Key to a Low-Carbon Energy Future: Transport Sector in NZ

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The Concept of Sustainability

Figure 1. The Three Spheres of Sustainability
Source: Rodríguez et al. (2002).
Sustainable transportation

Sustainability criteria have significant implications for transport planning:

• Efficient use of fuel
• Optimal control of traffic

A sustainable transport system should provide the inhabitants:

• Mobility
• Accessibility

➢ What are the current barriers that hinder us from developing a sustainable transport system?

➢ What policies should our government adapt in order to make our transport system sustainable?
Fuel consumption in Auckland

High car ownership per capita: cars are the #1 transport mode choice in NZ

Figure 5. Annual fuel consumption ($NZD) in the Auckland region, average

Source: Constructive Thinking, 2014
GHG emissions in Auckland

Transport accounts for 43.6% of gross GHG emissions.

CO₂ contributed 83.1%, CH₄ 10.5%, N₂O 1.7% and other GHGs 4.7%.

Figure 6. Auckland’s GHG gross emissions profile in 2016

Source: Auckland Council, 2019
Electric Vehicles – Current Status

- Electrification of road transport: benefit of reducing emissions
- The overall % is still miniscule compared to the large body of other types of vehicles in the fleet i.e. 1% of the entire vehicle fleet in NZ
- Barriers: *Range anxiety factor*, high price, the cost of batteries etc.

- ✓ Plug-In Hybrid Electric Vehicle (PHEV)
  - PHEV: plug into the grid so they can operate on electricity as well as an ICE

- ✓ Plug-In Battery Electric Vehicle (PBEV)
  - PBEV: run on electricity stored in batteries and has an electric motor rather than an ICE
Wireless charging – IPT

• Inductive Power Transfer (IPT) system (Zaheer and Covic, 2016): EVs can be energised wirelessly by embedding a wireless charging system.
IPT infrastructure for EVs

- Three types of IPT system:
  1. Stationary Inductive Power Transfer (SIPT)
  2. Semi-dynamic Inductive Power Transfer (SDIPT)
  3. Dynamic Inductive Power Transfer (DIPT)
IPT - Professor Covic and Boys
Wireless charging implementation

• Major technologies for commercialisation
• Wireless charging research labs and commercial licensing arm of the UoA

- The ground pad, and the wallbox with the mains interface.
- On the bottom of the vehicle is a receiving antenna.
- Inside the wallbox is the communication to the car to agree on charging power, safety, and control etc.
Wireless charging implementation
P3 case study of NZ - Outline

1. Public-private partnership (P3) overview
2. Economics of the DIPT roadway infrastructure: assumptions and simulation
3. Empirical results & environmental benefits
4. Sensitivity analysis on vehicle uptake and toll fee
5. Challenges and opportunities of DIPT roadway infrastructure through P3
P3 case study of NZ - P3 Overview

• **P3**: a form of collaboration between public and private bodies to enter into a contract
  - Involves undertaking specified roles for constructing and operating the infrastructure, while sharing any potential risks
  - Main challenge: forming the contract to uncover the optimal balance
    - Public sector: maximised social welfare - offer the highest level of community service
    - Private sector: maximised profit – ensure adequate cash flows to achieve the agreed return on investment

• To tackle uncertainties:
  - Minimum Return Guarantee
  - Flexible contract structure
    - Build-Transfer-Operate (BTO) - public sector owning the infrastructure after completion and leasing it to the private sector for operation during the contract period
P3 case study of NZ – Research Purpose

1. Yang, Long, Li and Rehman (2016)
   - P3 model for EV static charging infrastructure in China
   - Win-win situation based on long-term cooperation
   - Government sectors are enthusiastic but private investors’ willingness still needs to be stimulated
   - Requires collaboration between public and private body: capital participation; business involvement in management and operation, and the role of the market in resource allocation

   - Mathematical models of charging facility (stations or lanes) choice equilibrium in the US
   - Explore the optimal deployment plans of charging stations and lanes under either public or private provision
   - Charging lanes are competitive in both cases for attracting drivers and generating revenue

3. Our Objectives:
   - Address the challenges of large-scale investment needed through partnership in NZ
   - A viable solution that can contribute towards a low-carbon energy future?
P3 case study of NZ – EV uptake

EVs: 36.6% of the total vehicle fleet (buses, trucks, passenger vehicles, and utility vehicles) by 2040. Ministry of Transport's estimate: 40% of the total vehicle fleet by 2040.

*Based on the total # of vehicles in Auckland and the daily # of vehicles using the motorway, the average # of vehicles using the motorway was calculated at 51,570 per day in 2017. The % increase in the total vehicle fleet in Auckland is constant at 3.4% - the # of EVs using the motorway/hour is obtained based on our estimate of EV growth rate.
A traffic corridor of a specified length of $l \ (km)$ equipped with DIPT system

The DIPT roadway infrastructure is assumed to have a power of $P \ (kW)$ for charging the EVs with a recharging efficiency ($\varepsilon$).

The total # of EVs using the lane is given by $f$ as calculated in the previous section.

EVs have a battery capacity of $E \ (kWh)$ with an efficiency of $\eta$.

Constant speed of EVs travelling at $v \ (kmph)$ all along the corridor.

The facilities are provided in such a way that no vehicle can finish the trip without recharging and the charging provided is sufficient to complete the trip.

The EV drivers are assumed to have a range anxiety factor of $(1-x)$: the driver can be assured with a confidence level $x$. 
P3 case study of NZ - Economics of infrastructure

1. Cost

\[ C = \text{Civil Cost} + \text{Cost of Electronics} + \text{Charging Cost} \]

2. Revenue

\[ R = \# \text{ of vehicles} \times \text{cost of usage} \left( \frac{\$}{\text{kwh}} \right) \]

3. Net Cash Flow

\[ NPV = R - C \]

4. P3 Investment

\[ I = f(\text{Expected profit, Rate of return, Risks taken}) \]

- Optimal location of the charging facility? Rather, the model only calculates the length of the transmitter required for a vehicle to finish the trip – we have a separate paper
# P3 case study of NZ - Data for computation

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>Length of the corridor</td>
<td>300 km</td>
<td>-</td>
</tr>
<tr>
<td>E</td>
<td>Battery size</td>
<td>30 kWh</td>
<td>-</td>
</tr>
<tr>
<td>(\eta)</td>
<td>Battery efficiency</td>
<td>4 km/kWh</td>
<td>Chen, Liu and Yin (2017)</td>
</tr>
<tr>
<td>X</td>
<td>Range anxiety factor</td>
<td>0.7</td>
<td>-</td>
</tr>
<tr>
<td>V</td>
<td>Speed</td>
<td>80 km/hr</td>
<td>-</td>
</tr>
<tr>
<td>P</td>
<td>Power of charging infrastructure</td>
<td>100 kW</td>
<td>Jang, Suh and Kim (2016); Chen, Liu and Yin (2017)</td>
</tr>
<tr>
<td>(\varepsilon)</td>
<td>Recharging efficiency of IPT</td>
<td>0.75</td>
<td>Chen, Liu and Yin (2017)</td>
</tr>
<tr>
<td>(C_d)</td>
<td>Construction cost per unit length of transmitter</td>
<td>$732,957.50/km</td>
<td>Chen, Liu and Yin (2017)</td>
</tr>
<tr>
<td>(C_p^*)</td>
<td>Cost per unit power</td>
<td>$814/kW</td>
<td>Chen, Liu and Yin (2017) and (Nie and Ghamami, 2013)</td>
</tr>
<tr>
<td>(C_e)</td>
<td>Cost for charging EV including electricity cost</td>
<td>$0.29 $/kWh</td>
<td>MBIE (2018)</td>
</tr>
<tr>
<td>I</td>
<td>Discount rate</td>
<td>6%</td>
<td>Public Sector Discount Rates for Cost Benefit Analysis (2008)</td>
</tr>
<tr>
<td>(T_c)</td>
<td>Concession period</td>
<td>15 years</td>
<td>-</td>
</tr>
<tr>
<td>(\lambda)</td>
<td>Importance of profit maximising</td>
<td>0.5</td>
<td>Weightage given</td>
</tr>
<tr>
<td>(\omega_s)</td>
<td>Risk ratio the private sector takes</td>
<td>0.6395</td>
<td>-</td>
</tr>
<tr>
<td>R</td>
<td>Expected profit</td>
<td>$68,000,000.00</td>
<td>Calculated at the end of concession period</td>
</tr>
<tr>
<td>r</td>
<td>Expected rate of return for private investor</td>
<td>12.5%</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Project construction year/duration</td>
<td>2020/3 years</td>
<td>-</td>
</tr>
</tbody>
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Note: All currency used is in NZD; * - Assuming two inverter units per km (Shin et al., 2014)
P3 case study of NZ - Net Cash Flow

Concession period = 15 years
Government Investment = 9.46%
Toll fee = $0.37/kWh

NPV Millions

Year

$ 52,532,457
P3 case study of NZ – Environmental Benefits

- Pure EVs can reduce CO₂ emissions by 54.27% compared to petrol vehicles, and 52.33% when compared to diesel engines.
- CO₂ emissions from pure EVs is higher than PHEVs: higher demand for electricity; non-renewable power sources
P3 case study of NZ – Vehicle Uptake Analysis

Vehicles using the facility ±5%

The average value of the net cash flow at the end of 15 years > the expected rate of return for the private industry.

DIPT infrastructure for EVs is a good investment opportunity.
P3 case study of NZ – Toll Fee Analysis

Change in toll fee ±5%

<table>
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<tr>
<th>Toll Fee</th>
<th>NPV in 15 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.37</td>
<td>$52,532,398</td>
</tr>
<tr>
<td>$0.36</td>
<td>$43,521,240</td>
</tr>
<tr>
<td>$0.35</td>
<td>$29,937,767</td>
</tr>
<tr>
<td>$0.34</td>
<td>$16,354,294</td>
</tr>
</tbody>
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Change in initial investment

- A lower toll fee will provide a higher social benefit favouring consumers, however the Govt will need to bear the burden of the reduced social cost in the form of guarantee to the private industry for the concession period.

- As the importance of profit maximisation and allocation decreases, the value of risk-taking increases and hence the Govt. must invest more to compensate for the risk taken by the private industry, and *vice versa*.

- As the expected profit increases, the Govt. can initially invest less in the project as the rate of return for the private sector will be guaranteed.
P3 case study of NZ – Future Opportunities

• Economically viable option; capital intensive but possible

• Key takeaway message:
  ➢ Tax rebates could be given to make the price of an EV more competitive
  ➢ The # of charging facilities need to increase around the country
  ➢ Govt. needs to assist in the development of EV infrastructure to make the technology more viable for consumers
  ➢ Govt. formulates policies that could encourage private sector participation

• Future research:

  1) Integration with real-world traffic conditions, i.e. constant speed assumption

  2) Partial charging of the vehicle as they enter and exit the lane

  3) Electricity demand and grid load etc.
Traffic congestion issues

• Congestion
  ▪ Most prominent negative externality with economic cost: NZD$0.9 billion to NZD$1.3 billion ≈ 1% and 1.4% of Auckland’s GDP (NZIER, 2017)

• The Congestion Question in Auckland
  ▪ Auckland Council’s pilot study: how to reduce congestion on Auckland roads?
  ▪ No further progress as to date
  ▪ EVs don’t pay fuel tax, yet use roads
  ▪ Congestion as a result of a binary choice problem between a ‘safe’ route and a ‘risky’ route
  ▪ Solutions?
    1) Increase the road capacity
    2) Charging toll fees
    3) Justify the public transport price scheme
Traffic congestion issues

• A complementary method for achieving the “ideal” economically efficient vehicular diverging
  ▪ The combination of charging toll fee on the highway and applying an average pricing structure for public transportation

• Laboratory experiment: simulate transportation route-choice games
  ▪ Set the route-choice model of commuters as a coordination game:
    1. a set of \( I = \{1, 2, \ldots, n\} \) commuters
    2. an action set: \( D_i = \{R, M\} \)
    3. a binary choice: \( d_i \in D_i \)
    4. identical ex-ante preferences
Traffic congestion issues

• Theoretical background
  • Constant vs Average pricing schemes; Equal Pay-off Equilibria v.s. Socially Optimal Equilibria;
    Definition of the Route-Choice Games; Equilibrium Strategies; Parameters, Equilibria and
    Testable Hypotheses

• Experimental Interface: Example
Traffic congestion issues

• We obtained a panel dataset made by 240 subjects (i.e. 40 periods across 12 sessions)
• Order effects are where the order of treatments in an experiment matter
• We conducted a session-level random effects regression analysis to examine reverse order effects

\[ \sigma_r^S - \sigma^* = \alpha + \beta r + \gamma d + \theta(rd) + \epsilon_r^S \]

• The sequence dummy \( d \)
• In total, gamma is insignificant in all six regressions, therefore, we can conclude that reverse order effects do not exist in our sample.
Traffic congestion issues

- Equilibria Predictions vs Observations

- The observations: substantial variations
- Choice behaviour might include an inherent error component
Traffic congestion issues

- QRE vs Fitted QR

![Graphs showing comparison between QRE and Fitted QR]

- Quantal Response Equilibrium (QRE) justification: with a game dependent logit specification (McKelvey and Palfrey, 1995).

- Preliminary results:
  - If we increase road capacity then congestion will increase
  - Different policy mixes contribute to lowing congestion to a socially optimal level
  - E.g. A combination of congestion tolls with price differentiation in public transport reduces congestion
A selection of our work


Takeaway messages

• Transport system is a system of systems

• A widespread transition to e-mobility and introduction of congestion tax is economically feasible – but socially and politically desirable?
  
  ➢ Planned and strategic infrastructure network critical to supporting regional EV drivers
  
  ➢ Address barriers to deployment of charging stations/lanes in cities/regions

• Urban policy-making: priorities?
Thank you!

Source: The Economist, 2017

Questions?