System Dynamics Integrated Assessment Modelling with UniSyD

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- UniSyD – What is it and how does it work
- Output samples - UniSyD New Zealand and UniSyD Japan
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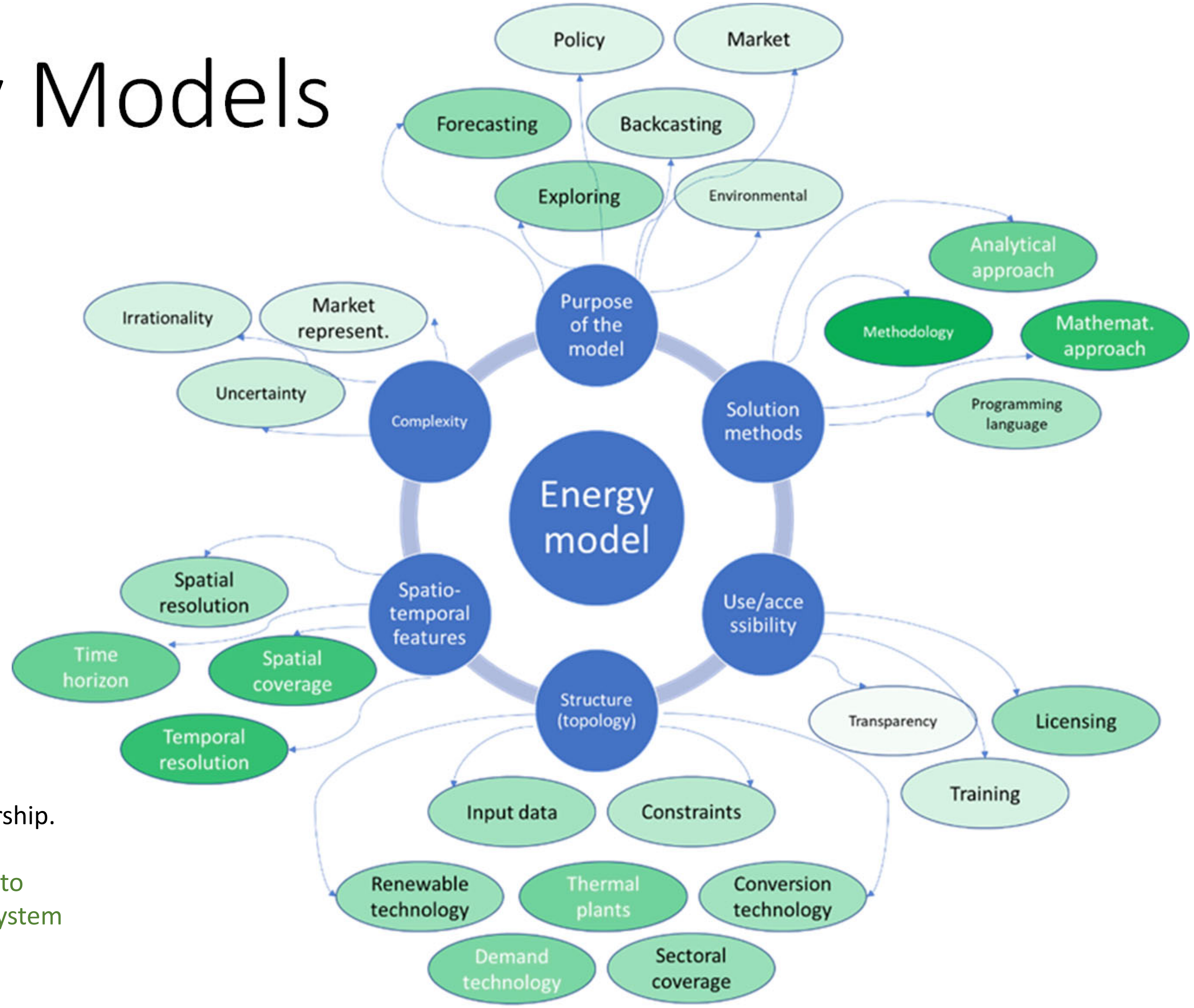
Taxonomy of Energy Models

How can we classify Energy Model? What are their distinguishing characteristics?

Survey of 140+ journal papers



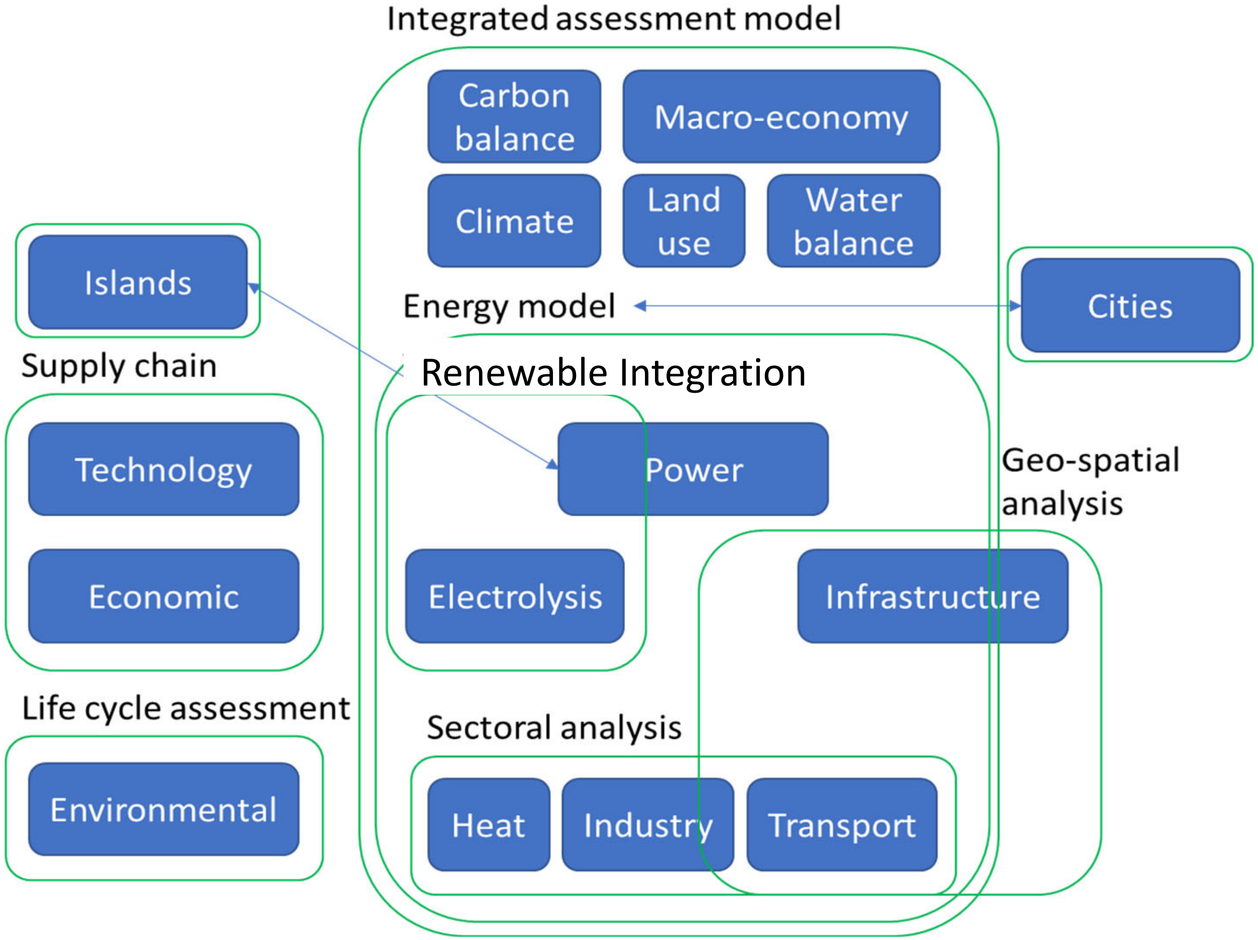
Source: International Energy Agency, Hydrogen Collaboration Partnership. Task 41 Data and Modelling (9 international collaborators)
Assessment of approaches to modelling hydrogen in energy systems to improve the understanding of the economic value of hydrogen sub-system deployment

Ref: Blanco… Leaver… et al. A taxonomy of models for investigating hydrogen energy systems. Submission pending 'Renewable and Sustainable Energy Reviews'

Energy Model Archetypes from literature

1. Integrated Assessment
2. Energy System
3. Power
4. Variable renewable energy integration
5. Cities
6. Islands/Off-grid
7. Sectoral analysis
8. Geo-spatial analysis and Networks
9. Integrated Life Cycle Assessment

Not mutually exclusive



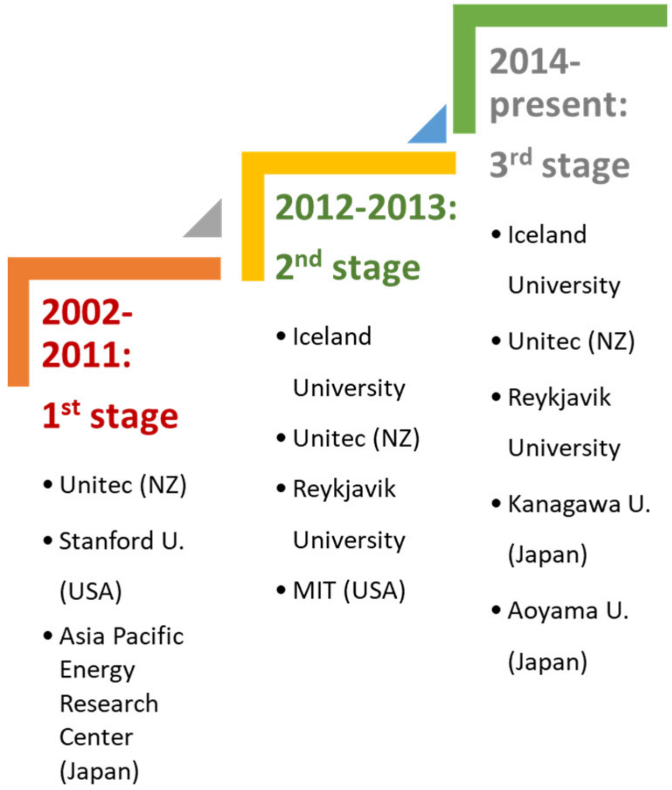
Ref: Blanco… Leaver… et al. A taxonomy of models for investigating hydrogen energy systems. Submission pending 'Renewable and Sustainable Energy Reviews'

Why System Dynamics

- Transparency through visually networked variable relationships
- Easy transportability between programmers
- Fast processing time
- Can use highly non-linear algorithms
- Stability

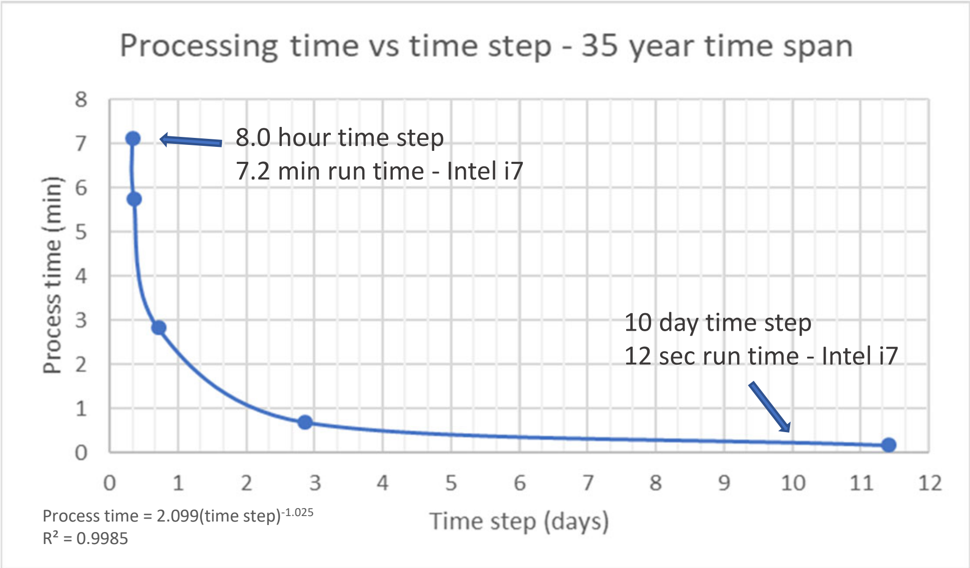
What is UniSyD

- Early development at Unitec with FRST funding 2002-2012 as part of the CRL/IRL project “Hydrogen Energy for the Future of New Zealand”.
- Principal UniSyD_NZ programmers:
  - Andrew Baglino, Kenneth Gillingham and Luke Leaver (Stanford University); Akihiro Watabe (Kanagawa University), Ehsan Shafiei (University of Iceland); Jonathan Leaver (Unitec).
- Currently used in national energy system/integrated assessment modelling for New Zealand, Japan, Iceland and Finland.
- IP jointly owned by Unitec, University of Iceland, Kanagawa University



Profile UniSyD_NZ

- 39,186 variables including arrayed expansions - 2122 primary variables
- 76 sectors with 35,091 equations including arrayed expansions
- Optimisation occurs at each time step in meeting electricity, hydrogen, biofuel and vehicle fleet demands.
- Dynamic market conditions influenced by the complex interactions among:
    - Resource supply costs
    - Technology costs
    - Infrastructure co-evolution
    - Demand patterns (consumer behaviour)
    - Market prices



Key Elements of the UniSyD Model

Energy Supply

- includes imported petroleum fuels, coal, gas, solar, hydropower, geothermal, wind, biomass.
- incorporates resource supply curves, existing/future capacities, expected future technologies, and supply costs.

Refuelling Infrastructure

- determines refuelling station availability as an important factor changing consumer preferences.
- expected profitability is used to represent fuel station viability.

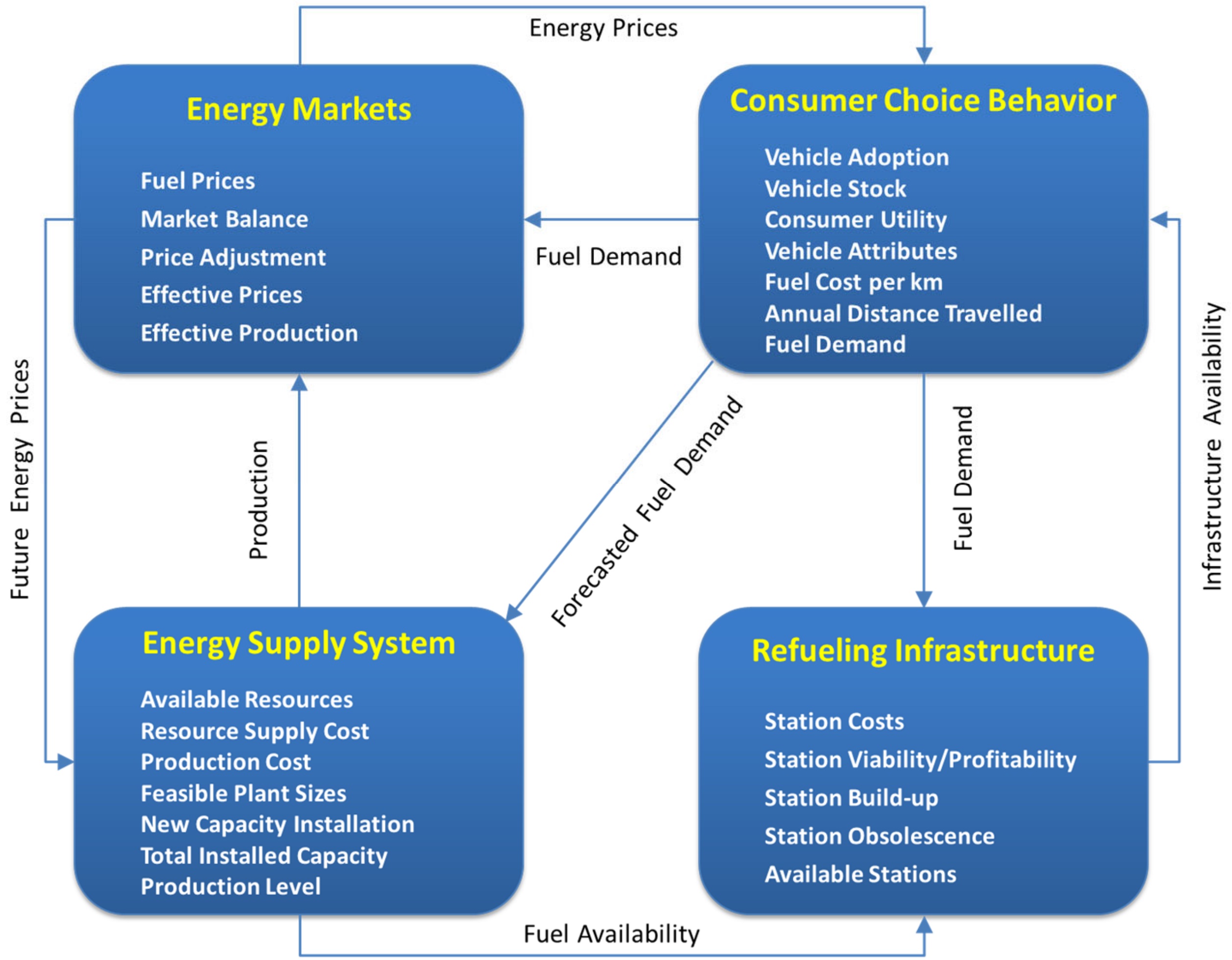
Energy Markets

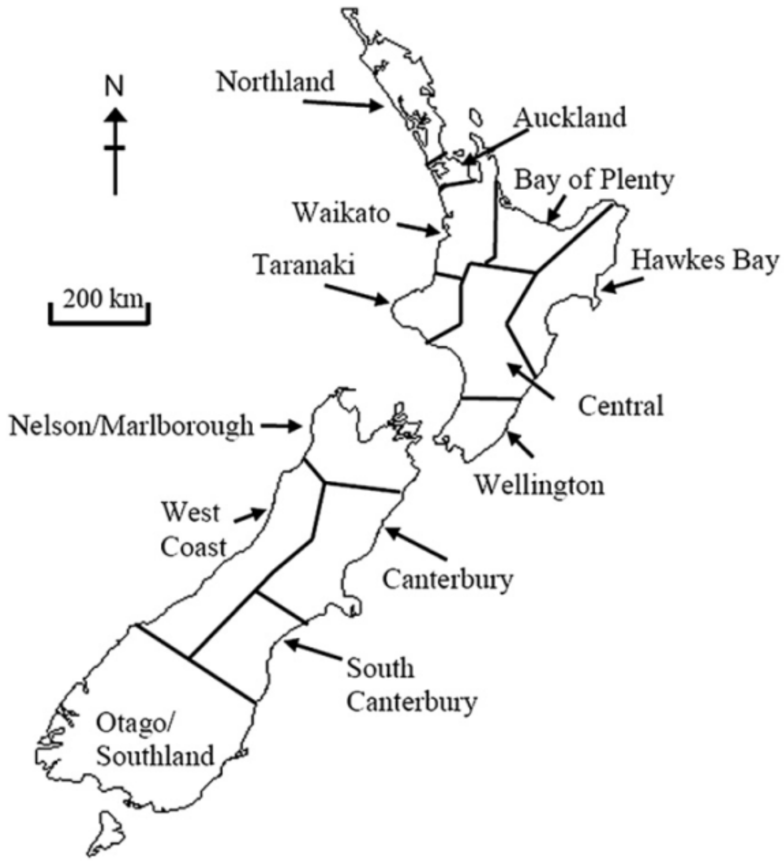
- a market-oriented economic system to balance demand with supply curves of production plants
- in short term, energy price signals to determine the fuel supply.
- in long-term, energy prices play a crucial role in new capacity installation.

Vehicle Choice & Fuel Demand

- a non linear MNL framework forecasts the market share of different vehicles.
- distance travelled, vehicle stock, fuel economies, vehicle & fuel switching are taken into account in forecasting the fuel demand.

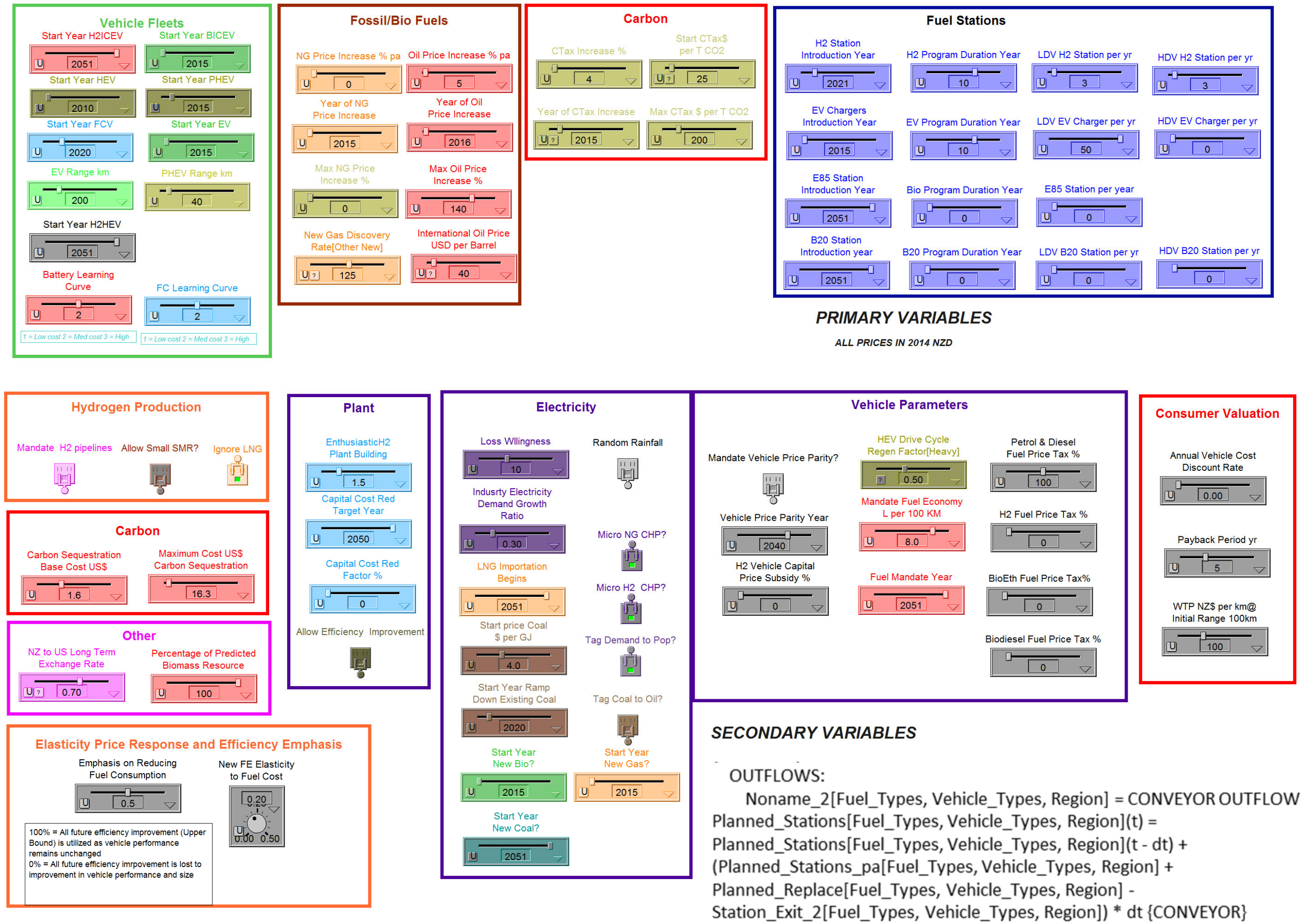
UniSyD: Modules and Key Variables





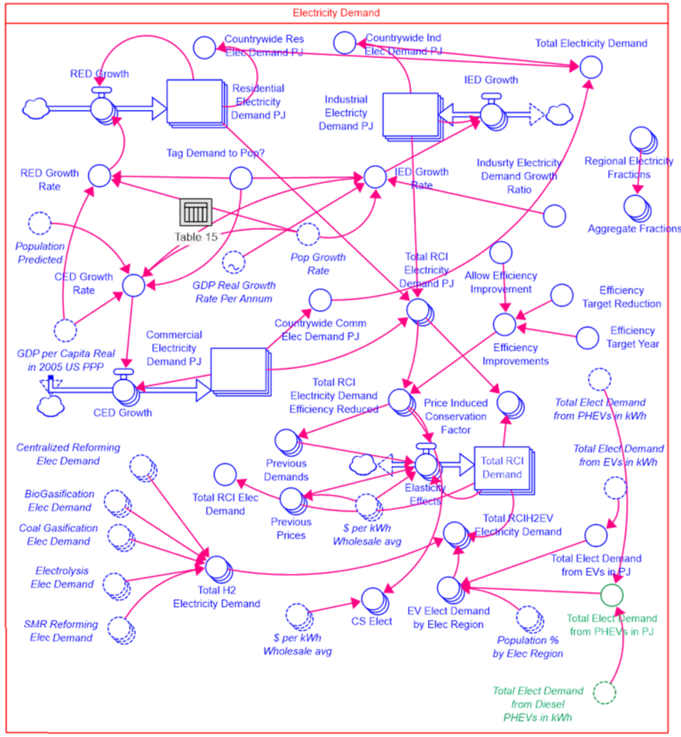
13 regions aligned with previous Electricity Authority boundaries

UniSyD Control Levels



3 Levels of Interaction:

- Interface (Control Panel)
- Model (Networks)
- Equation



SECONDARY VARIABLES

OUTFLOWS:

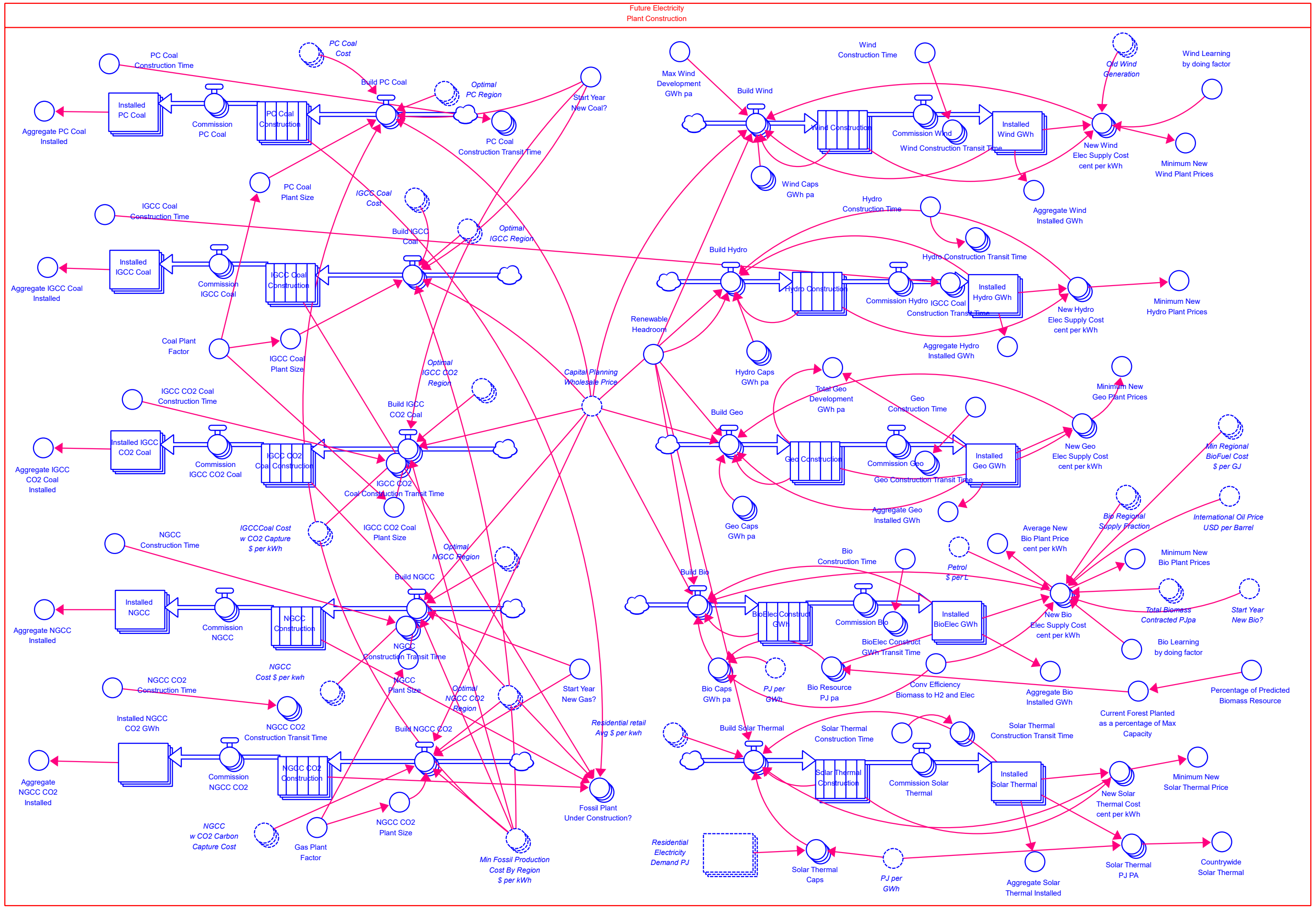
Noname_2[Fuel_Types, Vehicle_Types, Region] = CONVEYOR OUTFLOW

Planned_Stations[Fuel_Types, Vehicle_Types, Region](t) = Planned_Stations[Fuel_Types, Vehicle_Types, Region](t - dt) + (Planned_Stations_pa[Fuel_Types, Vehicle_Types, Region] + Planned_Replace[Fuel_Types, Vehicle_Types, Region] - Station_Exit_2[Fuel_Types, Vehicle_Types, Region]) * dt {CONVEYOR}

Transparency

- Arrows are dependent relationships
- Squares are stocks that delay the flow items

Planned_Infrastructure[Fuel_Types, Vehicle_Types, Region](t) =
Planned_Infrastructure[Fuel_Types, Vehicle_Types, Region](t - dt) +
(Noname_1[Fuel_Types, Vehicle_Types, Region] - Noname_2[Fuel_Types, Vehicle_Types, Region]) * dt {CONVEYOR}
  INIT Planned_Infrastructure[Fuel_Types, Vehicle_Types, Region] = 0
    TRANSIT TIME = 1
  CONTINUOUS
  ACCEPT MULTIPLE BATCHES
  DOCUMENT: Source of Electric chargers: Tinna Kjartansdóttir, (2012). Electric Vehicles in Iceland: Private Consumer Market 2013-2017
  INFLOWS:
    Noname_1[Fuel_Types, Vehicle_Types, Region] = Planned_Stations_pa {UNIFLOW}
  OUTFLOWS:
    Noname_2[Fuel_Types, Vehicle_Types, Region] = CONVEYOR OUTFLOW
Planned_Stations[Fuel_Types, Vehicle_Types, Region](t) =
Planned_Stations[Fuel_Types, Vehicle_Types, Region](t - dt) +
(Planned_Stations_pa[Fuel_Types, Vehicle_Types, Region] +
Planned_Replace[Fuel_Types, Vehicle_Types, Region] -
Station_Exit_2[Fuel_Types, Vehicle_Types, Region]) * dt {CONVEYOR}



Power Plant Construction Sector

Vehicle Fleet – Types and Utility

Utility of Vehicle Choice:

$$U_{k,t} = \beta_1.P_{k,t} + \beta_2.M_{k,t} + \beta_3.F_{k,t} + \beta_4.R_{k,t} + \beta_5.B_{k,t} + \beta_6.e^{\beta 7 \times A_{k,t}}$$

$P_{k,t}$ **Vehicle Price ($)**

$M_{k,t}$ **Maintenance Cost ($/yr)**

$F_{k,t}$ **Fuel Cost ($/km)**

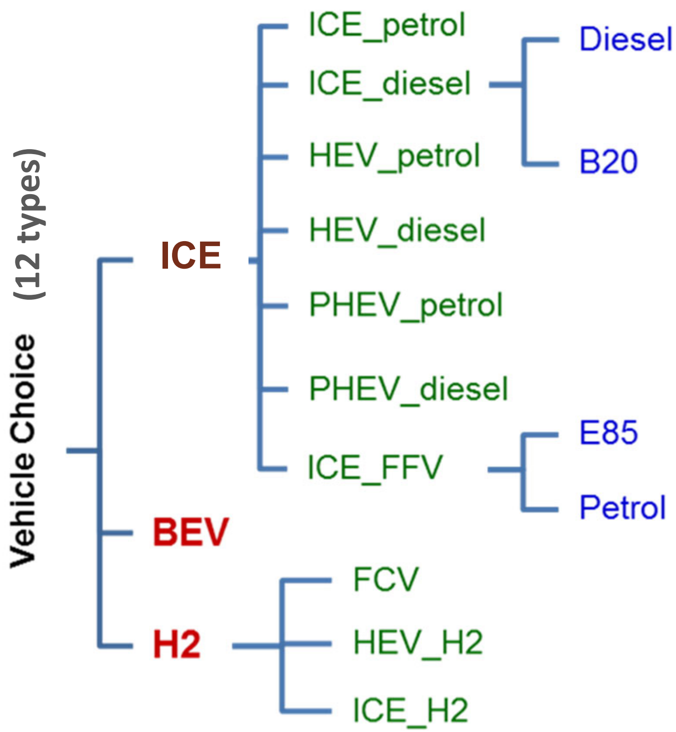
$B_{k,t}$ **Battery Replacement Cost ($)**

$R_{k,t}$ **Vehicle Range (km)**

$A_{k,t}$ **Fuel Availability**

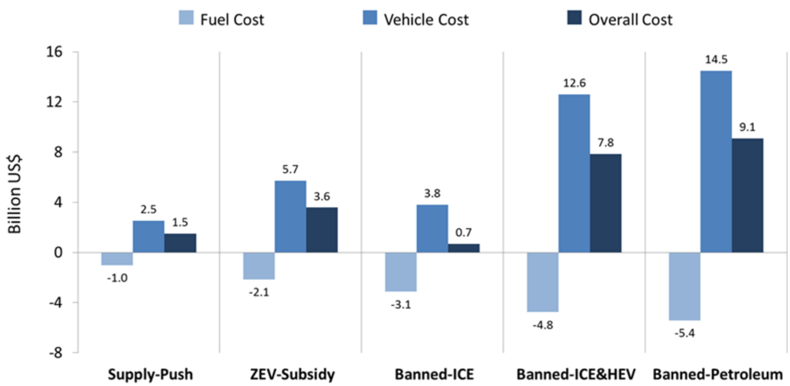
Probability of Vehicle Choice

$$S_{k,t} = \exp(U_{k,t}) / \sum_{k=1}^{V} \exp(U_{k,t})$$

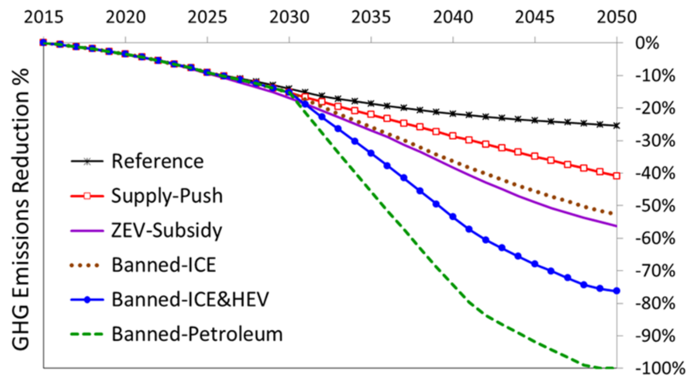


UniSyD New Zealand

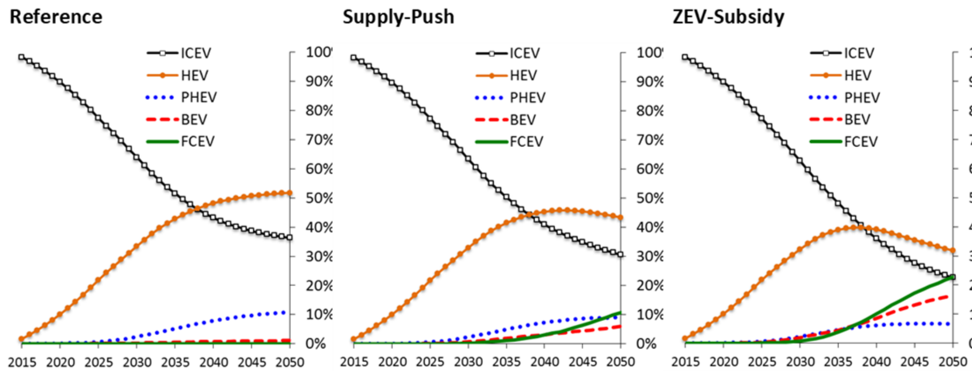
Shafiei, E., Leaver, J., & Davidsdottir, B. (2017). Cost-effectiveness analysis of inducing green vehicles to achieve deep reductions in greenhouse gas emissions in New Zealand. Journal of Cleaner Production, 150, pp.339-351. doi:10.1016/j.jclepro.2017.03.032 https://doi.org/10.1016/j.jclepro.2017.03.032



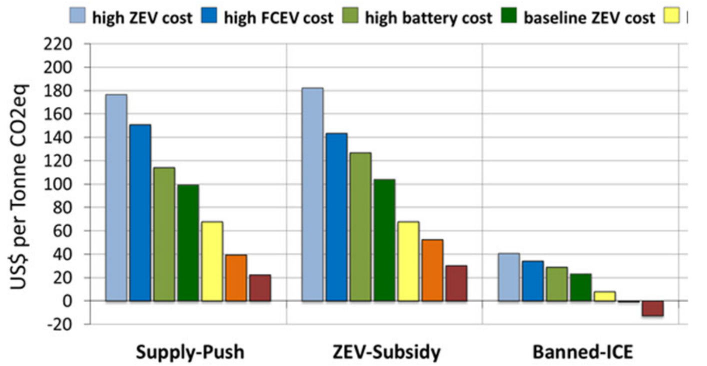
Discounted cumulative net costs with respect to the Reference scenario



Potential for the reduction of annual GHG emissions from the road transport sector



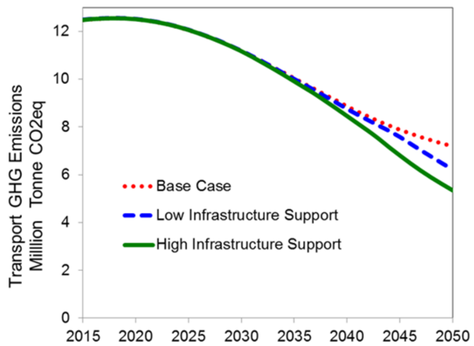
Market share evolution of vehicles within the LDV fleet

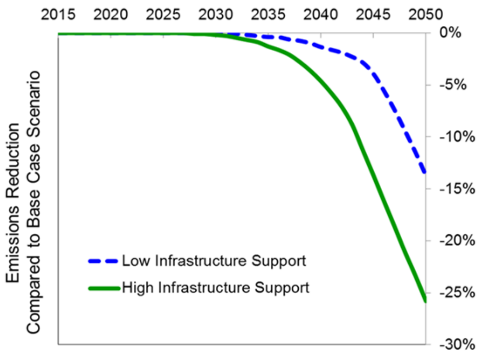


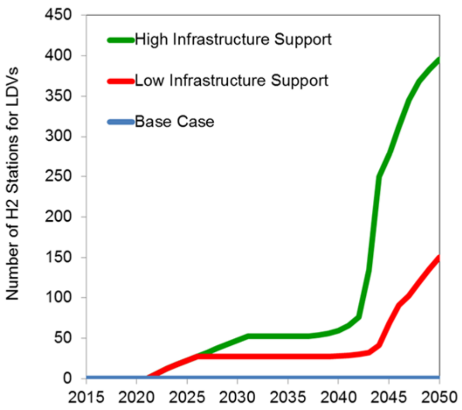
GHG mitigation cost of different strategies and its sensitivities with respect to ZEVs' cost

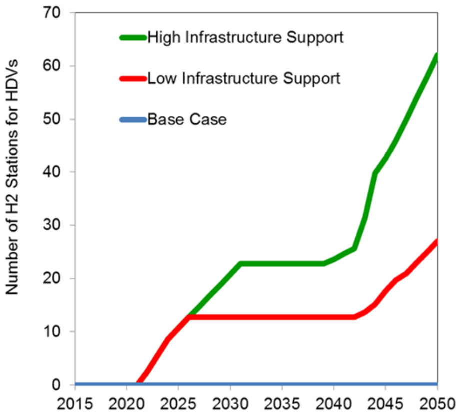
UniSyD New Zealand

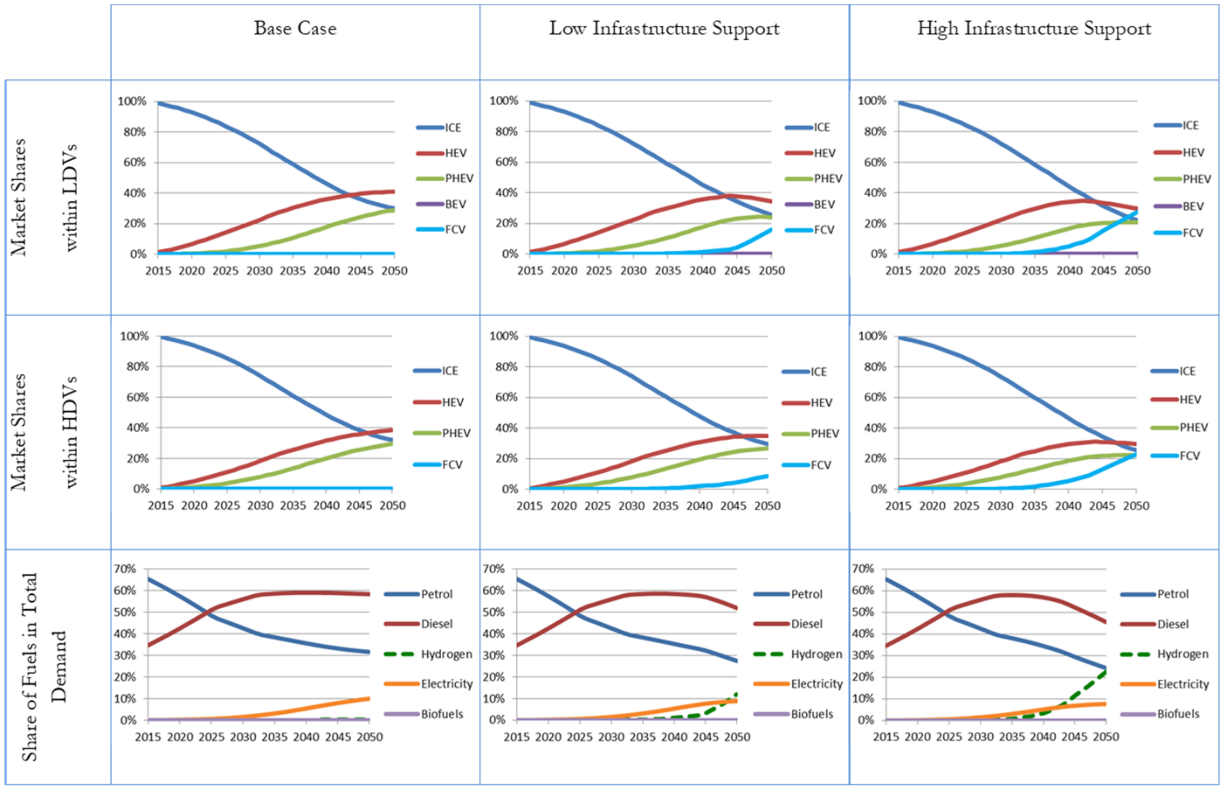
Leaver, J. D., Shafiei, E., & Davdisdottir, B. Simulating the Impact of Infrastructure Support on the Market Penetration of Hydrogen Vehicles in New Zealand. Proc. 21st World Hydrogen Energy Conference 2016. Zaragoza, Spain. 2016 ISBN: 978151083835







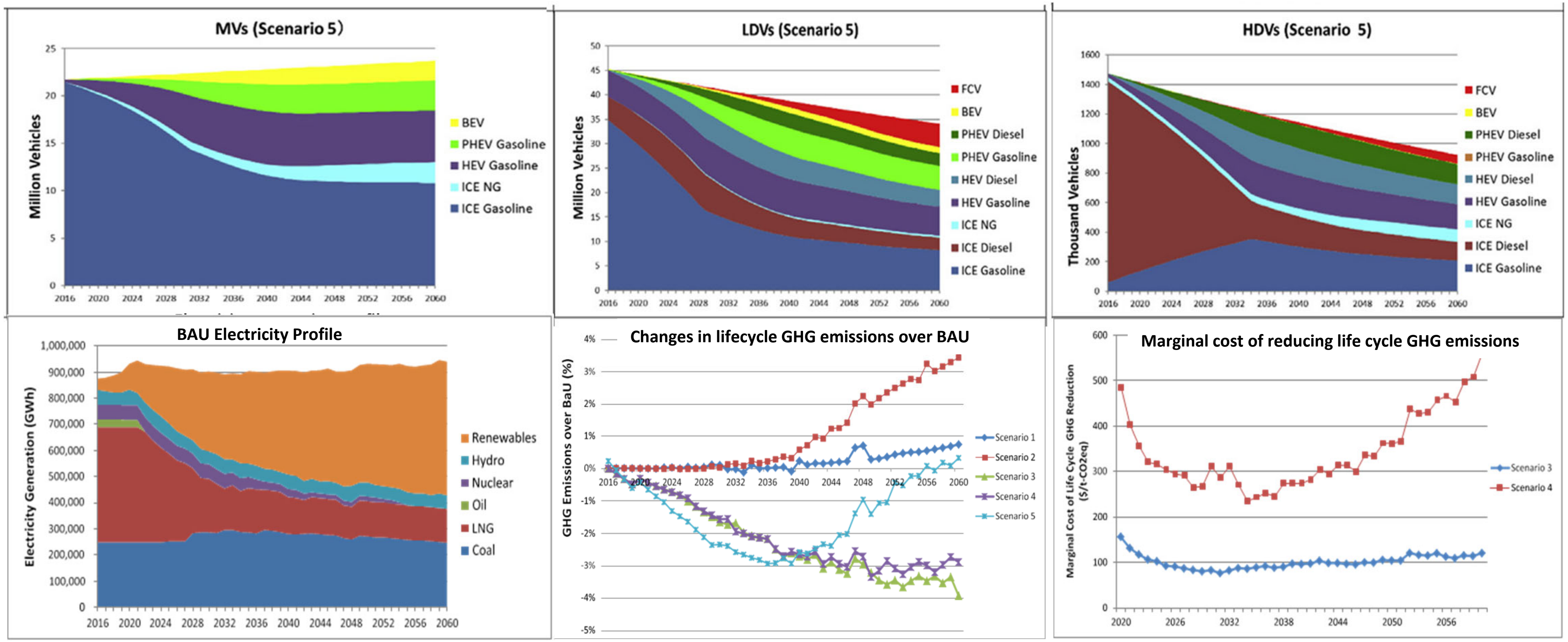




Market share of vehicles and fuels

UniSyD Japan

Akihiro Watabe, Jonathan Leaver, Hiroyuki Ishida, Ehsan Shafiei. "Impact of low emissions vehicles on reducing greenhouse gas emissions in Japan". Energy Policy Vol. 130, 227-242, 2019. https://doi.org/10.1016/j.enpol.2019.03.057



UniSyD Based - Journal papers

1. Akihiro Watabe, **Jonathan Leave**r, Hiroyuki Ishida, Ehsan Shafiei. "Impact of low emissions vehicles on reducing greenhouse gas emissions in Japan". Energy Policy Vol. 130, 227-242, 2019.
2. Shafiei, E., **Leaver, J.**, & Davidsdottir, B. (2017). Cost-effectiveness analysis of inducing green vehicles to achieve deep reductions in greenhouse gas emissions in New Zealand. Journal of Cleaner Production, Vol. 150, pp.339-351.
3. Shafiei, E., Davidsdottir, B., **Leaver, J.**, Stefansson, H., & Asgeirsson, E. (2017). Energy, economic, and mitigation cost implications of transition toward a carbon-neutral transport sector: A simulation-based comparison between hydrogen and electricity. Journal of Cleaner Production, Vol. 141, pp.237-247.
4. Shafiei, E., Davidsdottir, B., **Leaver, J.,** Stefansson, E., & Asgeirsson, E., Keith, D. (2015). Analysis of supply-push strategies governing the transition to biofuel vehicles in a market-oriented renewable energy system. Journal of Energy, Vol. 94, pp. 409–421.
5. Shafiei, E., Davidsdottir, B., **Jonathan Leaver**, Hlynur Stefansson, Eyjolfur Ingi Asgeirsson. (2015). Comparative analysis of hydrogen, biofuels and electricity transitional pathways to sustainable transport in a renewable-based energy system, Energy, Vol. 83, pp. 614-627.
6. Shafiei, E., Davidsdottir, B., **Jonathan Leaver**, Hlynur Stefansson, Eyjolfur Ingi Asgeirsson (2014). Potential impact of transition to a low-carbon transport system in Iceland. Energy Policy, Vol. 69, pp. 127-142
7. **JD Leaver**, LHT Leaver, (2011). Potential impact of consumer behaviour and fossil fuelled hydrogen generation on national energy policy in New Zealand. Energy Utility and Environment On Line journal, Vol. 5.
8. **Leaver J.D,** Gillingham K.T. (2010). Economic impact of the integration of alternative vehicle technologies into the New Zealand vehicle fleet. *International Journal of Cleaner Production*, Vol. 18(9), 908-916.
9. **Leaver J.D,** Gillingham K.T., Leaver L.H.T. (2009). Assessment of primary impacts of a hydrogen economy in New Zealand using UniSyD. *Int. J. Hydrogen Energy*, Vol. 34(7), 2855-2865.

Going forward - PhD Full Funded Opportunity in Energy Systems Modelling

This PhD project will use UniSyD to explore a number of important questions for the New Zealand energy system including

- The optimum role of hydrogen including storage options
- The optimum role of biomass
- The optimum evolution of hydrogen infrastructure

The successful PhD student will be based at the University of Otago and be jointly supervised by Associate Professor Michael Jack and Associate Professor Jonathan Leaver

The PhD scholarship will include tuition fees and stipend of $30,000 p.a. for 3 years.

Candidate Requirements and Application

- The applicant needs to be completing an honour degree (with GPA B+ or higher) or a master degree by the end of 2021 in Applied Mathematics, Engineering or Physics. Experience with process modelling using Matlab Simulink, Stella or Vensim will be advantageous. Applications from Maori and other minorities are welcomed.
- Interested candidates are invited to send your CV and transcripts as soon as possible to Associate Professor Michael Jack (Michael.jack@otago.ac.nz) in the Department of Physics, University of Otago. The application will be closed once the suitable candidates are identified.

Thank you for your attention

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