

Data-driven decision support for charging network planning and operations

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STandUPfor Energy

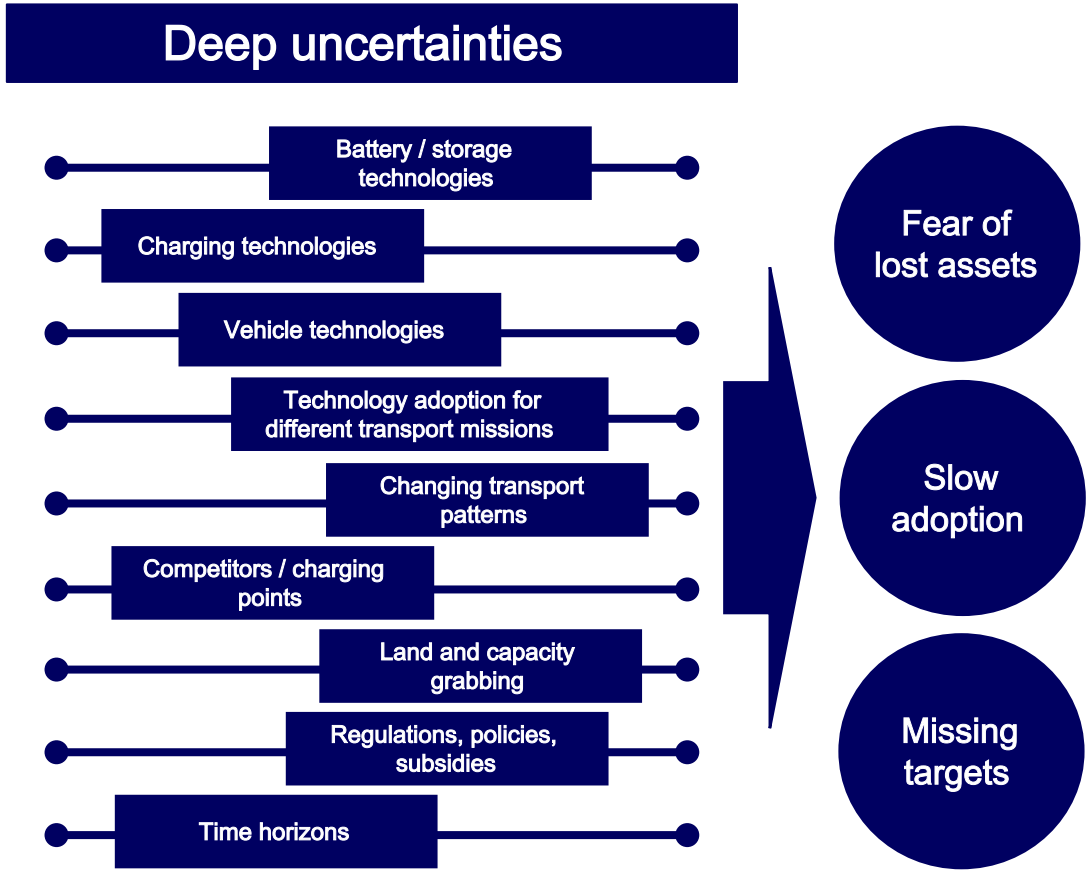
September 29, 2026

Problem: Transport electrification requires large, upfront, and risky investments

TRIPLEF
FOSSIL FREE FREIGHT

To reach 2030 CO_2-reduction targets in road transport, we need to:

- Annually invest:
  - €8 bn in charging infrastructure
  - €4 bn in grid upgrades
  - €7 bn in renewables
- Enable cost-effective e-logistics for 165,000 long-haul e-trucks, requiring 12 TWh of annual charging through 40,000 public 350+ kW fast chargers



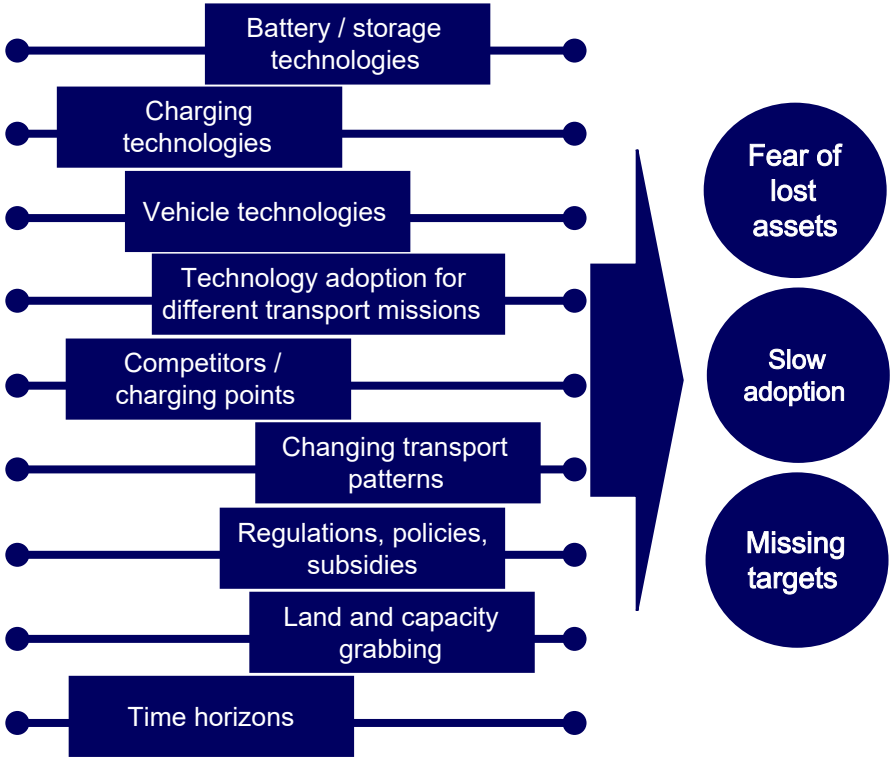
TRACER: TRansport DemAnd Centric Decision Support for Electric ChaRging Infrastructure Planning and Operations

- **Aim:** To provide comprehensive **data-driven decision support** for charging infrastructure developments / investments and operations of - and on them.
- **Research questions / needs:**
  1. CPO, LSP, Trafikverket: **At what pace, where, how many, and what type of charging infrastructure** solutions (charging stations and/or electric roads) should be developed?
  2. CPO: How can charging be managed and optimized to **maximize charger utilization** and **even out demand peaks** ? LSP: How **robust** is the charging infrastructure from a logistics point of view? How should (real-time or day-ahead) **charging logistics** be **managed** and **optimized** so that the **transport costs** (including wait and charging times) are **minimized** ?
- **Partners:** KTH, PostNord, Ellevio, Trafikverket
- **Previous research:** RENO, LOLA, RoSE



Charging infrastructure planning needs (1)

1. Evaluation of multiple future scenarios to manage deep uncertainties



2. Focus on **revenue** - and **impact** - maximizing charging network placement

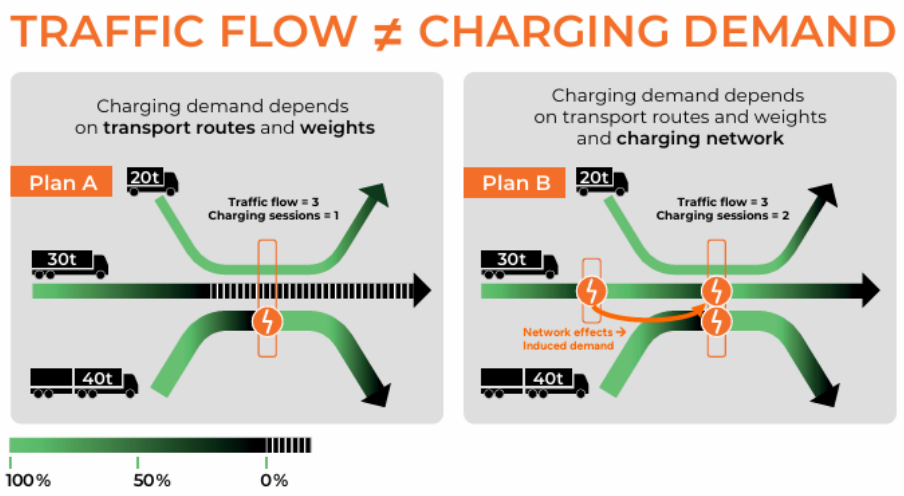
Revenue: making charging stations **economically viable** and **profitable** over time

Impact: making **fully electric operations** of logistics possible

- Increase station utilization
- Increase vehicle adoption
- Increase customer journey & loyalty

Charging infrastructure planning needs (2)

3. Realistic assessment of charging demand in a network (RBND)



Past and future charging opportunities of vehicles on their **transport routes in a network** affect:

- Charging demand
- Vehicle adoption & customer journey
- Charging queues & charger utilization

4. Dynamic adaptive planning with a human in the loop
   - **Adapt to deep uncertainties**
   - **Freely modify a plan** regardless of its criterion fulfillment or optimality

5. Incremental charging network placement method
   - **Iteratively** adapt to changing conditions
   - **Gradual network expansion** taking into account the network aspects

Data-driven RBND simulation model for TE scenarios and properties

TE scenario parameters

1. Transport route dataset
   - Sequences of road segments with transport weight
   - 20 segments (5 km each), *Weight 40 Ton*
2. BEV model
   - *Battery 100 kWh*
   - *Initial SoC 80%*
3. Network of charging stations
   - Location of a charging stations on the road segments
   - *Segment {X,Y,Z} with* *Charging power: 120 kW*
4. Energy use model
   - Amount of energy BEV uses per unit distance traveled (kWh/tkm) approximated as a linearly decreasing function of weight (heavier transports are more energy efficient)
   - *Consumption rate : 0.035 kWh/ tkm (weight 40 Ton)*
5. Charging (Behavior) Model
   - Stopping condition:
     - Drive time to next station > maximum drive time regulation
     - Energy to next station / end > available energy
   - Charging amount is the minimum of
     - Available battery storage capacity
     - Maximum based on rest stop duration
     - Energy needed to the end
   - *Maximum drive time & rest stop duration: 4.5 h & 0.5 h*
   - *Minimum SoC charging threshold : 30 %*

Properties of charging behavior model:

- Can be **termed** as:
  1. **Just in time** – Drive as far as possible (utilize driving time allowance)
  2. **As much as possible** – Make the stop worthwhile (fulfil/utilize resting requirements and battery storage)
  3. **But just enough** – Avoid overcharging at more "expensive" public chargers
- **Realistic** and **economical** from a fleet operator perspective

Incremental placement optimization problem in simple terms

Input

Transport routes

TE parameters

Data-driven simulation model 

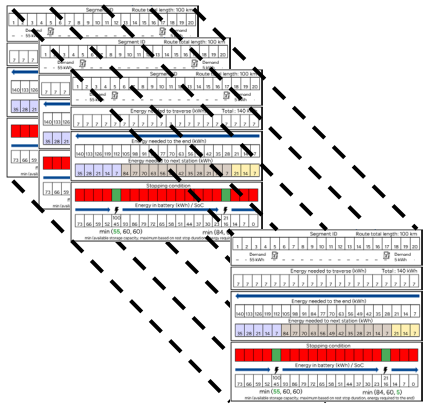
Existing network of charging stations (could be empty)

Candidate locations

Number of stations required (***k***)

Task

Find the combination of ***k*** stations that maximizes O1 and O2



Objective 1 (O1)

Maximize total network demand (kWh)

Objective 2 (O2)

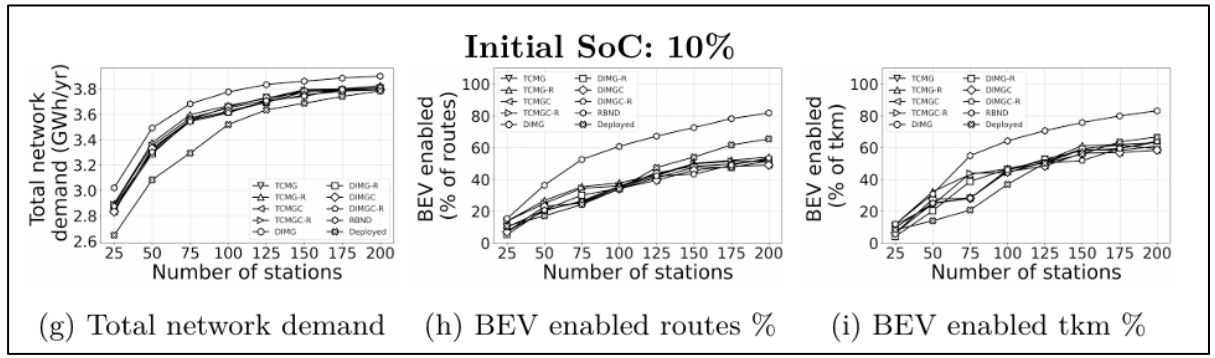
Maximize BEV enablement (tkm)

Output

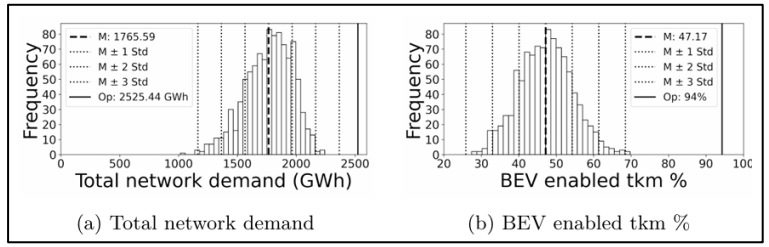
Expanded network of charging station

Route compression & indexing, vehicle -state caching of across expansions, & pruning to:

Find empirically near-optimal solutions for otherwise intractable large-scale problems



(g) Total network demand (h) BEV enabled routes % (i) BEV enabled tkm %



(a) Total network demand (b) BEV enabled tkm %

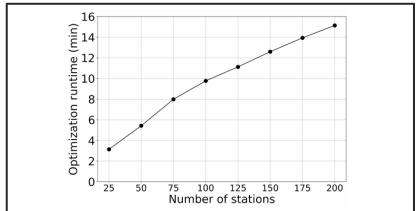
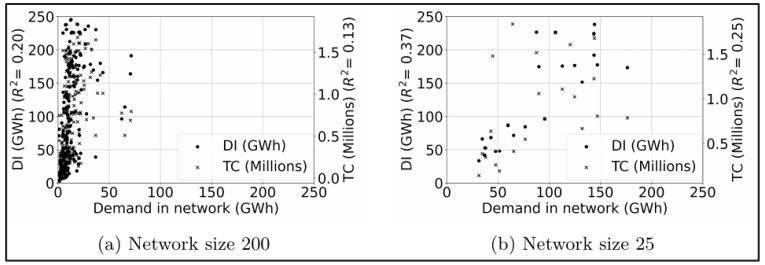
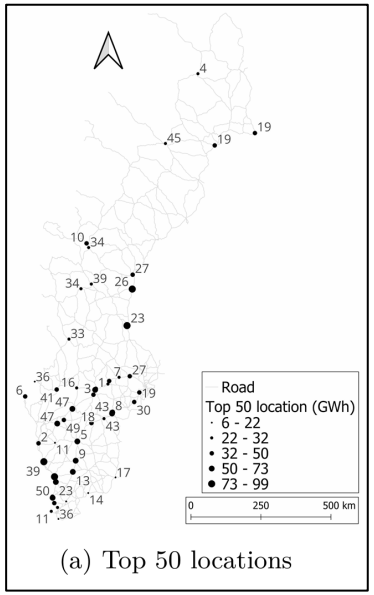


Figure 4.6: Optimization runtime vs. number of stations

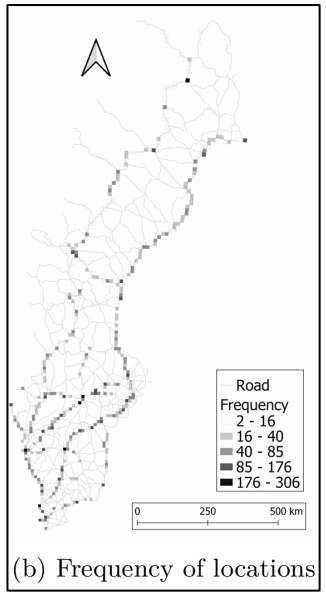


(a) Network size 200 (b) Network size 25

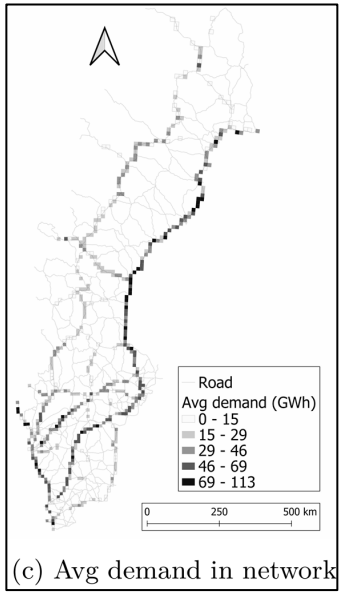
Find no-regret locations through sensitivity analysis of TE scenario parameters



(a) Top 50 locations



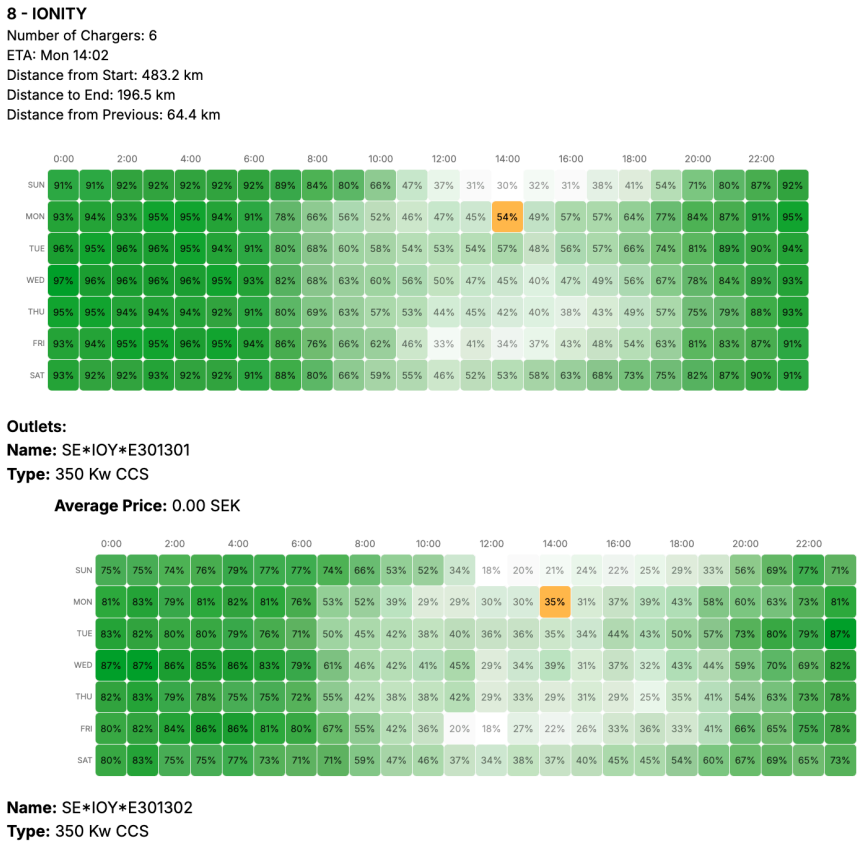
(b) Frequency of locations



(c) Avg demand in network

Model improvement 1: Time -Aware Route Electrification Simulation

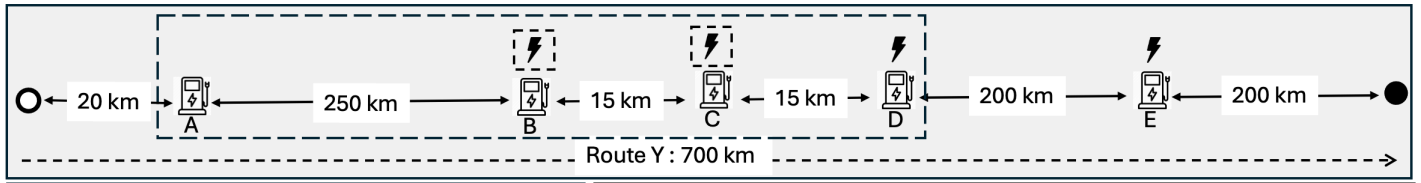
- **Explicitly models time in route execution:** route start times, segment travel times & arrival times at stations.
- From **path-based to trajectory -based** simulation
- Captures **charging events in time and space**
- Accounts for **operational charging constraints**
- Allows **matching of charging demand to** station **capacity**
- Enables **utilization, congestion, and peak analysis**



Model improvement 2: Flexibility -aware charging behavior modeling

- Identifies **feasible alternative charging opportunities** : (upstream locations meeting time -, energy demand and capacity constraints)
- Quantifies **route -level charging flexibility**
- **Distributes demand** across alternative stations
  - Equal probability
  - Proportional to supply - demand balance
  - With demand peak penalties

10 ton truck	Station						
Route Y – 700 km	Start	A	B	C	D	E	End
State of charge (SOC) %	90	86	36	33	30 -> 60	20 -> 40	0
Charging amount allowed* %		(**14**, 30 ,50)	(64, **30** ,50)	(67, **30** ,50)	(70, **30** ,50)	(80, 30 ,**20**)	
Charging session (CS)					⚡	⚡	
Alternate CS			⚡	⚡			
Demand JITJE (kWh) distributed equally among alternative CS					150 (30%)	100 (20%)	
Demand in network (kWh)			50 (10%)	50 (10%)	50 (10%)	100 (10%)	



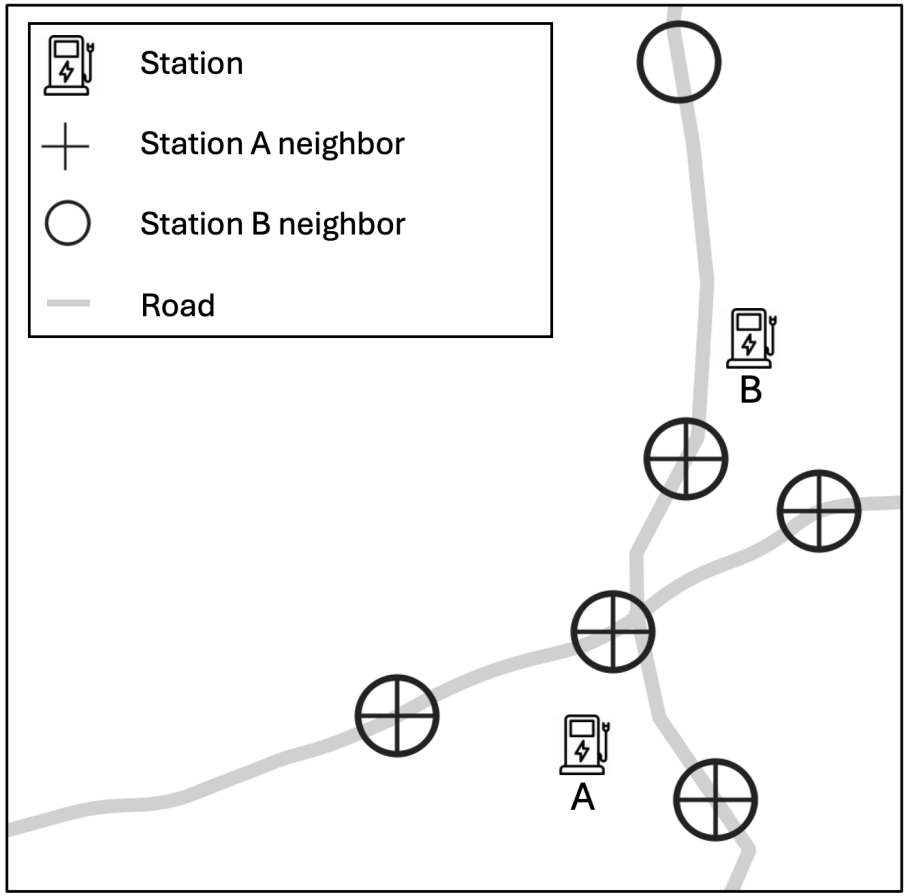
Initial State of Charge (iSoC): 90%
Range: 500 km
Charging power: 300 kW
Maximum rest stop duration: 30 min or 0.5 h

*minimum (the available storage capacity, maximum based on rest stop duration, energy needs to the end)

Station
Distance
Route
Alternative charging opportunity
Start
End
Charing Session (CS)
Alternate CS

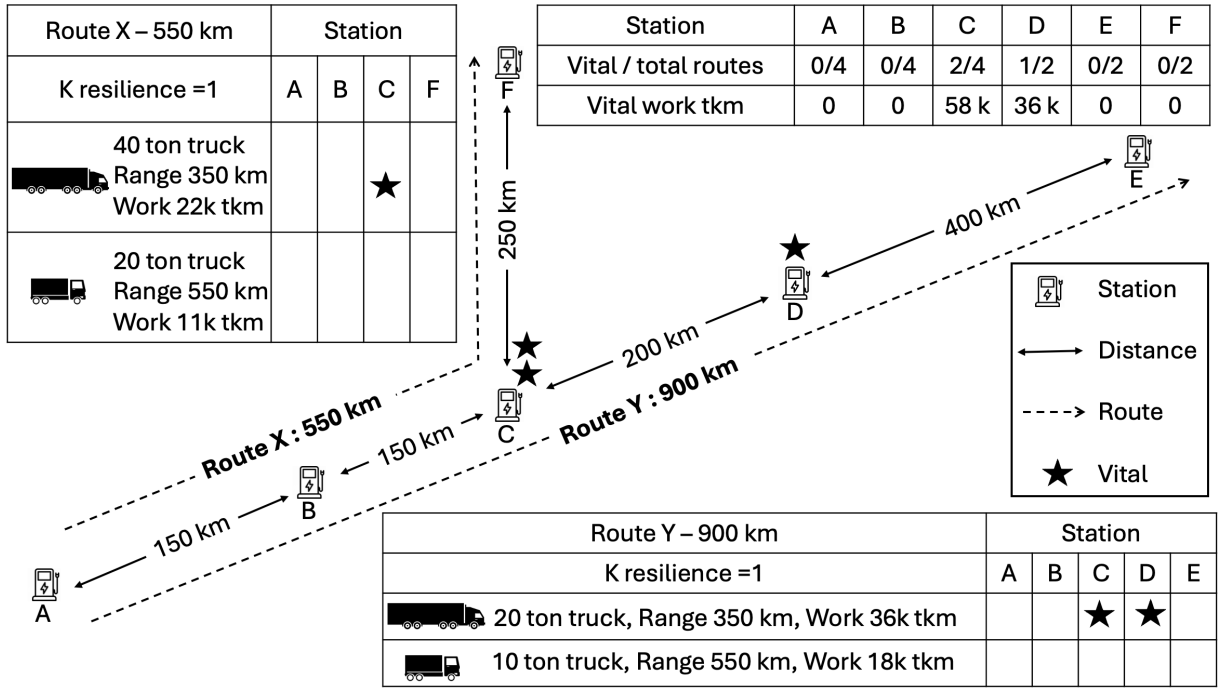
Model improvement 3: Accessibility - aware station representation

- **From one-to-one station –segment** mapping
- **To catchment -based** station accessibility
- Allows stations to serve nearby route segments
- Represents **realistic driver detours**
- Captures station **competition and overlap**
- Distinguishes **nearby stations on the same corridor**
- Produces **more realistic demand allocation**

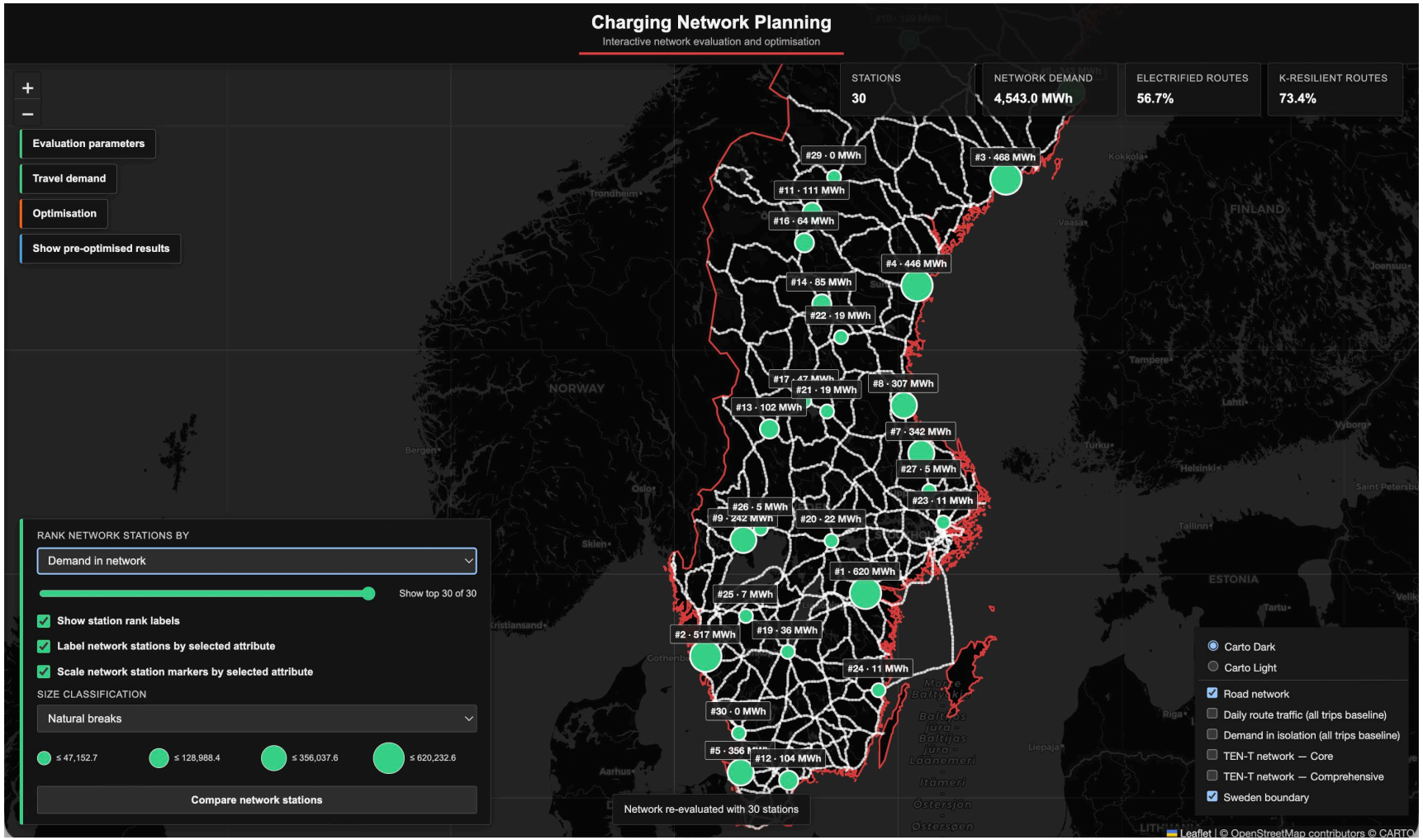


Model improvement 4: Robustness - and utilization -aware network optimization

- **Robustness and resilience** :
  - Introduces **k-resilience of routes**
  - Identifies routes operable under up to ***k*** **station failures**
  - Quantifies **station vitality** from route dependencies (vkm / tkm non-operable)
  - Measures structural redundancy of charging networks
- **Utilization** :
  - Utilization rate of charging slots
  - Peak penalties: 1-Gini of station demand
- **Joint optimization** of demand/coverage, utilization, and robustness and resilience objectives

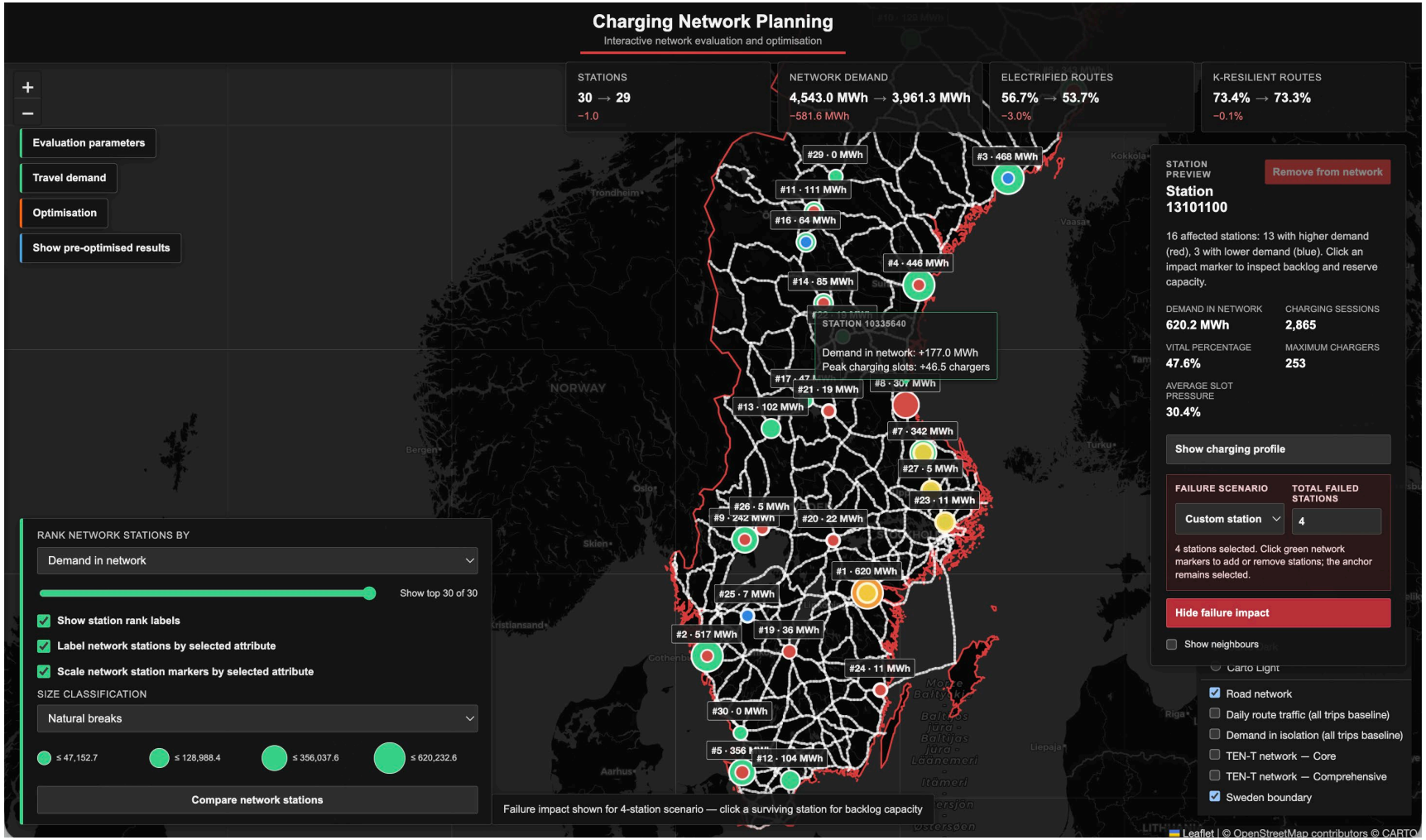


All packaged in a web -based SDSS to evaluate and optimize network designs



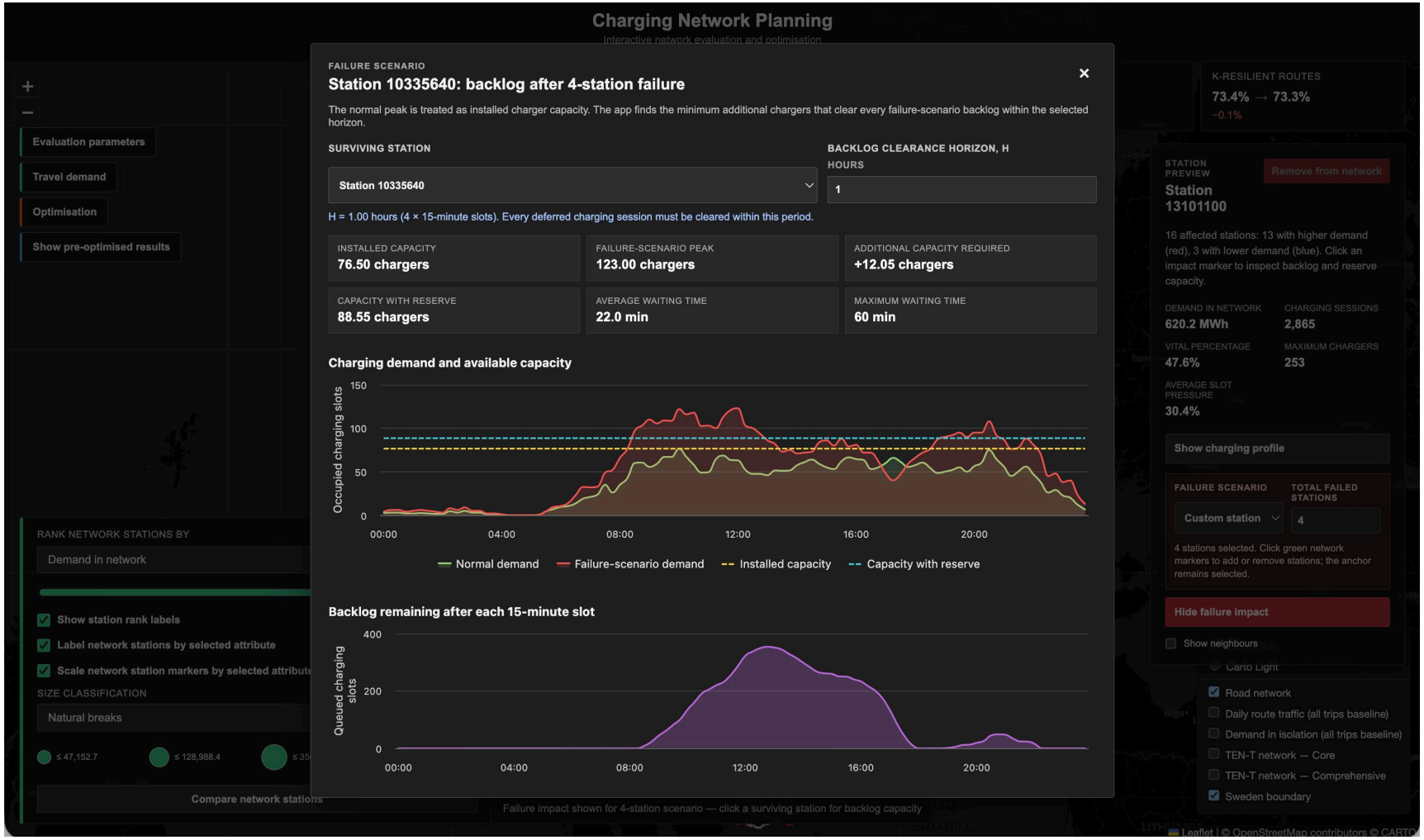
https://platform.thegordian.io/cip_rust/

All packaged in a web -based SDSS to evaluate failure scenarios



https://platform.thegordian.io/cip_rust/

All packaged in a web -based SDSS to evaluate system strain, QoS, & mgmt. strategies



https://platform.thegordian.io/cip_rust/

What's next? An SDSS with a system-of-systems (SoS) perspective

- From transport routes to **flexible fleets and logistics operations**
- From homogeneous charging slots with fixed power provision to **heterogeneous smart -charging systems** with load balancing, energy buffering, power boosting, and power throttling using batteries and renewable energy sources
- From flattened load profiles to **demand-responsive flexible load profiles and grid services**
- **Cross-system coordination and cooperation** through secure information interfaces

Publications

- Saqib, E., & Gidófalvi, G. (2024).*Dynamic Adaptive Charging Network Planning Under Deep Uncertainties.* **Energies, 17**(21), 5378. Published. Link
- Saqib, E., & Gidófalvi, G. *Route-Based Charging Infrastructure Planning under Uncertainty: A Heuristic Approach for Improving Network Demand and Electrification Impact.* **Environmental Research: Infrastructure and Sustainability.** Published. Link
- Saqib, E., & Gidófalvi, G. *Private Investor Centric Analysis of Mixed Charging Infrastructure Scenarios in Sweden.* **European Transport Research Review.** Under review.
- Saqib, E., Gidófalvi, G., & Dán, G. *Robustness and Resilience Analysis of Electric Vehicle Charging Network Designs.* **European Transport Research Review.** Under review.