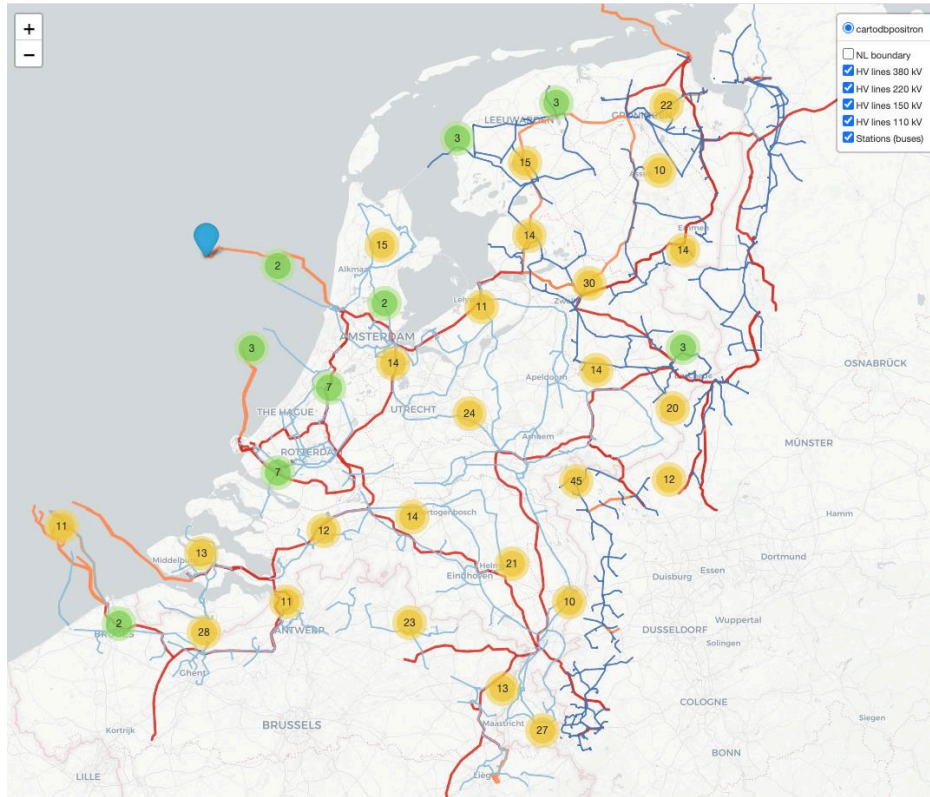
76% station match!

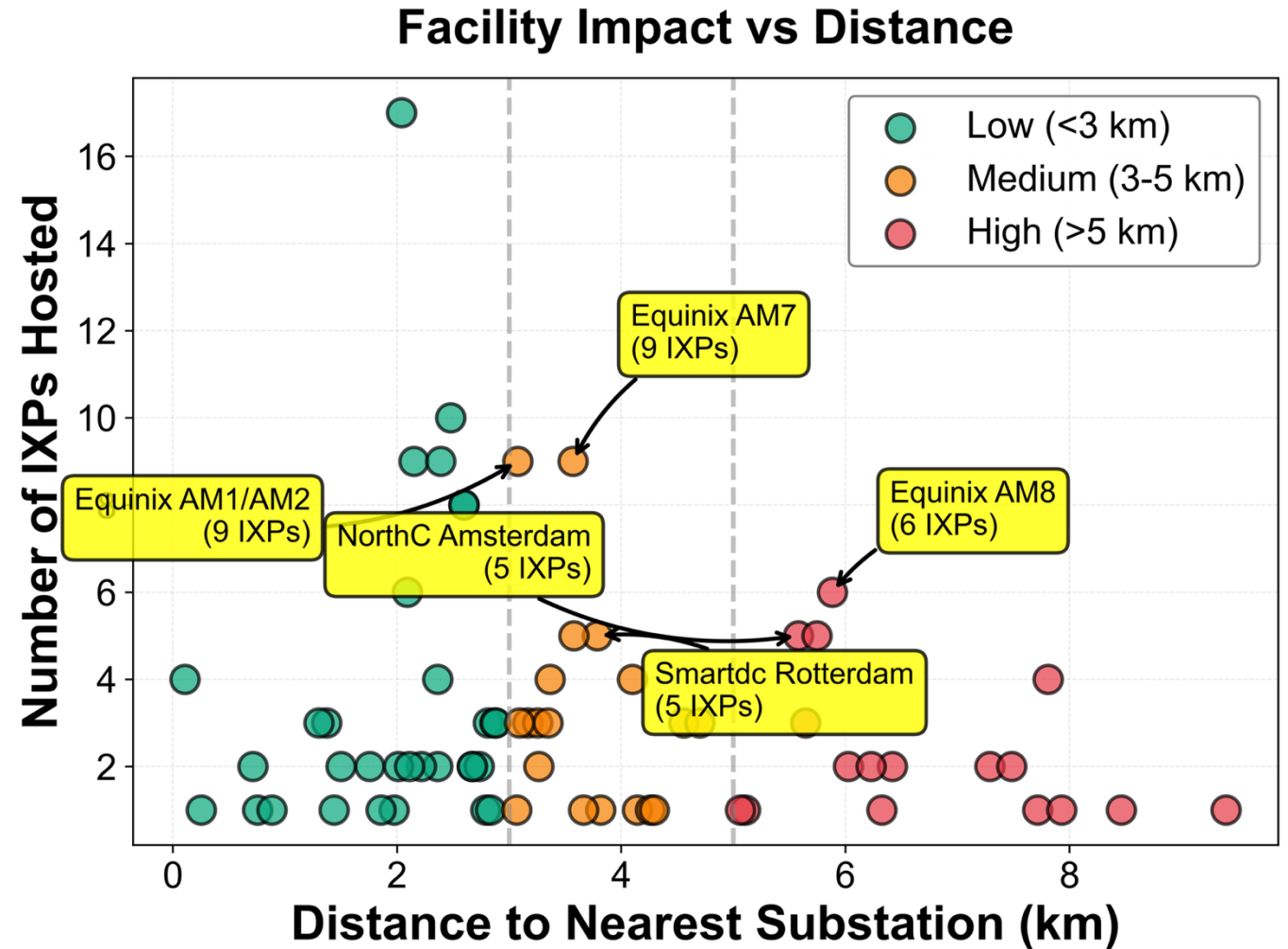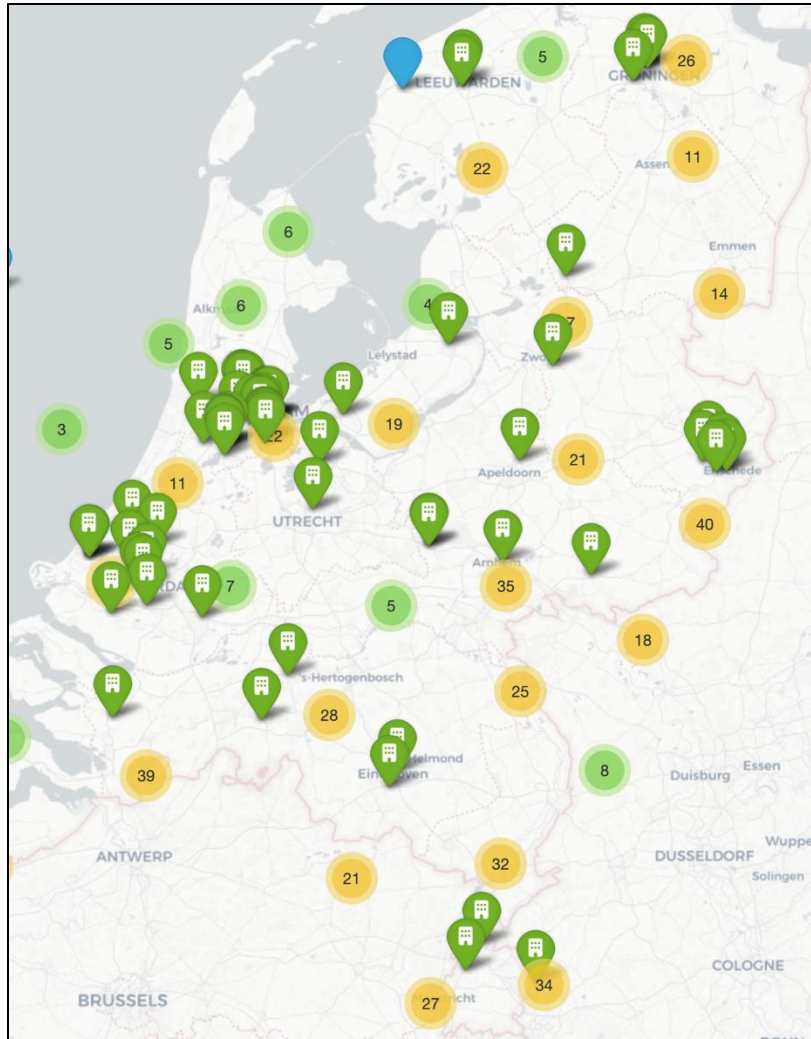median distance match: ≈250 meters

Geographic Mapping

OSM NL Power Network

PeeringDB Facility/IXP Network

Identifying Power ↔ IXP (Closest Correlation)

Facility Impact vs Distance

Legend:
- Low (<3 km)
- Medium (3-5 km)
- High (>5 km)

Y-axis: Number of IXPs Hosted
X-axis: Distance to Nearest Substation (km)

Annotations:
- Equinix AM7 (9 IXPs)
- Equinix AM1/AM2 (9 IXPs)
- NorthC Amsterdam (5 IXPs)
- Equinix AM8 (6 IXPs)
- Smartdc Rotterdam (5 IXPs)

Cascaded Failure Analysis

- Closest correlation may be limiting as (i) IX may not be drawing from closest station and (ii) IX may be multiple possible backup transmission lines.

<u>Solution</u>:

- Construct k-resilient bipartite graph from every IX facility to k nearest substations (in our experiments, $k=3$)

- k-resilient is more resilient to single substation failures and is more accurate to real world

<u>Failure Scenarios</u>

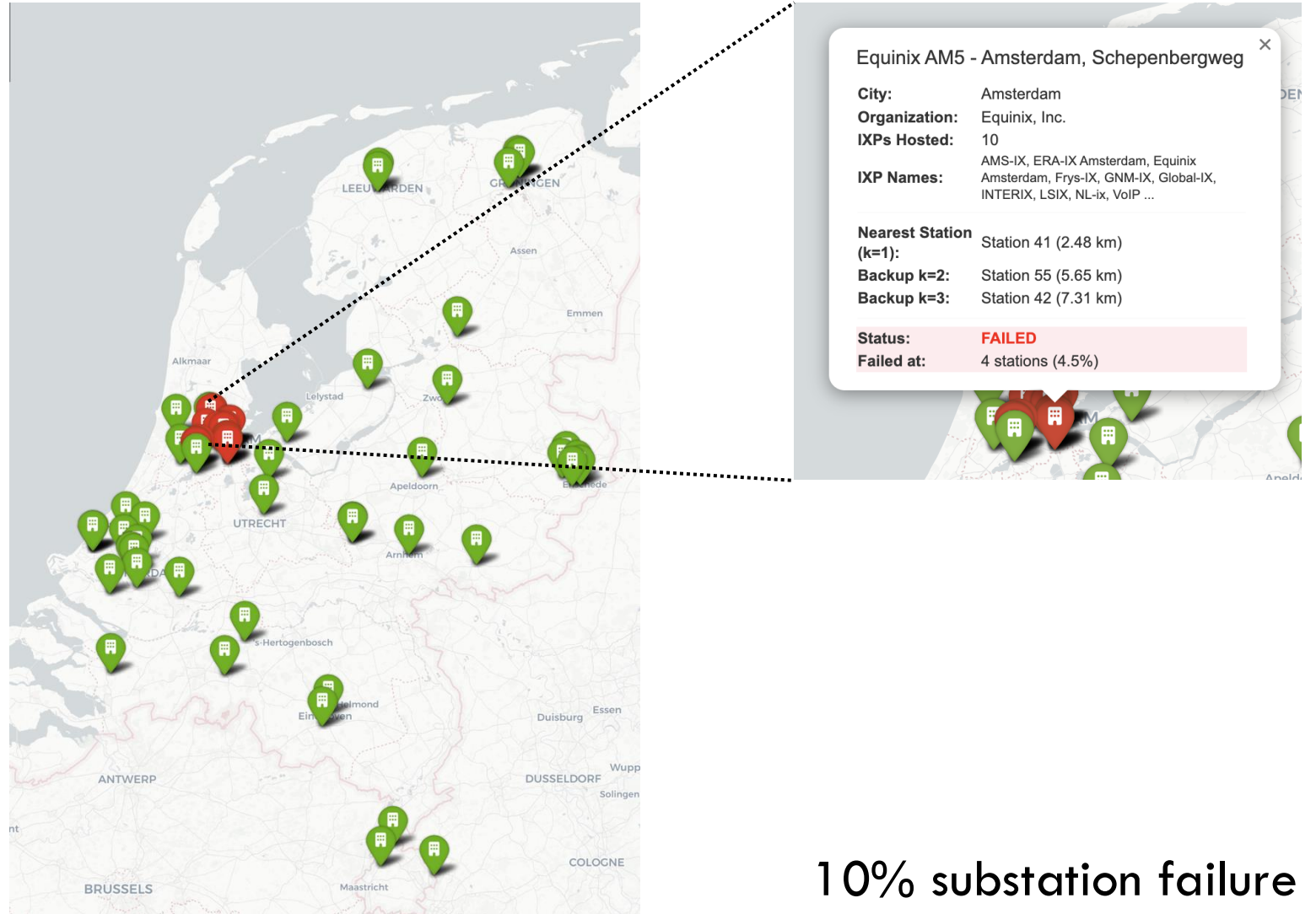(i) degree-first, (ii) betweenness-first, (iii) random

IX facility is failed if it loses all k stations
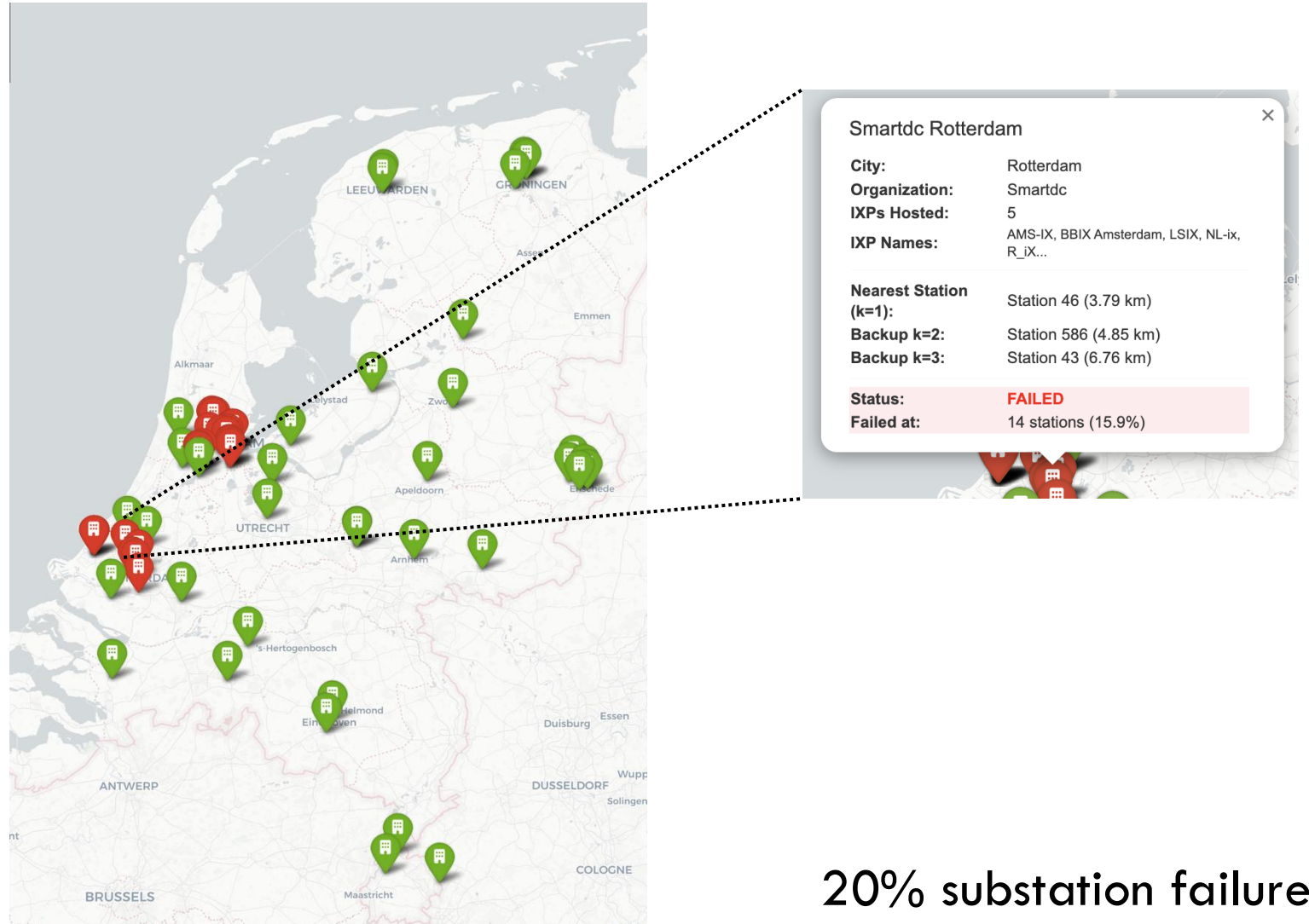
Cascaded Failure Analysis

0% substation failure

Cascaded Failure Analysis

Equinix AM5 - Amsterdam, Schepenbergweg

City:	Amsterdam
Organization:	Equinix, Inc.
IXPs Hosted:	10
IXP Names:	AMS-IX, ERA-IX Amsterdam, Equinix Amsterdam, Frys-IX, GNM-IX, Global-IX, INTERIX, LSIX, NL-ix, VoIP ...
Nearest Station (k=1):	Station 41 (2.48 km)
Backup k=2:	Station 55 (5.65 km)
Backup k=3:	Station 42 (7.31 km)
Status:	FAILED
Failed at:	4 stations (4.5%)

10% substation failure

Cascaded Failure Analysis

Smartdc Rotterdam

City:	Rotterdam
Organization:	Smartdc
IXPs Hosted:	5
IXP Names:	AMS-IX, BBIX Amsterdam, LSIX, NL-ix, R_iX...
Nearest Station (k=1):	Station 46 (3.79 km)
Backup k=2:	Station 586 (4.85 km)
Backup k=3:	Station 43 (6.76 km)
Status:	FAILED
Failed at:	14 stations (15.9%)

20% substation failure

Cascaded Failure Analysis

40% substation failure

Cascaded Failure Analysis

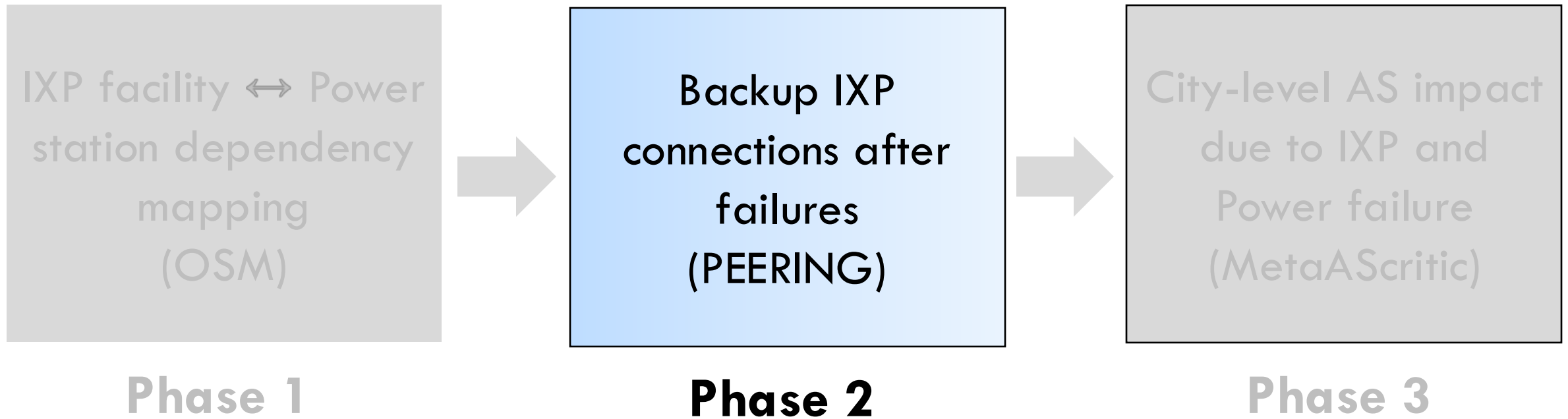60% substation failure

Cascaded Failure Analysis
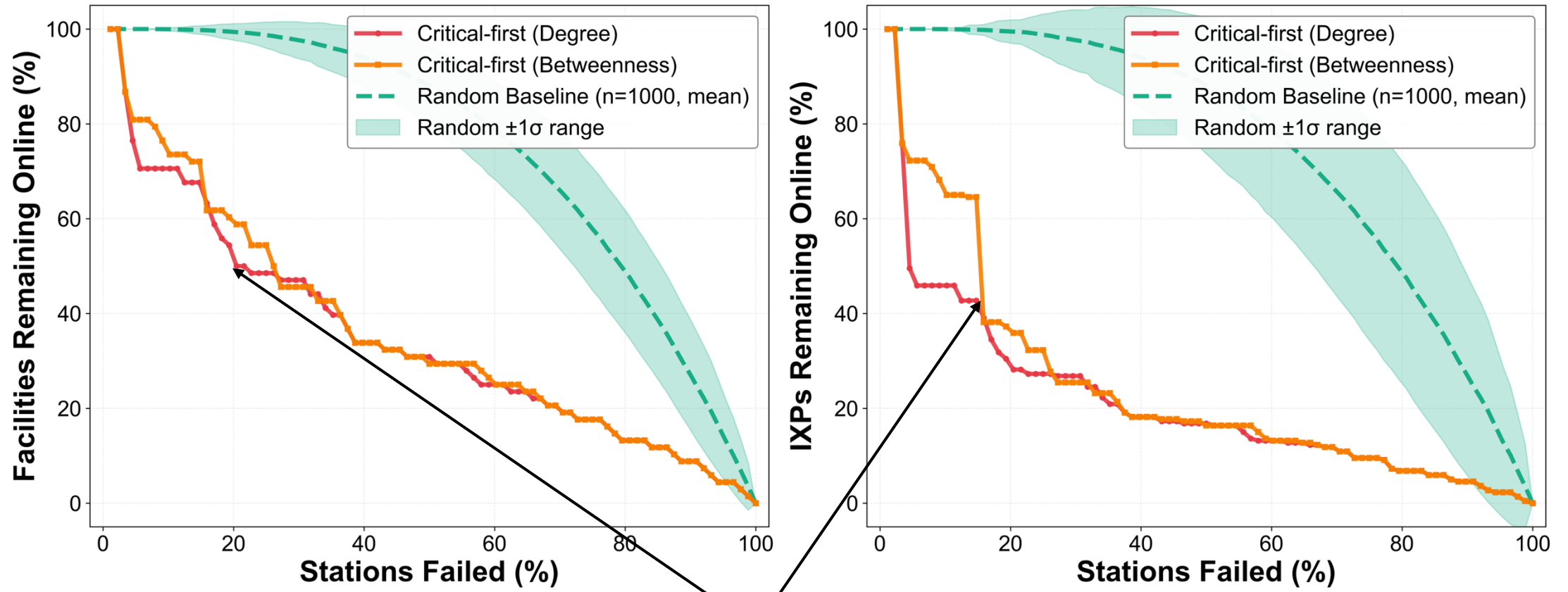
60% IXPs fail at 20% power substation failure due to colocation

Phase 1: Key Takeaways

- We see strong evidence of cascaded failure risk between power delivery network and Internet exchanges

- Due to co-location in the same physical building, many IXPs get impacted simultaneously
  - "Number of IX facilities" in a region is a misleading metric for network resilience

Are these cascaded impacted IXPs actually used in data path for real Internet traffic?

Approach

IXP facility ⟷ Power station dependency mapping (OSM)

Phase 1

Backup IXP connections after failures (PEERING)

Phase 2

City-level AS impact due to IXP and Power failure (MetaAScritic)

Phase 3

PEERING Testbed

PEERING: Pairing Emulated Experiments with Real Interdomain Network Gateways
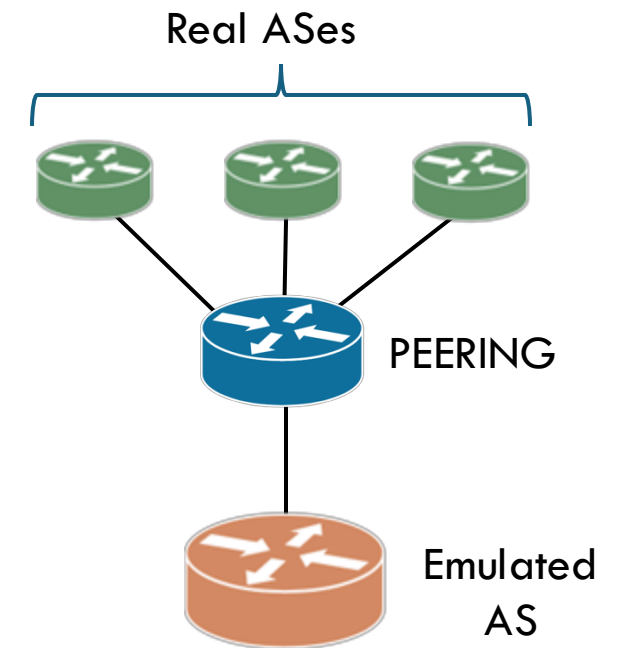
Methodology

1. Withdraw from one PEERING sub-site
   → second most preferred route.
2. Prepend from one PEERING sub-site
   → second most preferred route if the choice
   was based on path length.

Simultaneously continuously `traceroute` from
RIPE Atlas probes to the prefix
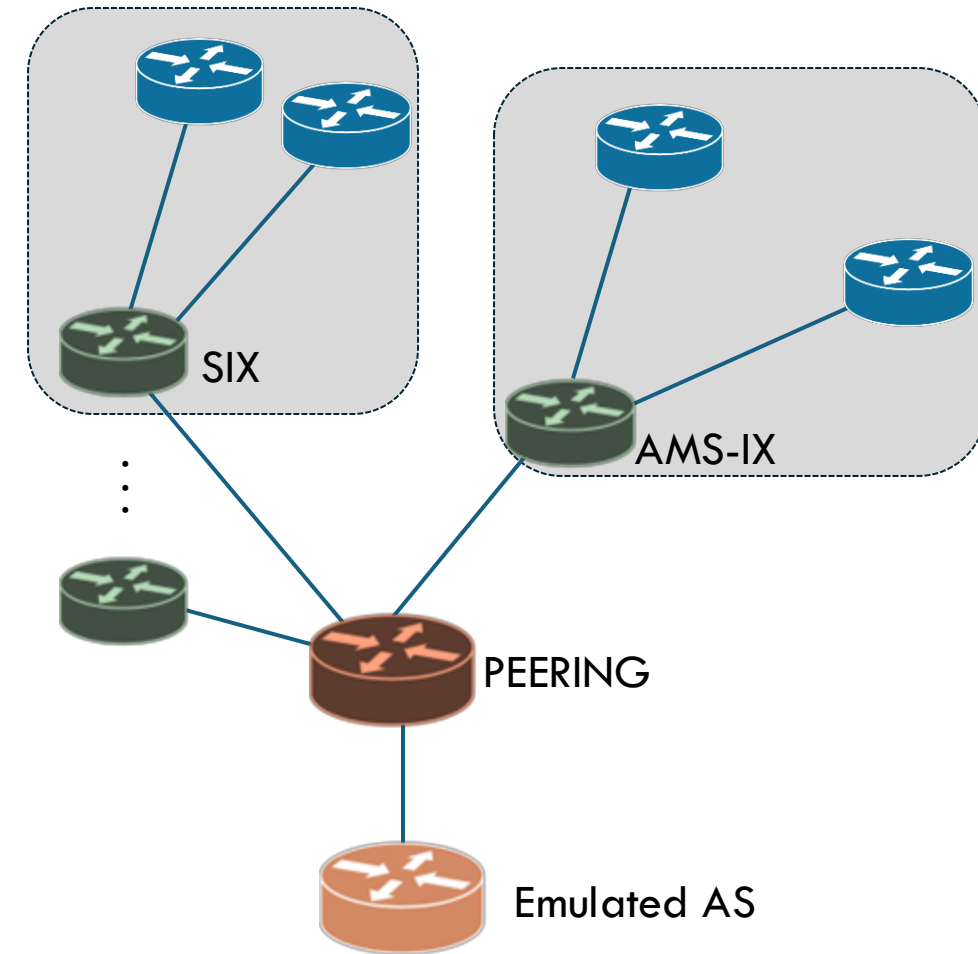
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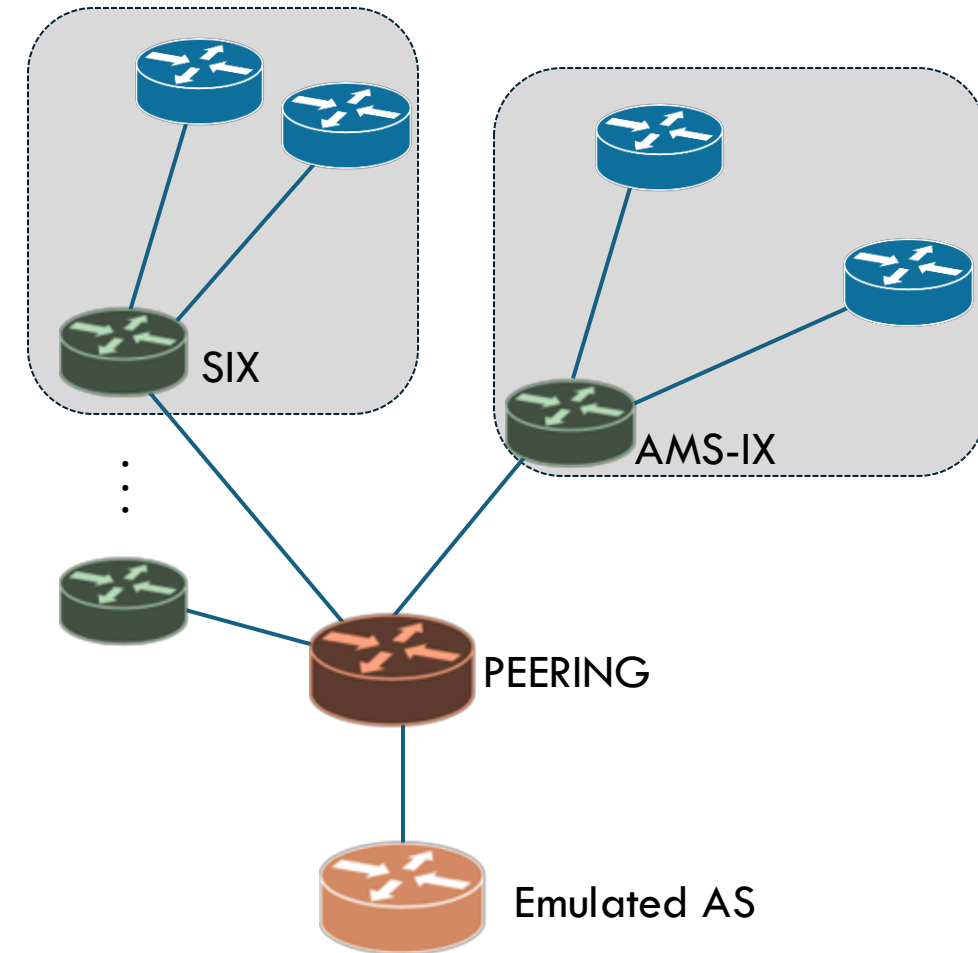
Work in progress! Stay tuned for results!

Conclusion & Recommendations

- Collaborate towards increasing resilience and sustainability?
  - Regulations and Policy development
  - Setting industry benchmarks
  - Setting up standard measurement methodology
  - Improving transparency
- IXP infrastructure dependence on other critical infrastructures (like power).
- Insights to IXPs about risk and dependencies in co-location facilities?
- What can we learn from the past outages?

Backup Slides

Cascaded Failure Analysis

80% substation failure