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ENERGY CENTRE

Moving towards a sustainable transportation system for New Zealand

A summary of recent research

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Dual Plenary 4: Energy Transition in Transport

Background

- Transport sector:
  - a main component of economic development
- Critical long-term challenge worldwide:
  - 20% of global energy
  - One-quarter of the overall energy-related CO2
  - Road transport: three quarters of total transport emissions
- New Zealand's unique emissions profile:
  - NZ's gross GHGs were 80.9 Mt CO2-e in 2017 = 2.2% increase from 2016 emissions, mainly caused by an increase of emissions from road transport
  - Two largest emitters in 2017: Agriculture (48.1%) & Energy (40.7%)
  - Road Transportation - 44% of total emissions from energy sector

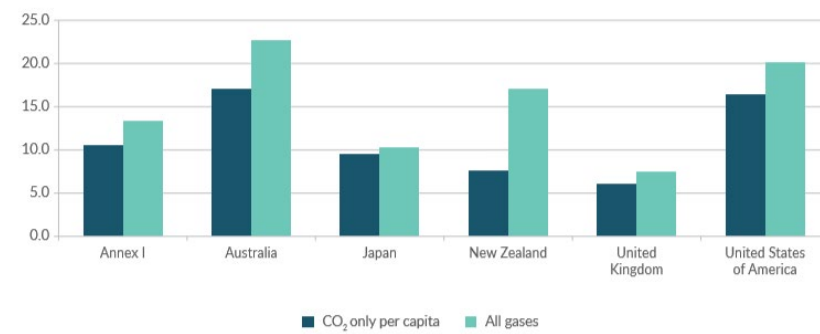

Fig. 1 NZ's gross and net emissions from 1990 to 2017, 23%+ (MfE, 2019) Fig. 2 International comparisons for per capita emissions in 2016 (MfE, 2019)

Sustainability and sustainable transportation

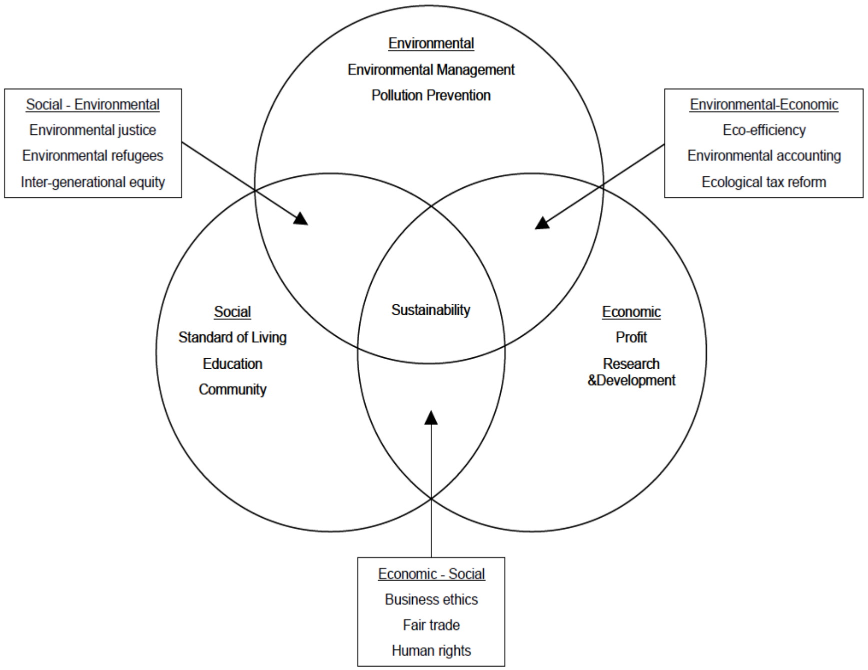

Figure 3. The Three Spheres of Sustainability
Source: Rodriguez *et al*. (2002).

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?*

Car ownership in New Zealand

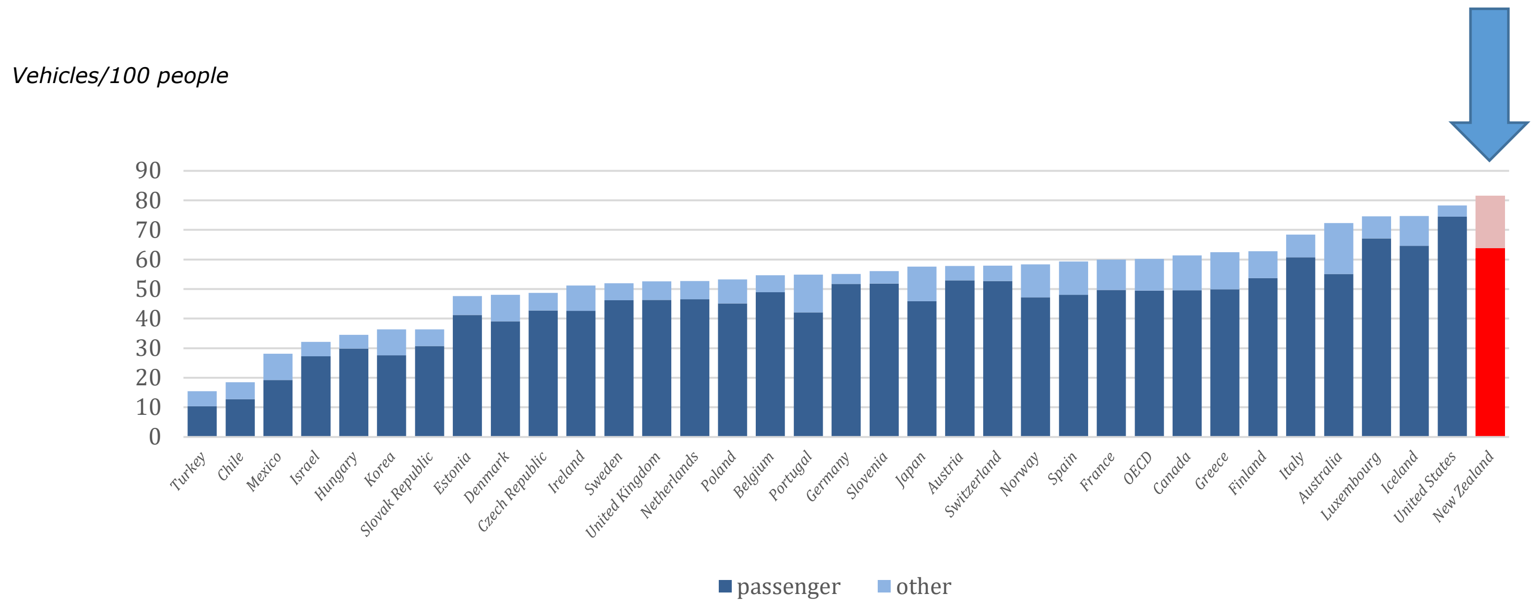

Figure 4. Motor Vehicle Ownership among OECD members in 2010

Source: OECD, 2013.

Note: 2009 data for Canada and Ireland; 2011 data for Australia, Iceland, Japan, Mexico, New Zealand and Switzerland. 2010 data for the other countries. The OECD totals are based on OECD Secretariat's estimates.

Transport choice in New Zealand

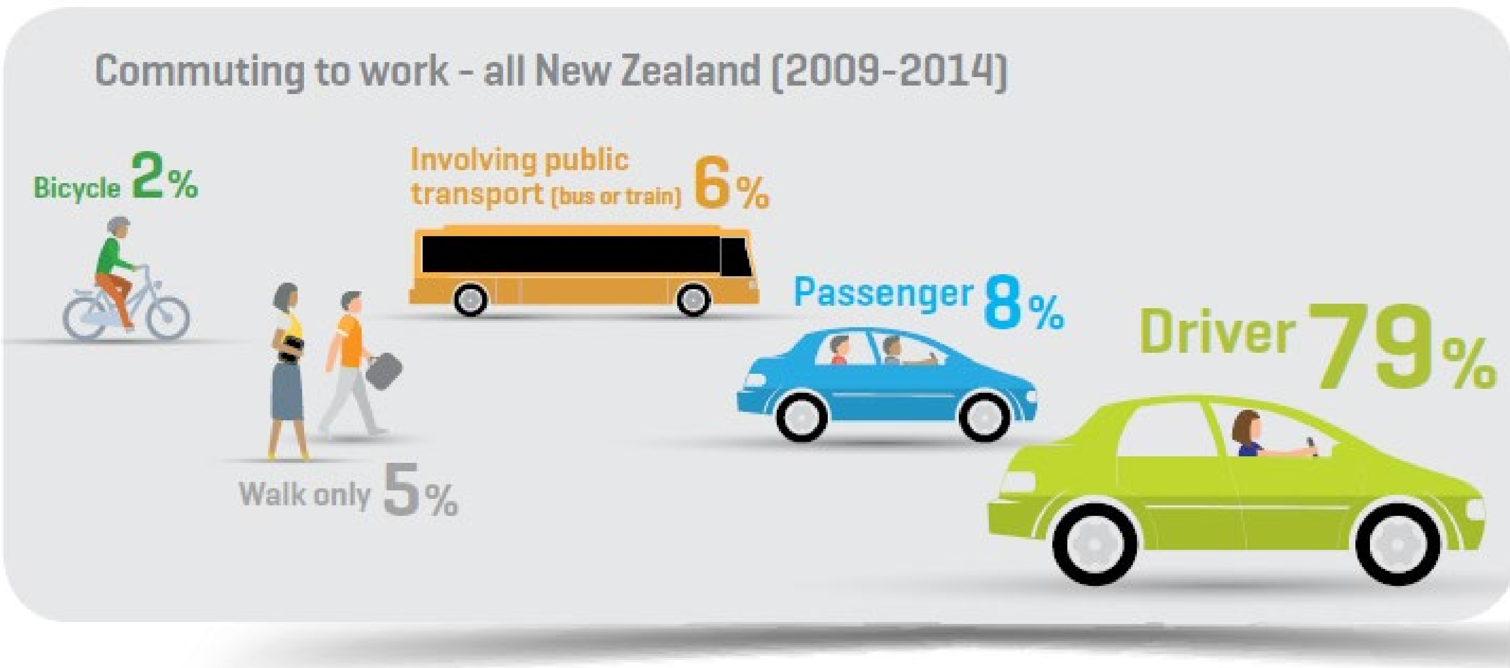

Figure 5. Commuting to work in New Zealand (2009 – 2014)
Source: MoT, 2015

Fuels we use

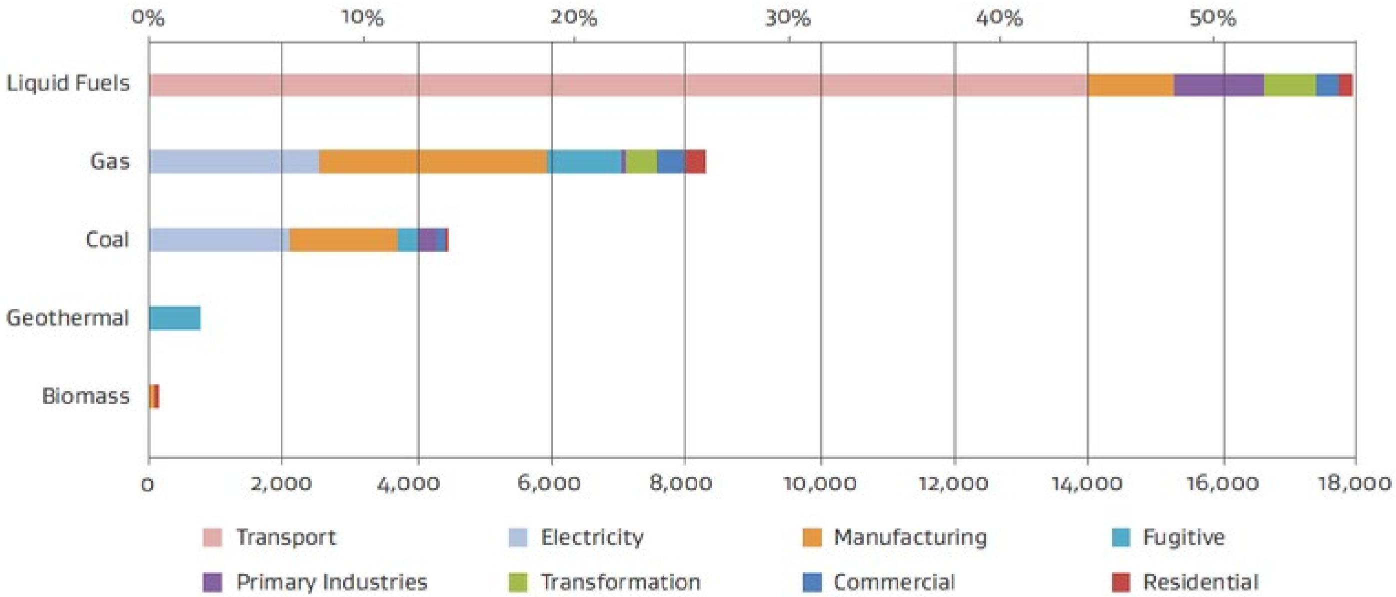

Figure 6. Energy Greenhouse Gas Emissions by Fuel Type (kt CO_2-e)

Source: MBIE, 2015

Fuel consumption in Auckland

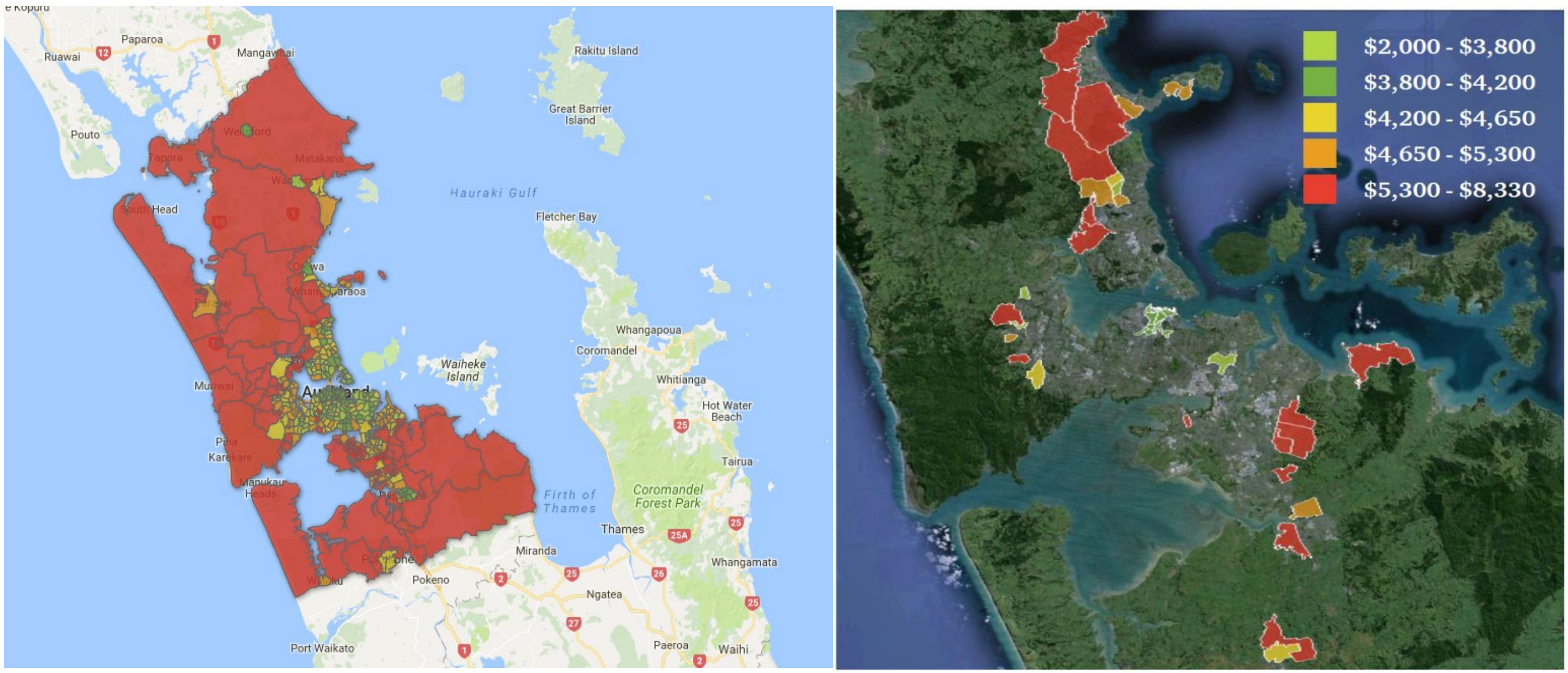

Figure 7. Annual fuel consumption ($NZD) in the Auckland region, average

Source: Constructive Thinking, 2014

GHG emissions in Auckland

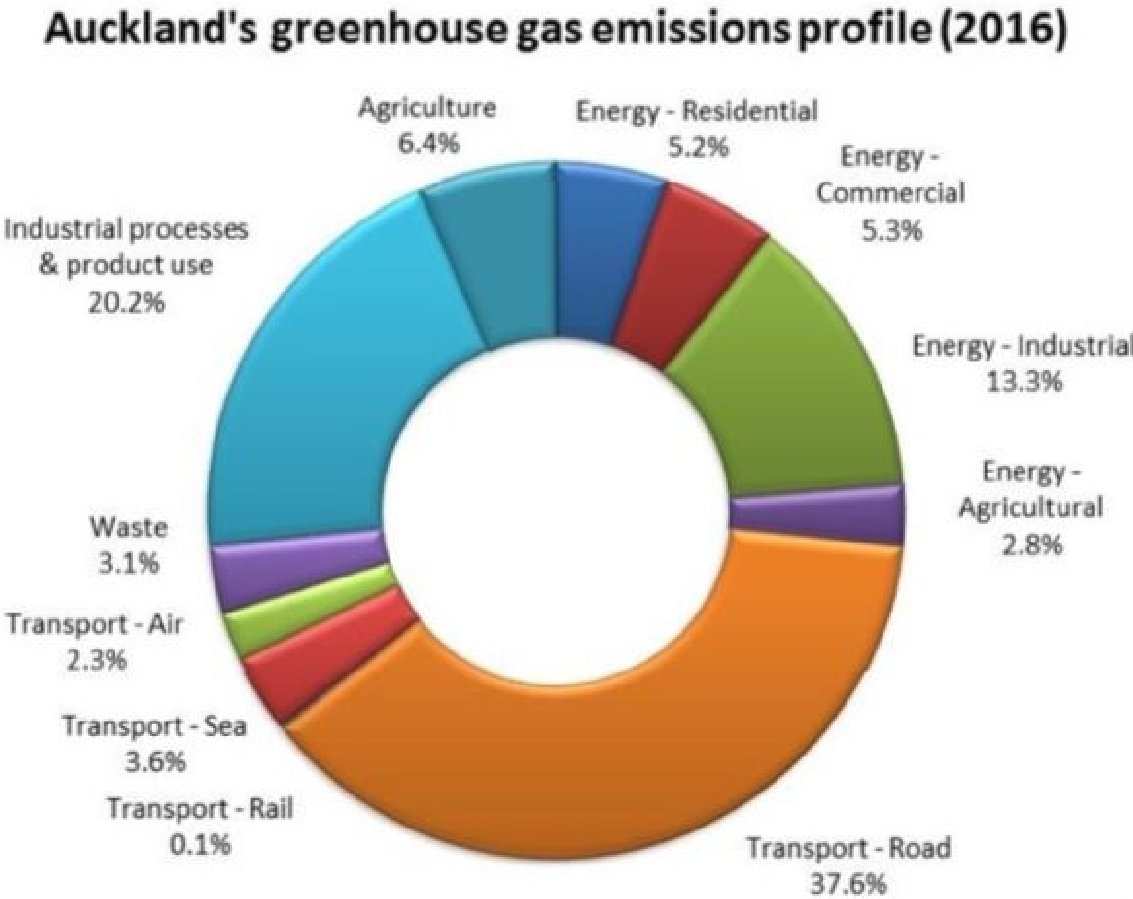

Figure 8. Auckland's GHG gross emissions profile in 2016

Source: Auckland Council, 2019

Transport is the dominant sector, accounting for 43.6% of gross GHG emissions.

CO_2 contributed 83.1%, CH_4 10.5%, N_2O 1.7% and other GHGs 4.7%.

Road transport externalities -1

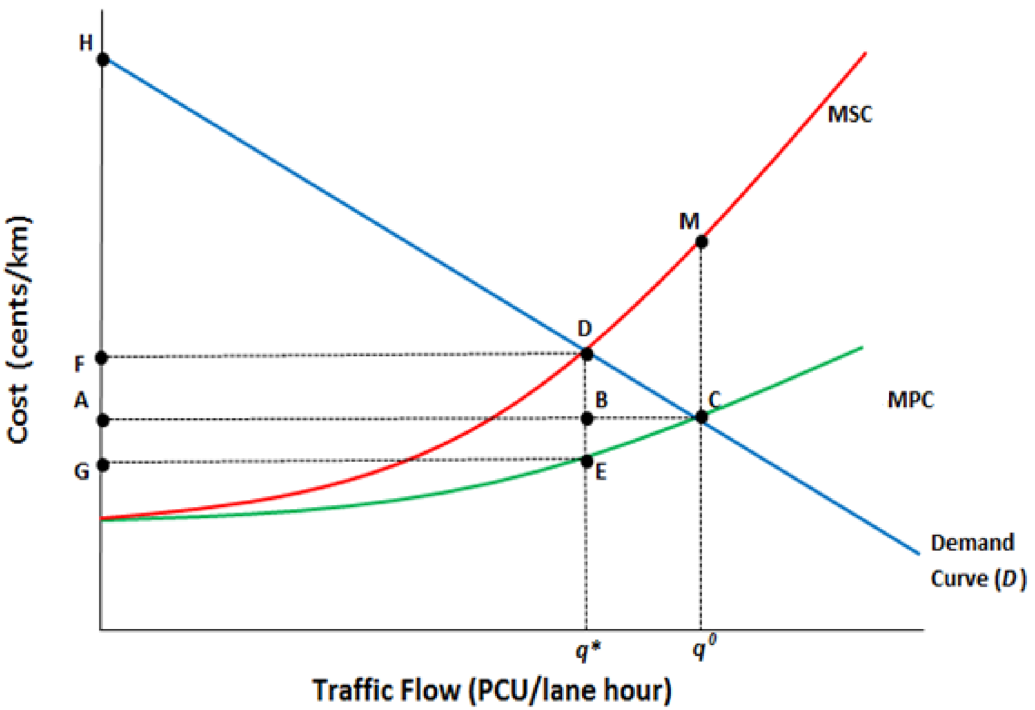

Figure 9. The Simple Diagram of Congestion Pricing

- Congestion is a flipside of a city's success.
- Congestion in Auckland is well above comparable cities (i.e. Perth, Brisbane, Adelaide)
- The economic cost of congestion is between \$0.9 - \$1.3 billion – equivalent to 1% and 1.4% of Auckland's GDP (NZIER, 2017).
  - ➢ hinders job matching
  - ➢ reduces labour force participation

Road transport externalities -2

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Environmental cost in New Zealand

Unit Cost of Carbon (NZD$25)	Public Transport	Private Transport
Per passenger and km	$0.001	$0.0067
To Society	$0.67 million	$57.76 million

Source: Jakob *et al*. (2006)

What happens if we increase the unit cost to **NZD$157**?

Road transport externalities -3

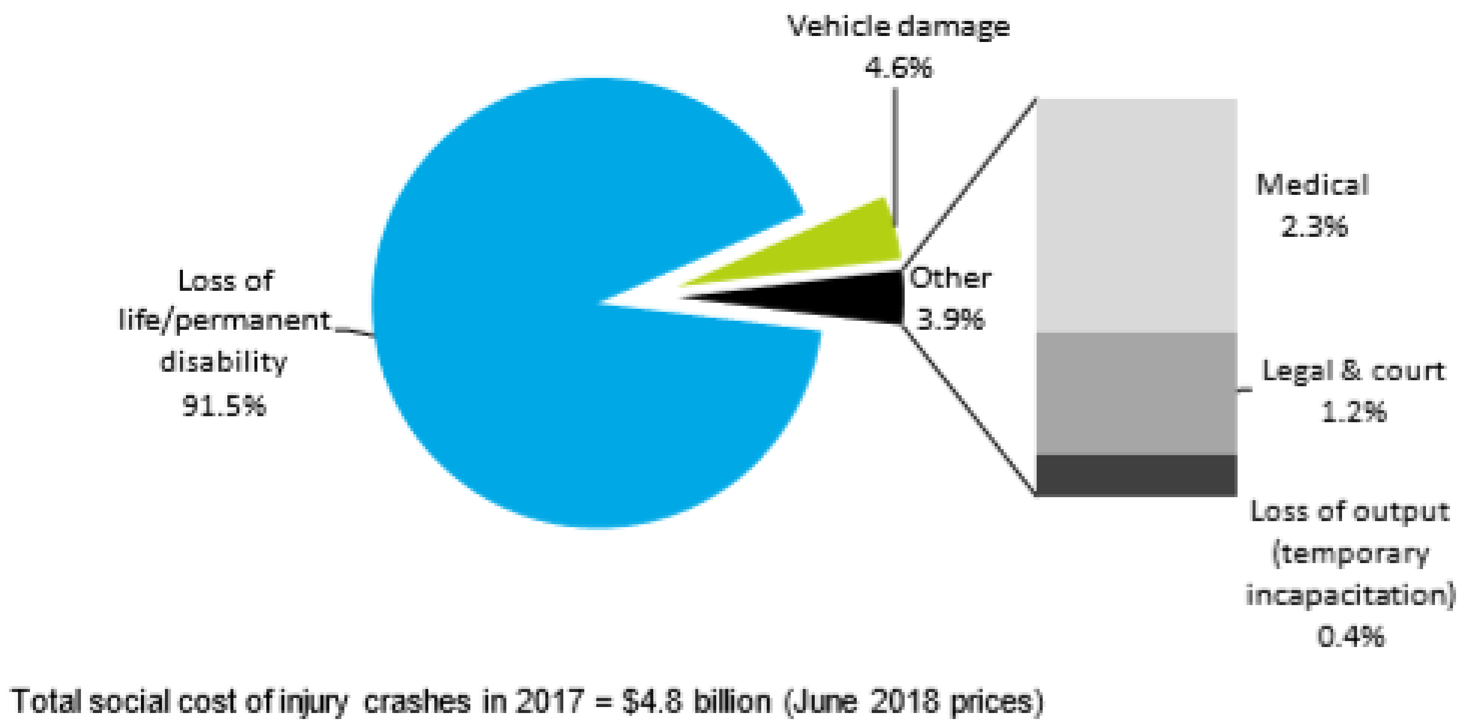

Figure 10. Share of total social cost of fatal and injury crashes in 2017 by cost component

Source: MoT, 2019

This is an increase of $0.6 billion (15%) compared to the previous year ($4.2 billion in 2016).

Objective: Maximise Net Benefits/Minimise Costs

$$\text{Households Travel Demand and Mode Choice}\begin{cases} Public\ Transport: \begin{cases} Bus \\ Train \\ Ferry \end{cases} \\ Private\ Transport: \begin{cases} ICEs \\ PEVs \\ wireless\ EVs \end{cases} \\ Active\ Transport: \begin{cases} Walk \\ Bike \end{cases} \end{cases}$$

$$\text{Transport Supply}\begin{cases} Public\ Transport\ Network \\ Roadway\ Infrastructure: \begin{cases} Conventional \\ IPT\ Options\ for\ wireless\ EVs \begin{cases} Static \\ Semi-Dynamic \\ Dynamic \end{cases} \end{cases} \\ Associated\ Infrastructure: \begin{cases} Local\ network \begin{cases} Home \\ Work \\ Carpark \end{cases} \\ Electricity\ Supply \\ Solar/Battery \end{cases} \end{cases}$$

$$\text{Road transport externalities}\begin{cases} Congestion \\ CO_2\ emissions \\ Health\ issues \end{cases}$$

$$\text{Exogenous Factors: } Road\ Pricing \begin{cases} Realtime \\ Fixed \end{cases}$$

Transport mode choice and social networks effect -1

- *What factors are important when people make their travel decisions (which transport mode to use)?*

- *What is the probability that a transport user will choose to use public transport to go to work, given the transport mode preference of his/her neighbours and the characteristics of the regions where he/she lives?*

Social Network Effects

Transit patronage: infrastructure service & accessibility; do not vary across neighbourhood

Positive Social Network Effects

When people prefer to use public transport *together* with other people as a result of social spillover

1) A utility gain through complementarity – not alone;
2) Avoiding a utility loss by not following others: meet & communicate, feel safer
3) A rise in utility level which stems from sending signals – feasible & reliable transport mode

Neighborhood effects/peer effects/social interactions/social spillovers

Transport mode choice and social networks effect -2

- Transport mode choice decision-making is dependent on social network effects.
- People's transport mode choice decisions DO influence each other, positively.
  - As the % of commuters taking public transport to work increases, we expect to see a spillover effect that changes some non-public transport users travel behaviour
- The social network effects = the 2nd largest impact (approx. 20%) on commuter's transport mode choice (in Auckland, after household vehicles, approx. 30%).
  - Shifting road user's travel behaviour - a more economical way?
- For urban/transportation planners:
  - Improving infrastructure
  - Strengthening the city's 'greener' transport mode culture

Future transport infrastructure for EVs

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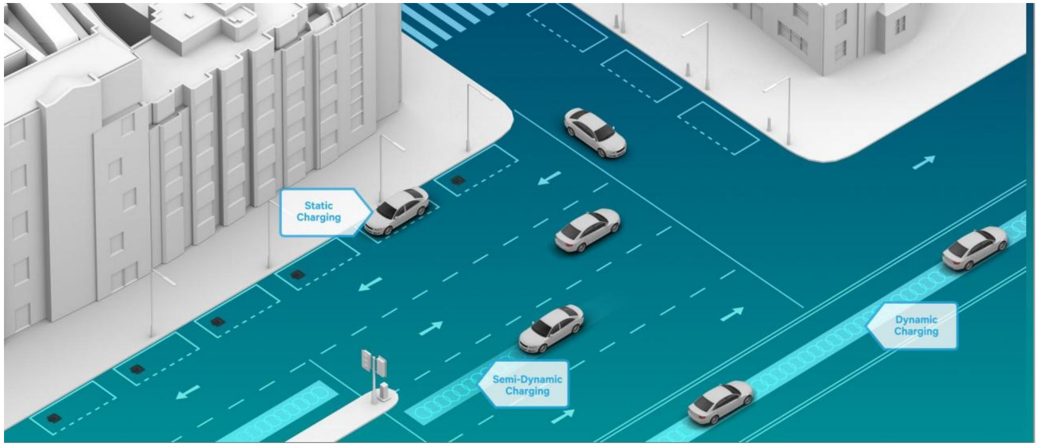
- Electrification of road transport: benefit of reducing emissions.
- The overall % is still miniscule compared to the large body of other types of vehicles in the fleet i.e. 1% of the entire vehicle fleet in NZ
- Barriers: *Range anxiety factor*, high price of EVs, the cost of batteries etc.
- Inductive Power Transfer (IPT) system (Zaheer and Covic, 2016): EVs can be energised wirelessly by embedding a roadway charging network while travelling in-motion.
    1. Stationary Inductive Power Transfer (SIPT)
    2. Semi-dynamic Inductive Power Transfer (SDIPT)
    3. Dynamic Inductive Power Transfer (DIPT)
- Economic Viability of IPT (Sheng *et al.*, 2019)
    - DIPT under PPP scheme
    - More details will be delivered in the afternoon transport session



Transport emissions, road energy consumption and economic growth -1

- Reducing Methane emissions from agriculture? Nah…
- Reducing Energy demand (CO_2 emissions) from transport? Yes!
- This study:
  - Investigates the impact of energy consumption from road transport and economic growth on CO_2 emissions from transport sectors;
  - Estimates a transport energy- Environmental Kuznets Curve using data in NZ (1970-2013).

A double-log quadratic equation is specified:

$$lnTCO2_t = \beta_0 + \beta_1 lnREC_t + \beta_2 lnGDP_t + \beta_3 lnGDP2_t + \epsilon_t \quad (1)$$

- $TCO2_t$ = the per capita carbon emissions from transport at time *t*;
- REC_t is the per capita fossil fuel consumption at time *t* (road energy consumption);
- GDP_t is the per capita real GDP at time *t* (economic growth);
- $GDP2_t$ is the quadratic term of GDP_t;
- β_1, β_2 and β_3 = impacts of REC_t, GDP_t and $GDP2_t$ on $TCO2_t$, respectively;
- β_0 is the intercept;
- ϵ_t is the disturbance term at time *t*, *i.i.d, mean = 0 & constant variance.*

- $\beta_1 > 0$: $\uparrow$ energy consumption $\uparrow$ economic activity $\uparrow$ CO2 emissions.
- $\beta_2 > 0$ while $\beta_3 < 0$, EKC theory suggests:
  - At the initial stages of economic growth, environmental pressure will tend to intensify,
  - After reaching certain turning point in income per capita, environmental quality improves.

Transport emissions, road energy consumption and economic growth -2

1) Bidirectional causality (transport CO_2 emissions & road energy consumption):

- The carbon abatement policy initiatives should be directed at energy use from fossil fuels and incentivise the adoption of alternative renewable energy sources.

- 85%+ of NZ's electricity: renewable sources, rapid adoption of EVs as replacements for ICE based passenger transport should be an obvious goal.

2) One-way causality (from economic growth to environmental pollutant emissions growth):

- Transport policies addressing carbon emissions abatement, will not hurt economic growth.

- Any investment in emission reduction strategies could serve as a practicable policy instrument for NZ govt. to achieve its net-zero emission target by 2050.

Traffic congestion issues -1

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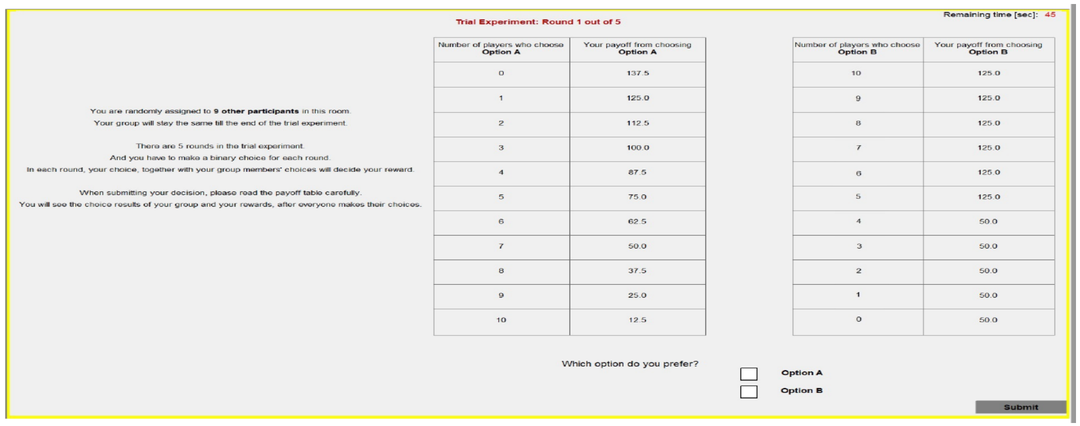
- Congestion
  - Most prominent negative externality with economic cost: NZD$0.9 billion to NZD$1.3 billion ≈ 1% and 1.4% of Auckland's GDP (NZIER, 2017)
- The Congestion Question in Auckland
  - Auckland Council's pilot study: how to reduce congestion on Auckland roads?
  - No further progress as to date
  - 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
- 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
- We conduct a laboratory experiment to simulate transportation route-choice games
  - Set the route-choice model of commuters as a coordination game

- a set of $I = \{1, 2, \cdots, n\}$ commuters
- an action set: $D_i = \{R, M\}$
- a binary choice: $d_i \in D_i$
- identical ex-ante preferences

Traffic congestion issues -2

- 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



- We obtained a panel dataset made by 240 subjects (i.e. 40 periods across 12 sessions)
- 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 reserve order effects ought to be captured by the sequence dummy d
- In total, is insignificant in all six regressions, therefore, we can conclude that reverse order effects do not exist in our sample.

Traffic congestion issues -3

Equilibria Predictions vs Observations

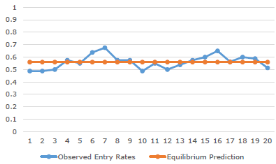


Figure: $G_{N,C}$

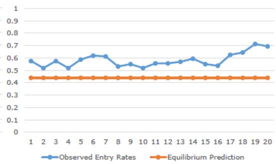


Figure: $G_{N,A}$

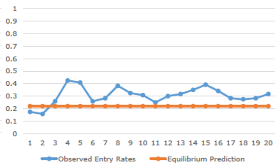


Figure: $G_{C,C}$

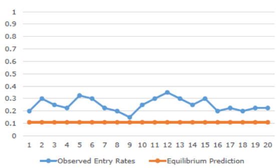


Figure: $G_{A,A}$

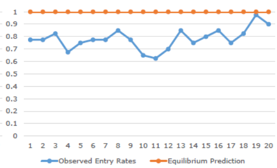


Figure: $G'_{N,A}$

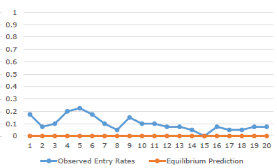


Figure: $G_{C,A}$

QRE vs Fitted QR

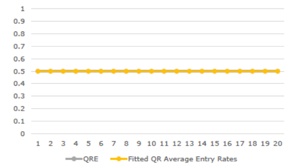


Figure: $G_{N,C}$

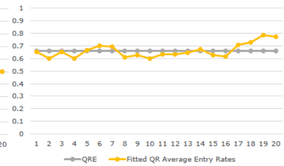


Figure: $G_{N,A}$

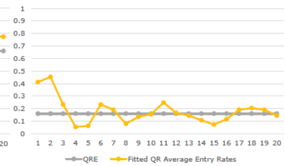


Figure: $G_{C,C}$

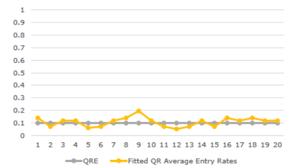


Figure: $G_{A,A}$

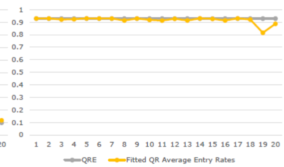


Figure: $G'_{N,A}$

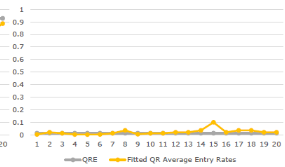


Figure: $G_{C,A}$

- The observations exhibit substantial variations: Choice behaviour might include an inherent error component.
- Quantal Response Equilibrium (QRE) justification: with a game dependent logit specification (McKelvey and Palfrey, 1995).
- Variations of the fitted QR are much lower than the raw data, we no longer observe the behaviour of over-use or under-use of the road.
- 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

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- **Sheng, M.** and Sharp, B. (2019). Aggregate Road Passenger Travel Demand in New Zealand. *Transportation Research Part A: Policy and Practice*, 124, 55-68.
- **Sheng, M.** and Sharp, B. (2019). Commuter's Transport Mode Preferences and Social Network Effects in New Zealand: An Instrumental Variable Approach. *Journal of Transport Economics and Policy*, 53(1), 19-46.
- **Sheng, M.**, Sreenivasan, A.V., Covic, G.A., Wilson, D.J., and Sharp, B. (2019). *Optimal Deployment of Inductive Power Transfer Charging Infrastructure for Electric Buses: A New Zealand Case Study.* Conference Proceeding at *2019 IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer.* London, UK.
- **Sheng, M.**, Sharp, B., and Yi, M. (2019). Transport Emissions, Road Energy Consumption, and Economic Growth: A Cointegration Analysis of the Environmental Kuznets Curve in New Zealand. (Submitted) *Energy Economics.*
- **Sheng, M.**, Screenivasan, A.J., Sharp, B., Wilson, D.J., and Ranjitkar, P. (2020). Economic Analysis of Dynamic Inductive Power Transfer Roadway Charging System under Public-Private Partnership – Evidence from New Zealand. (Accepted) *Technological Forecasting & Social Change*.
- **Sheng, M.**, Sreenivasan, A.V., Sharp, B. and Du. B. (2020). *Well to Wheel comparison of light-duty vehicles: A scenario analysis between New Zealand and Australia*. Working paper.
- **Sheng, M.**, Sharp, B., Wilson, D.J., and Ranjitkar, P. (2020). *Investigating the Importance of Fast Chargers and Spatial Effects on Electric Vehicle Adoption: Some Evidence from New Zealand*. Working Paper.
- Pan, A. and **Sheng, M**. (2020). *The Complementary Duet of Vehicular Diverging: An Experimental Approach*. Working Paper.

Takeaway messages

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- Transport system is not a perfect system by any manner or means.
- We have learned a lot along the way, we made some mistakes, we corrected some mistakes.
- Climate-related targets can play an important role in legitimating transport practices that advance sustainable energy transition.
- A widespread transition to e-mobility and introduction of congestion tax is economically feasible – but socially and politically desirable?
- Flows of funding from the national Govt. to major cities and regions – urban policy-making.

Thank you ☺