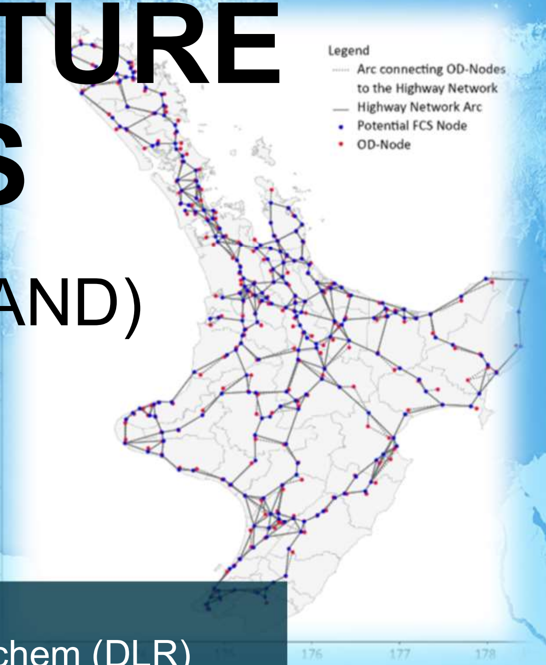
CHARGING INFRASTRUCTURE FOR ELECTRIC VEHICLES IN NEW ZEALAND (NORTH ISLAND)



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This presentation is mainly based on Rabl (2020)

Agenda

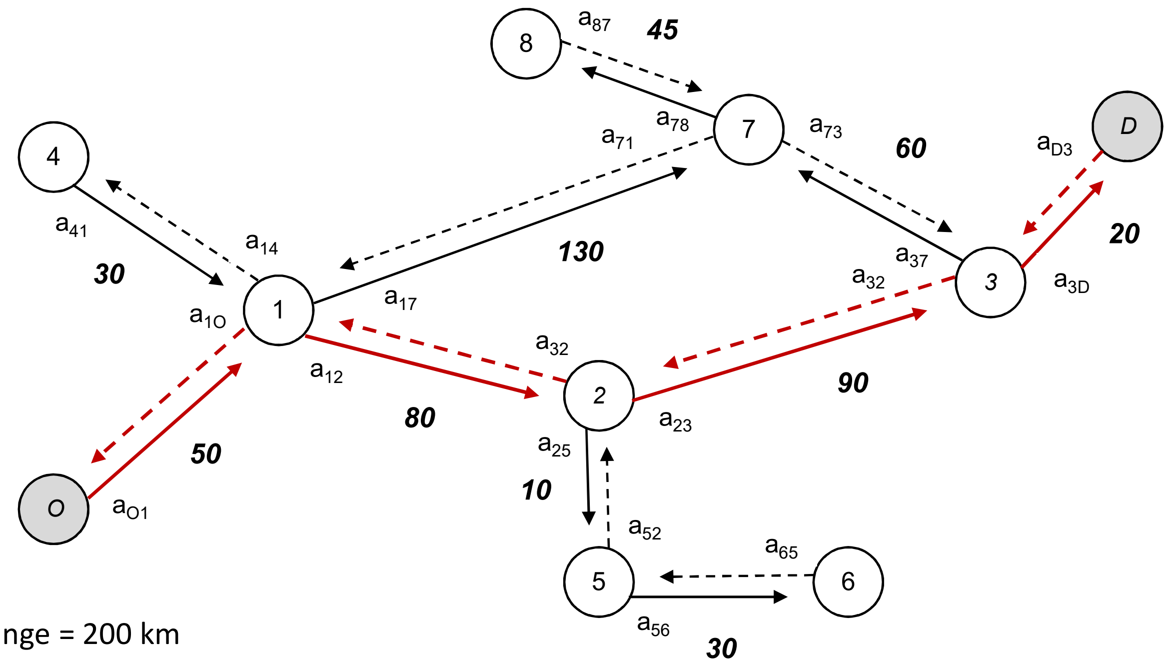
- Motivation
- Optimization Model
- Application to New Zealand North Island
- Results

Motivation and research questions

- Fast charging stations are mainly allocated along the highways where long distance trips occur (Jochem et al., 2015, 2019, 2022)
- Optimal allocation of fast charging stations is an old story (cf. Anjos et al., 2020):
  - Kuby and Lim (2005) introduced the Flow Refueling Location Model (FRLM)
  - Upchurch et al. (2009) extended the FRLM to the Capacitated Flow Refueling Location Model (CFRLM)
  - Recently, Zhang et al. (2015, 2017 and 2018) introduced a multi-periodic point of view in the Arc Cover-Path Cover (ACPC) formulation → capacitated and multi-periodic version of the ACPC-FRLM
- Research questions:
  - Where to place charging facilities to support long-distant journeys but yield minimum costs for their installation? → including grid costs!
  - In which quantity are charging facilities required at each location to serve the demand? → number of charging points per location
  - How to do an efficient upscaling in line with EV registrations over time? → dynamic development over time

Key concept: Enabeling long journeys → Demand is flow-based

- Problem is modelled as Flow Refueling Location Model: A trip is covered if an EV does not run out of electricity between charging stations (Kuby & Lim 2005)
- To cover the charging demand along a path, it is to be ensured that all arcs of the path are covered (Arc-Cover Path-Cover Concept) (Capar et al., 2013)



EV-Range = 200 km

Investment-Optimal Multi-Periodic Capacitated Arc-Cover Path-Cover Model:

$$\min \sum_{i \in N} \sum_{t \in T} \delta_t [(z_i^t - z_i^{t-1}) C_{i,fix} + (x_i^t - x_i^{t-1}) C_{i,var}] \quad (1)$$

⟹ Minimize the costs for newly installed stations and each newly added charging unit

$$\text{s.t.} \quad \sum_{i \in N_{jk}^{1q}} v_{iq}^{1t} + \sum_{i \in N_{jk}^{2q}} v_{iq}^{2t} \geq y_q^t \qquad \forall q \in Q, a_{jk} \in A^q, t \in T \quad (2)$$

⟹ Only those can travel who can charge where it is required

$$\sum_{q \in Q} \sum_{d \in D} f_q^t v_{iq}^{dt} \leq c x_i^t \qquad \forall i \in N, t \in T \quad (3)$$

⟹ The station capacity may not be violated

$$v_{iq}^{dt} \leq z_i^t \qquad \forall q \in Q, i \in N, t \in T, d \in D \quad (4)$$

⟹ Charging is only possible at opened stations

$$x_i^t \leq M z_i^t \qquad \forall i \in N, t \in T \quad (5)$$

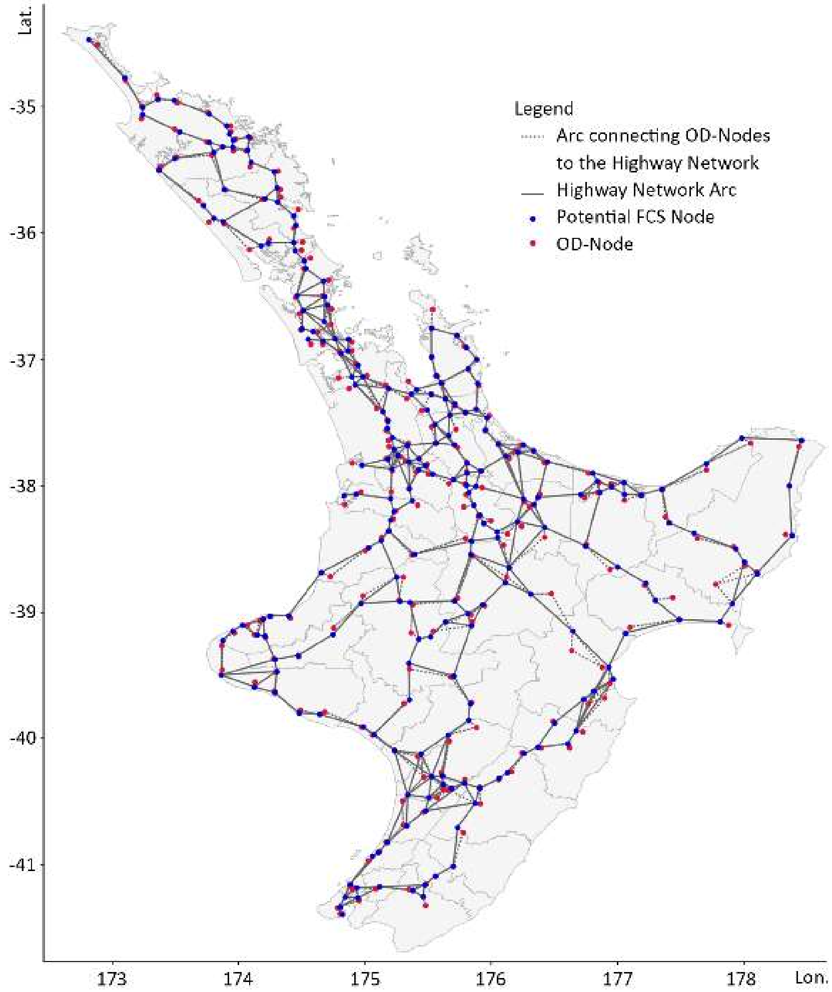
⟹ Install charging units only in opened stations

Investment-Optimal Multi-Periodic Capacitated Arc-Cover Path-Cover Model (continued):

$z_i^t \leq z_i^{t+1}$	$\forall i \in N, t \in T$	(6)	⇨ Once opened stations remain opened
$x_i^t \leq x_i^{t+1}$	$\forall i \in N, t \in T$	(7)	⇨ Once installed charging units remain installed
$\sum_{q \in Q} f_q^t y_q^t \geq S \sum_{q \in Q} f_q^t$	$\forall t \in T$	(8)	⇨ Ensure that a minimum fraction of the total EV-traffic in the system is enabled
$x_i^t \leq x^{max}$	$\forall i \in N, t \in T$	(9)	⇨ Limit the size of the charging stations to a maximum
$0 \leq y_q^t \leq 1$	$\forall q \in Q, t \in T$	(10)	
$0 \leq v_{iq}^{dt} \leq 1$	$\forall q \in Q, i \in N, t \in T, d \in D$	(11)	⇨ Definition of decision variables (10)–(13)
$z_i^t \in \{0, 1\}$	$\forall i \in N, t \in T$	(12)	
$x_i^t \in \{0\} \cup \mathbb{Z}^+$	$\forall i \in N$	(13)	

The coverage of long-distant journeys between regions requires to place charging facilities at relevant locations

- Representation of the **highway network** as a graph
- Extension of the graph with Origin- and Destination (OD)-nodes
- Routing between OD-nodes to determine travelled paths



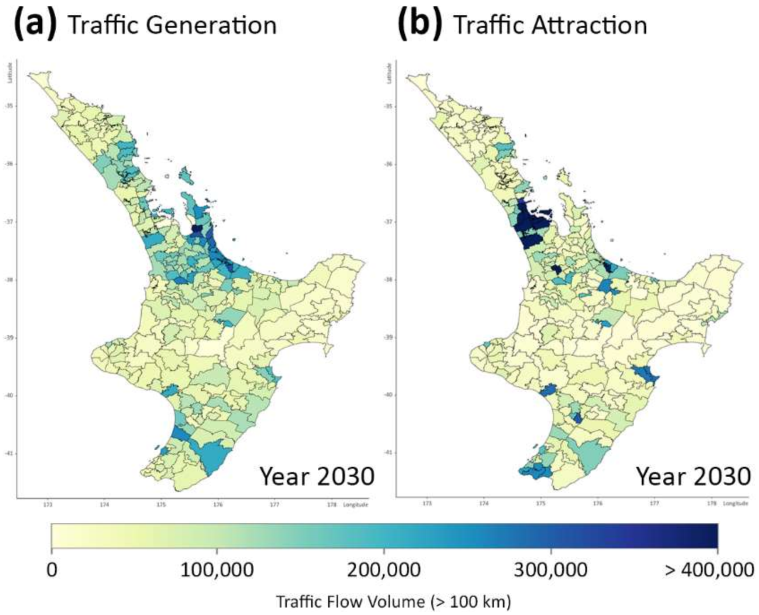
Traffic volumes between OD-nodes significantly affect the infrastructure requirement and need to be determined accurately

- Determination of traffic based on the Gravity Modell (LeSage & Fischer (2010) and O'Kelly 2009):

$T_{i,j}$	Traffic volume between origin i and destination j
$V(i)$	Push-factors of the origin
$W(j)$	Pull-factors of the destination
$C(i,j)$	Spatial separation of origin i and destination j, e.g. the distance $d_{i,j}$
$xs,\ yr,\ \beta$	Weighting parameters

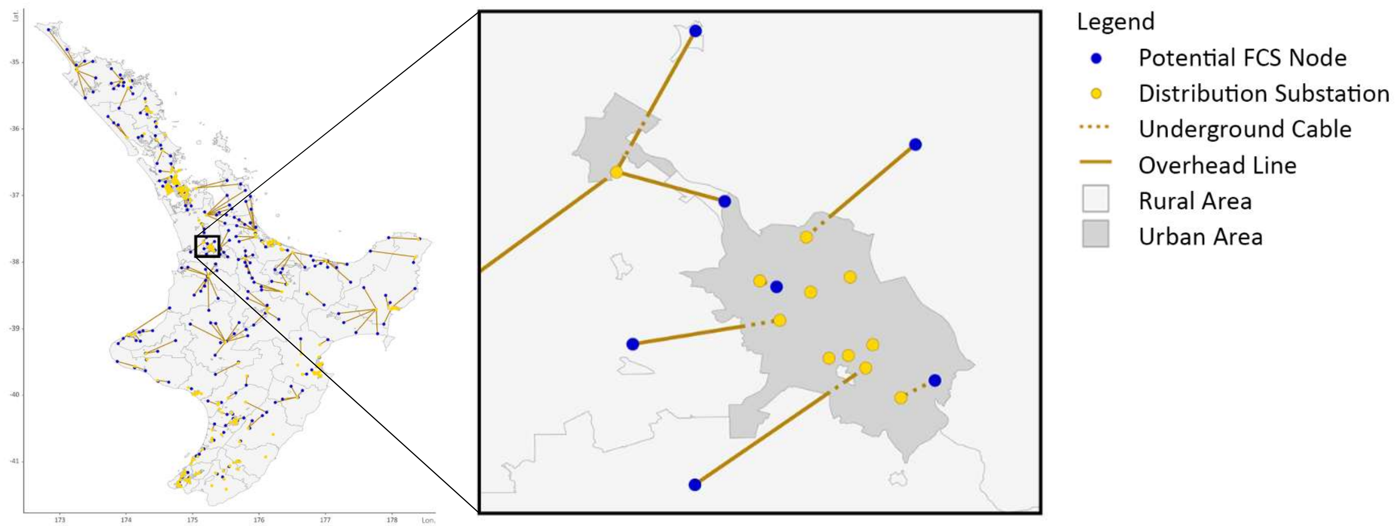
$$T_{i,j} = f(V(i), W(j), C(i,j))$$
$$V(i) = \Pi_{s \in S} V_{is}^{xs}$$
$$W(j) = \Pi_{r \in R} W_{jr}^{yr}$$
$$C(i,j) = d_{i,j}^{\beta}$$

- Push-/Pull-factors: Number of households, Avg. number of people per household, income
- Determination of weighting parameters based on observed traffic counts (New Zealand Transport Agency 2019):
  - Choose weights in a way that resulting traffic volumes resemble observed traffic counts most accurately
- Predict traffic for future periods based on regression of traffic count data

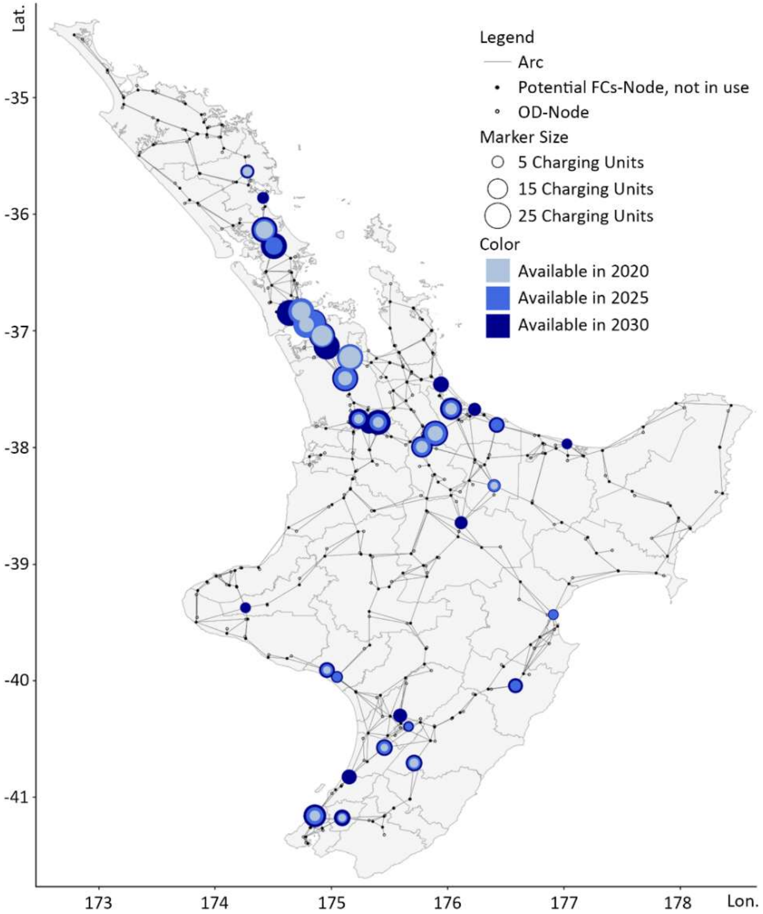


Different locations have different **connection costs** to the electricity distribution grid

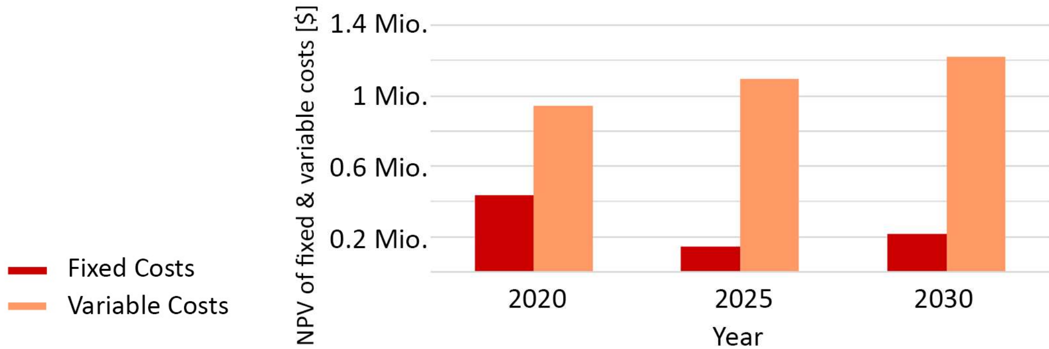
- Investments have a fixed and a size-dependent component:
  - Fixed: 95,070 $ per site (without grid connection)
  - Variable: 82,800 $ per charging unit
- Costs for grid connection highly depend on the required line type:
  - 35,970 $/km of overhead lines
  - 141,700 $/km of underground cables (CONSENTEC 2006))



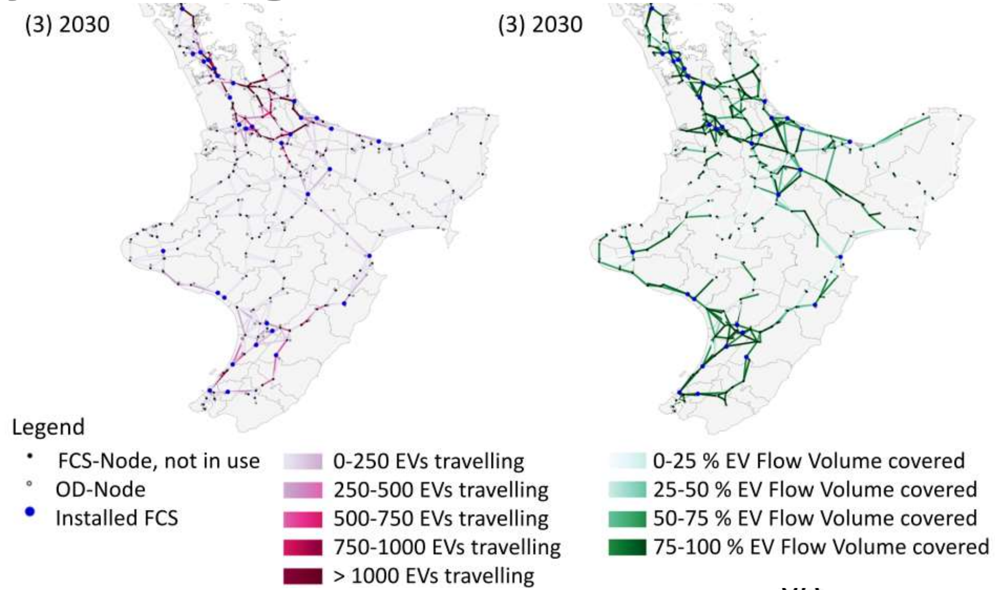
Charging stations are placed in densely populated areas along major traffic corridors and enlarged over time



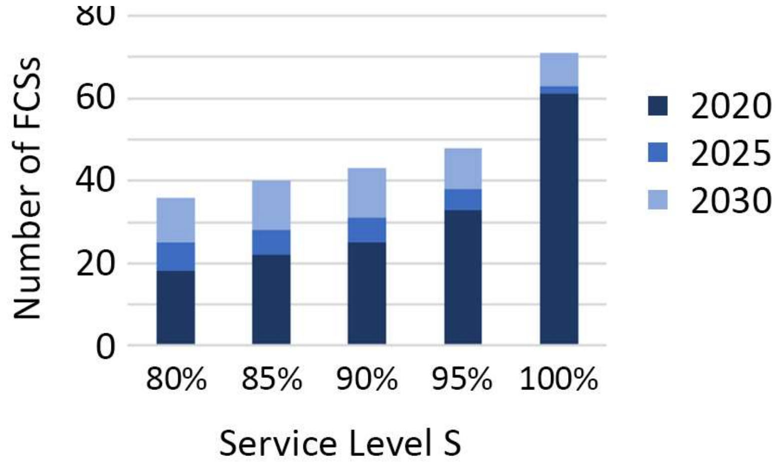
- Total number of required stations:
  - 18 in 2020, 25 in 2025, 36 in 2030
- Locations have relatively low grid connection costs and line lengths to be installed
- Most EVs will be present in densely populated and highly trafficked areas



The provision of charging stations focuses on short to medium distant journeys with high traffic volumes



- Short to medium distant and highly trafficked paths are on average well covered
- Very long and lightly trafficked paths can only be covered by sufficient charging infrastructure under significantly high additional costs



Concluding remarks and implications for future research

- Major Findings:
  - Charging infrastructure should be placed along highly trafficked corridors in densely populated regions with high traffic volumes
  - Grid connection costs should be considered
  - The installation of large stations is beneficial in terms of cost minimization compared to the installation of many small stations

- Future research:
  - Strategies for a cost-efficient coverage of remote regions or long-distant journeys
  - Deeper analysis on connection costs to several different electricity grid levels
  - Consideration of user acceptance

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Thank you for your kind attention!

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