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

Dr Selena Sheng
Energy Centre, UoA Business School

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Sustainable transportation

Implications for transport planning:

• Efficient use of fuel/alternatives
• Optimal control of traffic

A sustainable transport system:

• Mobility
• Accessibility

My research:

➢ Current barriers?
➢ Policies?

Figure 1. The Three Spheres of Sustainability
Source: Rodriguez et al. (2002).
GHG emissions in New Zealand

Fig. 1 International comparisons for per capita emissions in 2017

- The Agriculture & Energy sectors = 47.8% & 40.5% of gross emissions in 2018, respectively

- Emissions from road transport = 19.1% of gross emissions

Electrification of road transport: benefit of reducing emissions

The overall EV% is still miniscule

Barriers: *Range anxiety factor & high upfront purchase cost (\$ of batteries)* etc.

**Research Project 3714101. 2017 – 2022, MBIE Endeavour Fund 2017 - 2021**

Inductive Power Transfer Technology = Wireless transfer of Power

(Zaheer and Covic, 2016)
Why would one invest in wireless charging technology?

EV & AV Market outlook in 2035: [1]

- EVs: 16% of the LDV market (GlobalData)
- AVs: 25% market share of new car market
- 12M fully autonomous cars/year
- 18M partially autonomous cars/year
- Total AV market: 77 billion USD

Why wireless charging?

• Wireless charging allows self-driving EVs to recharge autonomously
  o “Who will plug in your self-driving car?” No one

• Wireless charging simplifies the use of EVs
  o Reduces range anxiety, promoting EV adoption
  o Unique selling point of EVs

→ Wireless charging is **essential** for future automotive industry
Charging Solutions

Plug-in charging (PC)

Wireless charging (WC)

- Stationary Wireless Charging (SWC)
- Semi-Dynamic Wireless Charging (SDWC)
- Dynamic Wireless charging (DWC)
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
Wireless charging implementation

- Major technologies for commercialisation
- Wireless charging research labs and commercial licensing arm of the UoA
Wireless charging implementation
Growing interests from the Academia

Number of publications and patents per year related to wireless charging for EVs[1]

- Introduction of Nissan Leaf & the Tesla Roadster around 2008 until 2010
- Disruptive technology

Some performance figures: [1]

Conductive charging
- Up to 95% efficiency
- Up to 5 kW/dm³

Inductive energy transfer
- Up to 92% efficiency
- realise 1.5-2.5 kW/dm³

Wireless charging:
- A technological compromise - air gaps
- Trade-off: transmitter/receiver volume & the transmission efficiency.

More research needed

Research questions for wireless charging:

• Positioning of car exactly on top of charging pad?
• Communication from vehicle to ground? (no wires!)
• Detecting foreign objects (key) in air gap?
• Detecting living creatures (cat) in air gap?
• Electromagnetic compatibility?
• Mechanical issues: strength, heat, weather-proof?
• Health issues? Security? Safety?
• NZ should take the lead in this direction!

(1) FLIR image from WiseHarbor Spotlight Report, sept. 2015
IPT Roadway Project Team

Research Team:
- University of Auckland: Power Electronics & Inductive Power Research, Centre for Advanced Composites Materials, Transportation, Engineering Science, Business School
- GNS Science, Wellington
- Victoria University of Wellington, Robinson Research Institute
1. Optimise placement strategies to maximise network efficiency and benefit
2. Optimise strategies for sustainable implementation of roadway IPT
3. Evaluation of potential economic and environmental benefits of faster EV take-up through roadway IPT implementation
4. Engagement with Iwi to improve economic & sustainability outcomes

From left to right: Dr Doug Wilson (CEE); Dr Prakash Ranjitkar (CEE); Dr Tumanako Fa’aui; Prof Basil Sharp; Dr Selena Sheng; Dr Andrea Raith; Mr Majhi; Mr Ajith Sreenivasan
Research Methodology/Scenarios

Simulation Model Scenarios

DWC

EV characteristics Based

SOC State
- Threshold – 20%
- Recommended level (40-80percent)

EV Category
- Car
- Public Transit – Bus

EV Range
- Small (<150km)
- Medium (150-250km)
- High (>250km)

EV user Based

Route choice Behavior

Exclusive path

Single route
- Travel Time
- Presence of charging facility
- Presence of toll

Shared path

Multiple route

EV demand Based

EV Trip Demand
- 40%, 50%, 60% of HBW Trips

Total Trip projection
- Current trip (2016 O-D Data)
- By 2026 and 2036

Infrastructure Based

IPT Characteristics
- Slow (<20KW)
- Medium (20KW-100KW)
- High (>100KW)

Efficiency (70%, 80%, 90%)
University joins global consortium for vehicle electrification

6 August 2020  |  Faculty of Engineering, Science and Technology

Work at the University of Auckland will play a significant role following this week’s launch of the National Science Foundation (NSF)-funded Engineering Research Centre for Electrified Transportation in Utah, USA.

"Sustainable, electrified transportation and the enabling technologies that support this, such as the electrified road, are key to the global future."

Professor Dawn Freshwater
Economic analysis of dynamic inductive power transfer roadway charging system under public-private partnership—Evidence from New Zealand

Mingyue Sheng1,2, Aijith Viswanath Sreenivasan2, Basil Sharp3, Douglas Wilson2, Prakash Ranjitkar2

1 Energy Centre, Faculty of Business and Economics, The University of Auckland, New Zealand
2 Department of Engineering Science, Faculty of Engineering, The University of Auckland, Auckland, New Zealand
3 Department of Economics, Faculty of Business & Economics, The University of Auckland, New Zealand
4 Department of Civil and Environmental Engineering, Faculty of Engineering, The University of Auckland, New Zealand

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ABSTRACT
Electric vehicles (EVs) are contributing to a decarbonization of conventional Internal Combustion Engines (ICEs) in the transport sector. With recent technological advancements in Dynamic Inductive Power Transfer (DPT) systems, EVs can be energized wirelessly by embedding a roadway charging network while travelling in motion. However, the provision of a viable DPT system still remains challenging, given the large-sized investment required and some potential risks involved. This study assesses the economic viability of a DPT system for EVs through public-private partnership (PPP), by employing a net present value (NPV) framework, to determine the optimal PPP ratio. The PPP model could be considered an effective pathway for leveraging capital, alleviating uncertainties associated with construction and operation, and achieving a nation’s Sustainable Development Goals (SDGs). New Zealand is used as a real-world case study. Our results indicate that, for a 15-year concession period under PPP where the private investor is expecting a 12.5% return, the government can contribute 9.46% towards the initial investment and charging roadway users a toll of 37 cents/kWh. By implementing the DPT system, EVs could achieve a significant reduction in carbon dioxide (CO2) emissions compared to ICEs. The robustness of the model is validated through Monte Carlo sensitivity analysis.

1. Introduction
Sustainable development is surely a focus of many policy makers around the globe. The main idea around this concept is to transition from a pure economic emphasis to a more integrated social, economic and environmental framework. With huge losses in biodiversity and the risk of irreversible temperature increase (Steffen et al., 2015), there is an urgent need to change our practices and business models in a way to encompass all the three elements of sustainable development. In January 2015, the United Nations refamed the Millennium Development Goals and strengthened their global agenda with the inclusion of Sustainable Development Goals (SDGs). Countries who adopted the agenda should address sustainable development through 17 goals and 169 targets by 2030. Since then, there has been a shift in the paradigm for assessing issues or evaluating projects not only from a business standpoint, but also taking into consideration the effect on environment and society as a whole (United Nations, 2015). A number of indices and indicators such as Happy Planet Index, Sustainability Report cards have been developed to assist countries clearly outline targets and pathways for meeting the SDGs. By the end of 2015, the Conference of Parties ratified the Paris Climate Agreement to restrict temperature increase within 1.5 °C. While SDGs focused on sustainable business models, the Climate Agreement put more weight on the technical aspects of climate change. Technological advances are required to mitigate the carbon footprint left by industries and provide the foundations for enhanced energy efficiency.

Globally, road transport contributed more than one fifth of energy consumption and approximately 17% of carbon dioxide (CO2) emissions in 2013 (ETR, 2015). To decarbonize the transport sector, it is generally accepted that electric vehicles (EVs), among other alternative fuel vehicles such as hybrid, bio-fuel, and fuel cell vehicles, are an ideal replacement of fossil fuels (European, 2017). Electrification of road transport could reduce the demand for petroleum and mitigate negative environmental impacts by lessening greenhouse gas emissions, especially when implemented simultaneously with renewable energy sources to supply the new electrical load (Dong et al., 2014). As such,
Public Private Partnership

• **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; community service
    
    • Private sector: maximised profit; cash flow
  
  • 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
Economics of infrastructure -1

• 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 $x$. 
1. Cost

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

2. Revenue

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

3. Net Cash Flow

\[ NPV = R - C \]

4. P3 Investment

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

Concession period = 15 years

Government Investment = 9.46%

Toll fee = $0.37/kWh
Project 2: Auckland Motorway SH1 Corridor

Corridor Information:
- SH-1 and Southern Motorway
- Billing Road Junction to Pokeno Interchange
- Total Length: 87Km (One-way)

Case Study

- A microscopic traffic simulation model - AIMSUN
- Calibrated & validated based on 2016 data
- Only light fleet are considered - Nissan Leaf 2011 model
- DWC scenarios for different energy parameters & traffic flow conditions
- Optimal placement of the IPT facility on a larger road network
Findings and future works

-ve relationship:

• Length of charging sections & Energy demand

• DWC power supply & energy transfer efficiency
Project 3: Bus Route 70 – Botany to Britomart

**Model Assumptions**

- Regular weekday service Only
- Route = flat
- Electricity cost = be constant over time
- Charging systems: only by buses
- The charging system knows the amount of charge available in the bus
- The bus is recharged to full upon reaching the depot
Speed profile from Sumo
Main findings

• Battery size: 219 kWh complete the trip; no charging

• -ve correlation between velocity of the bus & the SOC
  ✓ As the bus spends more time over the charging pads, more power is transferred to the bus battery and hence the SOC increases

• Largest costs:
  1) Variable cost associated with the length of the charging transmitters
  2) Battery size

• Capital intensive - multiple services using the same route
Designing the “best” wireless chargers!

- Multi-physical
  - Power electronics
  - Electromagnetics
  - Control systems
  - Mechanics
  - Electromagnetic compatibility

- Multi-objective
  - System cost
  - Converter size
  - Transmission efficiency
  - Transmission range
  - System reliability

- Multi-mode
  - LDV
  - MDV
  - HDV

The best wireless charger is the **best mix** of all properties

→ Highly application-specific
→ Pareto-optimal design methods required
→ Optimisation cost-functions to be defined
Project 4: EV, Public Charging Facilities & Solar Potential (with Vector) - Data matching

**EV data from MoT**
- 148 area units
- Aggregated format

**PV data from Vector**
- 533 SA units
- Standard ‘sa22018_v1_00_name’ by StatsNZ for (GIS)

1. **Name sorting**

<table>
<thead>
<tr>
<th>EV Areaunit</th>
<th>PV SAA name</th>
<th>PV count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albany</td>
<td>Albany Central</td>
<td>1</td>
</tr>
<tr>
<td>Albany</td>
<td>Albany Heights</td>
<td>12</td>
</tr>
<tr>
<td>Albany</td>
<td>Albany South</td>
<td>17</td>
</tr>
<tr>
<td>Albany</td>
<td>Albany West</td>
<td>7</td>
</tr>
</tbody>
</table>

2. **QGIS to manually check overlapping areas**
Relevant studies

- Only a few relevant studies found
- Mostly from a mechanical point of view
- Lack of economic/econometric analysis on whether solar potential has impacts on EV uptake
- Microscopic vs. macroscopic analysis
- No NZ data
Selection of variables

Main factors

- Public chargers
- Availability of PV panels
- Distance to CBD
- Transport mode
- Vehicle ownership
- Social and economic factors

Figure 3 - Number of Electric Vehicles adoption
Tests & Hypotheses

• **Solar potential effects**: to test if the availability of PV panels has any impact on EV uptake
  - Hypothesis (H1):
    The availability of PV panels has a positive and significant impact on EV uptake in the community.

• **Spatial autocorrelation**: to test if EV-charging infrastructure has a “neighbourhood effect” on EV uptake
  - Hypothesis (H2):
    EV-charging infrastructure in the neighbouring areas have a positive and significant impact on EV uptake.

• **Marginal effects**: to examine if EV adoption by technology enthusiasts during the early-adopter phase could affect subsequent adoption once the technology becomes more widely spread
  - Hypothesis (H3):
    Early adoption has an overall positive effect on subsequent technology adoption: the lagged EV adoption having a statistically significant positive value in all time-lagged spatial models
Econometric model

• Spatial model

\[ Y = X\beta + WX\gamma + \varepsilon \]

• Negative binomial regression models

➢ The Poisson model states that the probability that the dependent variable \( Y \) will be equal to a certain number \( y \) is:

\[ p(Y = y) = \frac{e^{-\mu} \mu^y}{y!} \quad \mu = \exp(x_i' \beta) \]

Where \( \mu \) is the intensity or rate parameter: \( \text{var}(y \mid x) = \mu + \alpha \mu^2 \)

➢ The negative binomial model has a less restrictive property that the variance is not equal to the mean

When \( \alpha > 0 \), overdispersion (test if \( \alpha \) is significantly different from 0).
## Preliminary results

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>Model 1</th>
<th>Model 2 (band 100)</th>
<th>Model 3 (band 100)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main factors</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar PV (H1)</td>
<td>0.012**</td>
<td>0.012**</td>
<td>0.011**</td>
</tr>
<tr>
<td></td>
<td>(0.006)</td>
<td>(0.006)</td>
<td>(0.006)</td>
</tr>
<tr>
<td>Charger count update</td>
<td>0.260</td>
<td>0.311*</td>
<td>0.355**</td>
</tr>
<tr>
<td></td>
<td>(0.192)</td>
<td>(0.181)</td>
<td>(0.150)</td>
</tr>
<tr>
<td><strong>W X charger count update</strong></td>
<td>4.660**</td>
<td>6.297***</td>
<td>9.110***</td>
</tr>
<tr>
<td>(H2)</td>
<td>(1.979)</td>
<td>(1.647)</td>
<td>(1.639)</td>
</tr>
<tr>
<td>Total EV origin (H3)</td>
<td>0.027***</td>
<td>0.027***</td>
<td>0.027***</td>
</tr>
<tr>
<td></td>
<td>(0.009)</td>
<td>(0.009)</td>
<td>(0.009)</td>
</tr>
<tr>
<td><strong>W X total EV origin</strong></td>
<td>-0.071**</td>
<td>-0.090***</td>
<td>-0.191***</td>
</tr>
<tr>
<td></td>
<td>(0.035)</td>
<td>(0.032)</td>
<td>(0.065)</td>
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<tr>
<td><strong>Distance to CBD</strong></td>
<td>-0.039***</td>
<td>-0.066***</td>
<td>-0.088***</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
</tr>
<tr>
<td><strong>Car ownership</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Two vehicle</td>
<td>0.006***</td>
<td>0.006***</td>
<td>0.005***</td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td>(0.002)</td>
<td>(0.002)</td>
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<tr>
<td><strong>Social and economic factors</strong></td>
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<tr>
<td></td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td><strong>Other control variables</strong></td>
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<tr>
<td>lnalpha</td>
<td>-0.864***</td>
<td>-0.937***</td>
<td>-0.996***</td>
</tr>
<tr>
<td></td>
<td>(0.147)</td>
<td>(0.148)</td>
<td>(0.156)</td>
</tr>
</tbody>
</table>
Discussions

• Solar panels = one way that sustainable tech can be integrated into homes
• The use of smart metering technology in the residential charging systems - apps which provide data such as how much energy has been used, the cost of charging and charge history
• Behaviour change programs needed when combined with other forms of support for home efficiency improvements
• Co-ordinated national program needed with a commitment to multi-year government investment
• Investment wise - PPP?
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 & 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?
A selection of our work


Thank you!

Source: The Economist, 2017

Questions?
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>
<thead>
<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>
</table>

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.
The Impact of COVID-19 on Transport


Figure 1. Variation of transport modes in NZ

Notes: Authors' elaboration based on Apple Mobility Trends Reports.
(a) Percentage change in requests for directions by transport mode in New Zealand
(b) Average percentage change for (a).