Potential Impact of Consumer Behavior and Carbon Price on National Energy Policy in New Zealand

Jonathan D. Leaver[1,*] and Luke H.T. Leaver[2]

[1] *Unitec NZ, Auckland, New Zealand,* [2] *Asia Pacific Energy Research Centre, Tokyo, Japan*
* Corresponding author. Tel: +64 98494180, Fax: +64 98154372, E-mail: jleaver@unitec.ac.nz

ABSTRACT

In 2008 greenhouse gas emissions from the transport sector in New Zealand accounted for 19% of total emissions. Studies using the multi sector partial equilibrium model UniSyD show that vehicle costs and driving range when weighted to reflect consumer choice can result in a 38% reduction in the penetration of alternative fuelled light vehicles by 2050 and consequently is a significant factor in determining the rate of reduction in greenhouse gases. Furthermore even under a high carbon tax of US\$120/t-CO_2, greenhouse gas emissions in 2050 in the electricity generation and transport sectors are unlikely to be reduced to less than 8% above 1990 levels. Reductions in emissions below this level will require government policy interventions to limit the use of petroleum based transport fuels.

INTRODUCTION

The rate of consumption and reliance on finite petroleum resources is an increasingly urgent issue in both emerging and developed economies. Pricing and policy mechanisms act as important yet complex tools which can induce structural changes in consumer behavior. New Zealand is a small developed economy of 4.3 million people situated across two main islands encompassing a total land area of 269,000 km^2. Like similar developed countries with a comparatively low population density, New Zealand has a high level of vehicle ownership being 0.74 vehicles with four or more wheels per capita in 2008 [1].

The reliance of mobility demand on conventional vehicles exposes economic growth in New Zealand to an undesirable level of risk due to the potential for rapid increases in the price of oil. In addition, in 2011 New Zealand publicly committed to reduction targets in 1990 greenhouse gas (GHG) emissions of 50% by 2050 [2]. In 2008, the transport sector accounted for 19% of gross GHG emissions in New Zealand [3]. To reduce fossil fuel reliance in the transport sector, the two New Zealand federal governments since 2007 have both suggested replacing up to 48% of the conventional light vehicle fleet by electric drive vehicles before 2050 [4, 5]. In order to achieve this goal, New Zealand will need to invest in infrastructure for recharging and/or refuelling of electric vehicles [6]. Policy incentives to influence consumer behavior would also be needed to encourage the adoption of alternative vehicle technologies. The realisation of these targets will require close examination of the complex interaction between pricing mechanisms and consumer behavior over the next several years. Pricing mechanisms will need to be targeted at overcoming consumer resistance to higher capital costs for battery and fuel cell assisted vehicles as well as allaying concerns on safety, reliability, maintenance costs, refuelling/recharging time and availability of refuelling/recharging stations [6].

In this study the impact of consumer behavior and carbon tax on fossil fuel reductions in the road transport sector of the New Zealand economy is investigated using the dynamic multi-region partial equilibrium economic model UniSyD version 5.0.5 [7] [8].

MODEL DESCRIPTION

UniSyD is a large scale multi sector partial equilibrium model of the New Zealand energy market calibrated to simulate the New Zealand economy. It utilises a high degree of technological and resource specificity [7]. The model includes carbon capture and storage (CCS) as an option for two types of coal plants, namely pulverised coal bed and integrated gasification combined cycle (IGCC). A CCS option is also available for natural gas combined cycle (NGCC) plants.

Equilibrium interactions are modelled across four key markets: electricity, hydrogen, lignocellulosic biofuel and vehicle fleets. Supply and demand in these four primary markets are determined through dynamic price elasticity interactions. Each market is further categorized into sub-markets across the 13 geographic regions of New Zealand. The purpose of UniSyD is to provide a platform for the formulation of an energy outlook from which cost effective and efficient policy initiatives can be implemented.

The electricity market equilibrates electricity supply and demand through the import and export of regional generation whilst accounting for transmission losses. The marginal price of new generation is calculated regionally across each technology. Resource dependent technologies such as wind, solar and hydro have larger price variations between regions. New generation capacity is installed when the forward looking electricity spot price for any given region exceeds the marginal price of the next lowest cost regional generation option. Technology learning curves are applied to lower production cost for maturing technologies. Temporal fluctuations in wind (minutes) and hydro generation (seasonal) are neglected.

The hydrogen market functions in an equivalent manner to the electricity market. It has four centralised plant technologies: biomass gasification, coal gasification, steam methane reforming; and coal co-generation of hydrogen and electricity with sequestration of emissions using a solid oxide fuel cell topping cycle [7]. In the model, the market has five plant sizes for each technology so as to match supply with demand by the most cost efficient means. The construction of new generation stations for both the electricity and hydrogen markets is formulated by extrapolating demand growth from the previous three years. Large centralised stations require a four to five year planning horizon from construction to commissioning.

The lignocellulose market utilizes potential supply from forest residues and purpose grown forest resources [9]. The biomass price fluctuates in advance of actual fuel use to capture the forward planning necessary to meet fuel commitments of future committed generation. The price curve for biomass uses a marginal pricing equilibrium set in competition between the competing use of biomass for hydrogen, bioethanol production, or electricity generation.

The vehicle market uses a logit choice model to capture changes in consumer behavior. Conventional vehicles include petrol/diesel internal combustion engine vehicles (ICEVs) and hybrid electric vehicles (HEVs). Alternative fuelled vehicles include biofuel (BICEVs), hydrogen fuel cell (FCVs), battery electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs).

In this study two logit models were implemented to model the interaction of consumer behavior on the vehicle market. The models are designated *standard* and *conditional* logit models.

Logit Choice Models

The logit decision making process is a mathematical model applied in the prediction of vehicle sales [10, 11]. Consumer behavior in the context of vehicle sales relates to the value and weighting a consumer places on both real and perceived vehicle attributes. Two logit choice models were implemented based on a standard and conditional choice.

The ***standard*** logit choice model was formulated on price elasticity in conjunction with a consumer preference variable to determine the sales share of each vehicle technology. The standard logit model is defined in Eq. (1) as:

$$S_i = \frac{\exp(\beta_i \mathrm{p_i} - \mathrm{\gamma_i})}{\sum_j \exp(\beta_j \mathrm{p_j} - \mathrm{\gamma_j})} \tag{1}$$

where S_i is the sales share of vehicle *i*, *p* is the annual vehicle cost including capital and operating expenses, β is the price elasticity and γ represents the intrinsic preference parameter that captures consumer preference for considerations such as availability of refueling infrastructure.

The ***conditional*** logit model is most suited when the consumer choices are modelled as a function of the attributes of the alternatives, rather than the attributes of the individual making the choice [12]. In the context of the vehicle fleet a conditional logit choice model quantifies the importance of the attributes or utilities *U* to consumer preference [10, 11]. The utility coefficients β_i are detailed in [10] and reflect the importance or weighting of each utility factor. The form of the conditional logit model is given in Eq. (2) as:

$$S_i = \frac{\exp(\beta_{FC}U_{FCi}+\beta_{PP}U_{PPi}+\beta_{DR}U_{DRi}+\beta_{CMDD}U_{CMDDi}+\beta_{PLDD}U_{PLDDi}+\beta_{CV}U_{CVi})}{\sum_j \exp(\beta_{FC}U_{FCj}+\beta_{PP}U_{PPj}+\beta_{DR}U_{DRj}+\beta_{CMDD}U_{CMDDj}+\beta_{PLDD}U_{PLDDj}+\beta_{CV}U_{CVj})} \quad (2)$$

where the utility variables are dependent on fuel cost (FC), purchase price (PP), driving range (DR), convenient medium distance destinations (CMDD), possible long distance destinations (PLDD) and reluctance to drive conventional vehicles (CV).

METHODOLOGY

To explore the impact of consumer behavior on the transport sector, both standard and conditional logit vehicle choice models were implemented to model the vehicle sales share for each vehicle technology. The impact on fossil fuel use was assessed by comparing the results of both logit choice models under a business-as-usual (BAU) scenario. An additional high carbon tax (HCT) scenario was used to assess the effect of policy change on fossil fuel use. All scenarios contain the following baseline assumptions:

i. PHEVs and EVs are available from 2015; FCVs from 2020; and sales of conventional vehicles are not constrained.
ii. Oil price at US$80/bbl in 2010 increases by 2.3% per annum to a maximum of US$200/bbl. Natural gas price increases are linked to the oil price increase.
iii. No liquid natural gas (LNG) facilities are constructed in New Zealand, thereby preventing the importation of LNG. As of 2011 there are no publicly announced plans to construct an LNG terminal. However, as New Zealand is an isolated island nation this may change depending on the extent of future domestic natural gas discoveries and the international price of natural gas.
iv. Carbon dioxide sequestration costs are capacity based starting at US$1.6 per tonne CO_2 equivalent (/t $CO_{2\text{-eq}}$)) and reaching a maximum of US$16 /t $CO_{2\text{-eq}}$.
v. The carbon tax from 2010-2012 is set to US$7.5/t CO_{2eq}.

Scenario Descriptions

The three scenarios analysed were:

1. BAU standard logit (BAUSL) – Consumer behavior for the vehicle stock is governed by the standard logit choice model. The carbon tax rises to US$15/t CO_{2eq} after 2012.

2. BAU conditional logit (BAUCL) - Consumer behavior for the vehicle stock is governed by the conditional logit choice model. The carbon tax rises to US$15/t CO_{2eq} after 2012.

3. HCT standard logit (HCTSL) - Consumer behavior for the vehicle stock is governed by the standard logit choice model. The carbon tax rises to US$120/t CO_{2eq} after 2012.

RESULTS

(i) BAUSL Scenario

Gas-fired generation is replaced by 2030 with cheaper integrated gasification combined cycle coal plants along with some additional wind and geothermal generation (Fig. 1a). Coal-fired generation peaks in 2031 at 23% of total generation but then declines to near zero by 2050. After 2030, cost reductions in wind energy generation make wind the dominant provider of new electricity generation to meet projected demand growth from 2020-2050.

The wholesale electricity price increases steadily between 2020 and 2030 with the depletion of domestic gas resources (Fig. 1b). The price stabilises at an average of 6.6cUS[1] after 2030 before dropping slightly after 2047 due to the replacing of coal as the marginal generator with a wind/hydro combination.

A mixed share of vehicle technologies are operating in the light and heavy vehicle fleets by 2050 (Figs. 1c and 1d). In 2050 the total share of alternative fuelled vehicles (BICEVs, FCVs, PHEVs, EVs) for the light and heavy vehicle fleets are 42% and 23% respectively.

Net petroleum transport energy use declines 36% by 2050 (Fig. 1e) due to increased market share of alternative fuelled vehicles and improving efficiency of ICEVs and HEVs.

Gross GHG emissions decrease 38% (9 Mt) by 2050 (Fig. 1f). Carbon dioxide capture and storage (CCS) is introduced from 2026 following the installation of new thermal hydrogen and electricity generation. Up to 17% or 2.4 $MtCO_{2\text{-eq}}$ is sequestered in 2050. This modest volume is considered to be easily accommodated in New Zealand in abandoned gas fields, unmineable coal seams or deep saline aquifers [13].

Demand for hydrogen reaches 190 kt/yr in 2050 (Fig. 1g). Initially small scale methane reforming provides a fast measure to bridge the rising hydrogen demand until large scale fossil fuelled cogeneration plants are installed.

The average hydrogen wholesale price during the period 2030-2050 for both the North and South Islands (Fig. 1h) is US$3.7/kg. Prices drop in 2025 due to large scale production of hydrogen from cogeneration plant as demand from the fledgling fuel cell fleet increases.

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[1] 2008 dollar values.

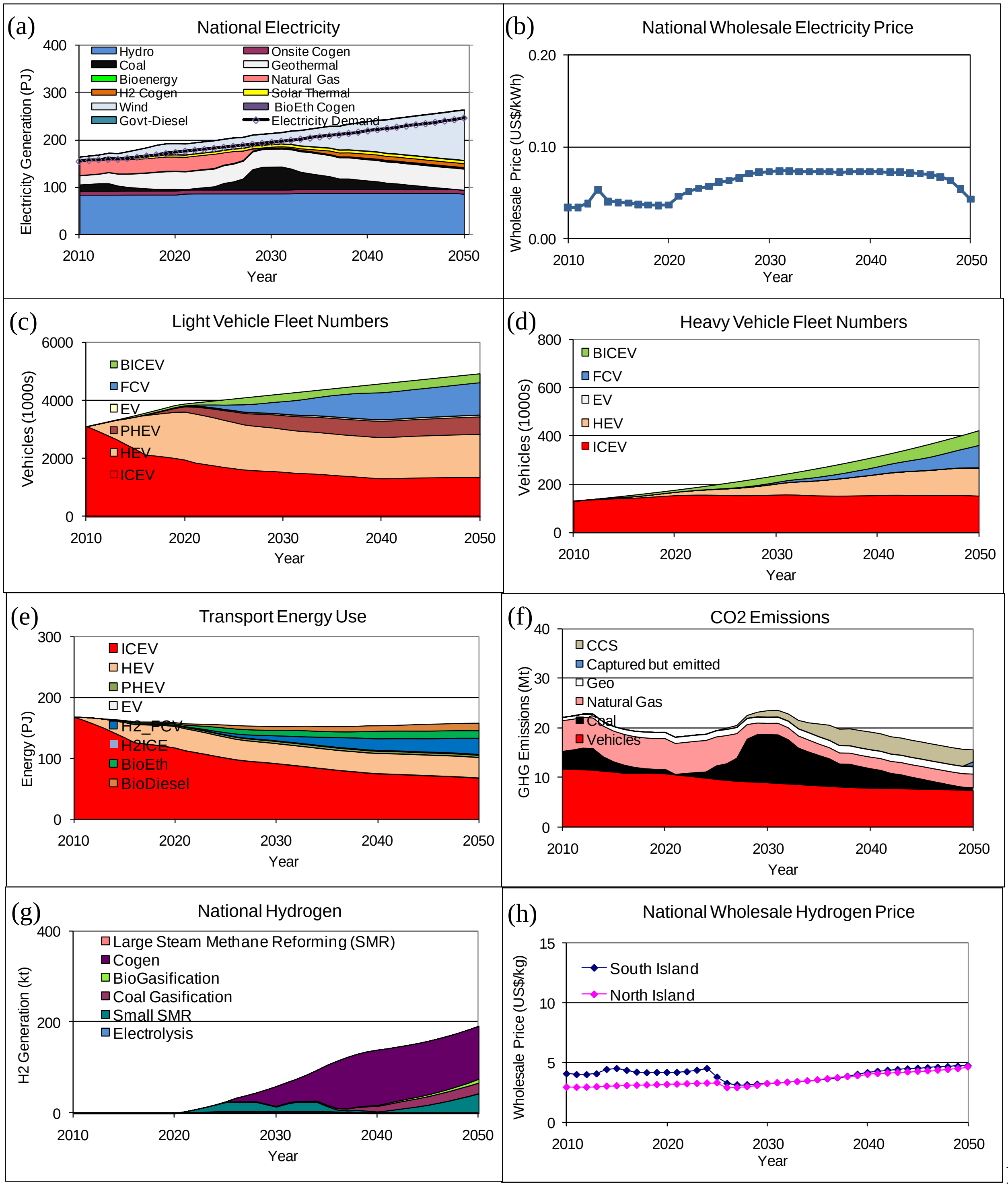

Figure 1. BAUSL scenario from 2010 to 2050. (a) National electricity supply and demand (b) Wholesale electricity price (c) Light vehicle fleet share (d) Heavy vehicle fleet share (e) Total transport energy use (f) GHG emissions (g) National hydrogen supply (h) Wholesale hydrogen price.

(ii) BAUCL Scenario

The demand for wholesale electricity is 9% lower by 2050 than in the BAUSL scenario (Fig. 2a).

Long term electricity prices are not materially different to the BAUSL scenario due to the high availability of cost effective wind generation (Fig. 2b).

From Fig. 2c the share of alternative fuelled light vehicles is 26% in 2050. In 2050, the fleet shares for the light vehicle fleet are ICEVs 38% (38% above BAUSL), HEVs 36% (+19%), BICEVs 8% (+26%), FCVs 10% (-56%), PHEVs 7% (-42%), and 1% EVs. In 2050 the total share of alternative fuelled vehicles for the light and heavy vehicle fleets are 26% (-38%) and 43% (+87%) respectively. While there is an 87% increase in alternative fuelled vehicles in the heavy fleet this is predominantly due to an increase in biodiesel fuelled vehicles. The total number of PHEVs, FCVs, EVs in the heavy fleet declines from 23% to 17%.

The fleet share for heavy BICEVs fuelled from biodiesel reaches 26% by 2050 (Fig. 2d) with no significant engine modifications required to use the biodiesel as a direct substitute fuel for diesel.

Between 2010 and 2050 the petroleum energy demand for the vehicle fleet reduces by 30% (Fig. 2e). In 2050 demand is 11% higher than in the BAUSL scenario due to the lower rate of adoption of alternative fuelled vehicles.

Gross GHG emissions in 2050 are 5% below the BAUSL scenario (Fig. 2f). The reduction in GHG emissions is the result of reduced primary demand for hydrogen fuel with lower utilization of large scale coal-based cogeneration of hydrogen and electricity.

Cogeneration of electricity from hydrogen remains cost effective for large scale hydrogen production (Fig. 2g).

The average hydrogen wholesale price during the period 2030-2050 in the North Island (Fig. 2h) is US$3.7/kg which is the same as in the BAUSL scenario.

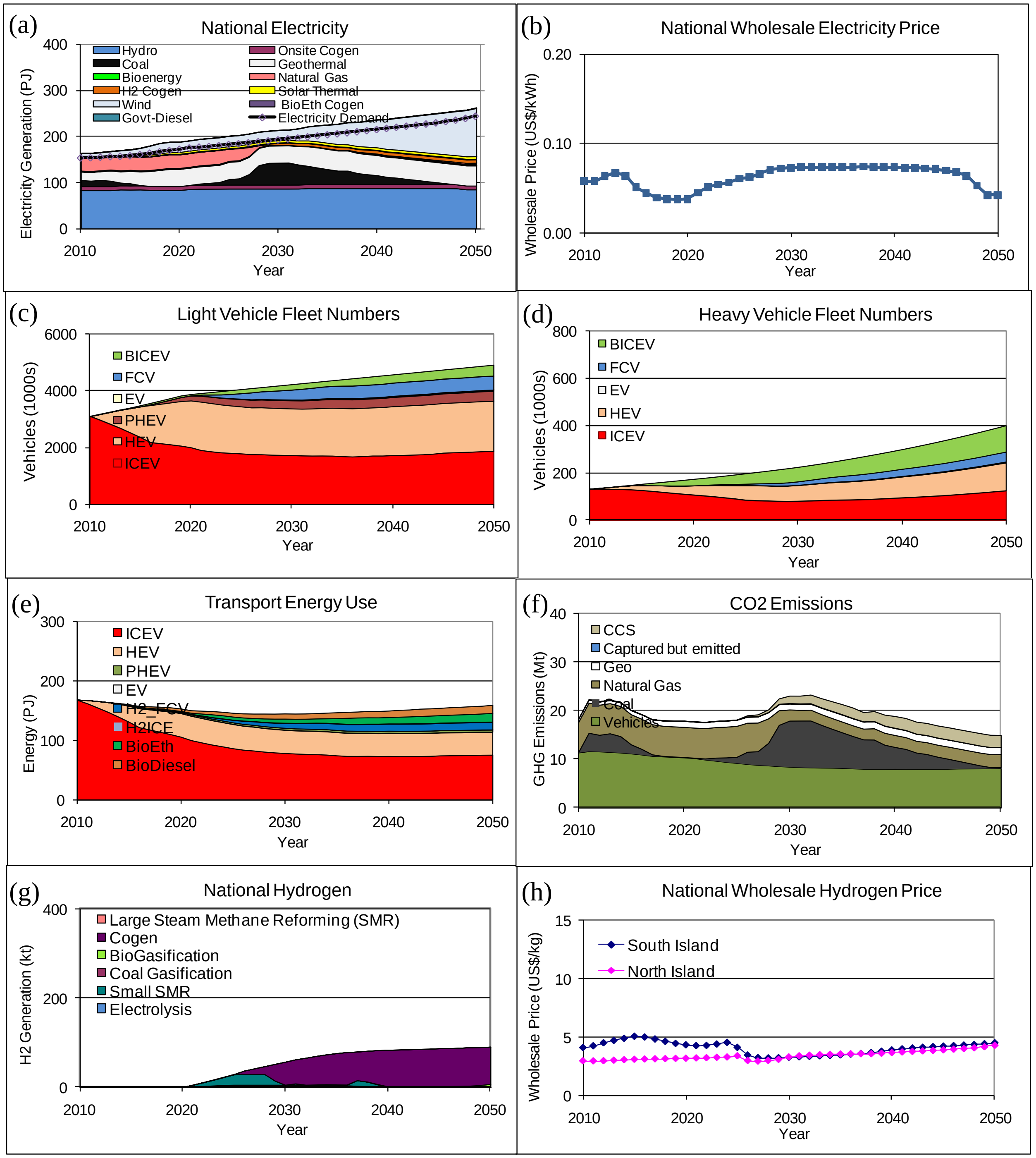

Figure 2. BAUCL scenario from 2010 to 2050. (a) National electricity supply and demand (b) Wholesale electricity price (c) Light vehicle fleet share (d) Heavy vehicle fleet share (e) Total transport energy use (f) GHG emissions (g) National hydrogen supply (h) Wholesale hydrogen price.

(iii) HCTSL Scenario

The relatively high carbon tax results in a more rapid reduction of 2010 fossil fuel utilisation for electricity generation (Fig. 3a).

The wholesale electricity price is elevated between 2012 and 2014 as thermal generation is replaced with new geothermal and wind generation (Fig. 3b). Electricity demand is 10% higher in 2050 in comparison to the BAUSL scenario with utilization of large scale electrolysis for direct hydrogen production. Long term wholesale electricity prices are comparable to the BAUSL and BAUCL scenarios as the marginal price is maintained by access to cost effective wind generation.

The fleet profile of the light and heavy vehicles for the HCTSL scenario is similar to the BAUSL scenario (Figs. 3c and 3d). In 2050, the share of alternative fuelled light vehicles increases from 42% in the BAUSL scenario to 44%. The share in the heavy vehicle fleet increases from 23% to 27%.

Between 2010 and 2050, the petroleum energy demand for the vehicle fleet reduces by 46% (Fig 2e). In 2050 demand is 15% lower that in the BAUSL scenario due to the higher rate of adoption of alternative fuelled vehicles.

Small scale sequestration is utilized between 2030 and 2040 with greenhouse gas emissions reducing by 54% by 2050 from 2010 emission levels (Fig 3f). In comparison the BAUSL scenario greenhouse gas emissions in 2050 are 26% lower.

Electrolysis replaces coal cogeneration as the primary source for large scale hydrogen production (Fig. 3g). Total demand for hydrogen in 2050 remains comparable to the BAUSL scenario.

The average hydrogen wholesale price during the period 2030-2050 in the North Island (Fig. 2h) is US$5.4/kg, 46% higher than under the BAUSL scenario due to the higher cost of hydrogen production by electrolysis.

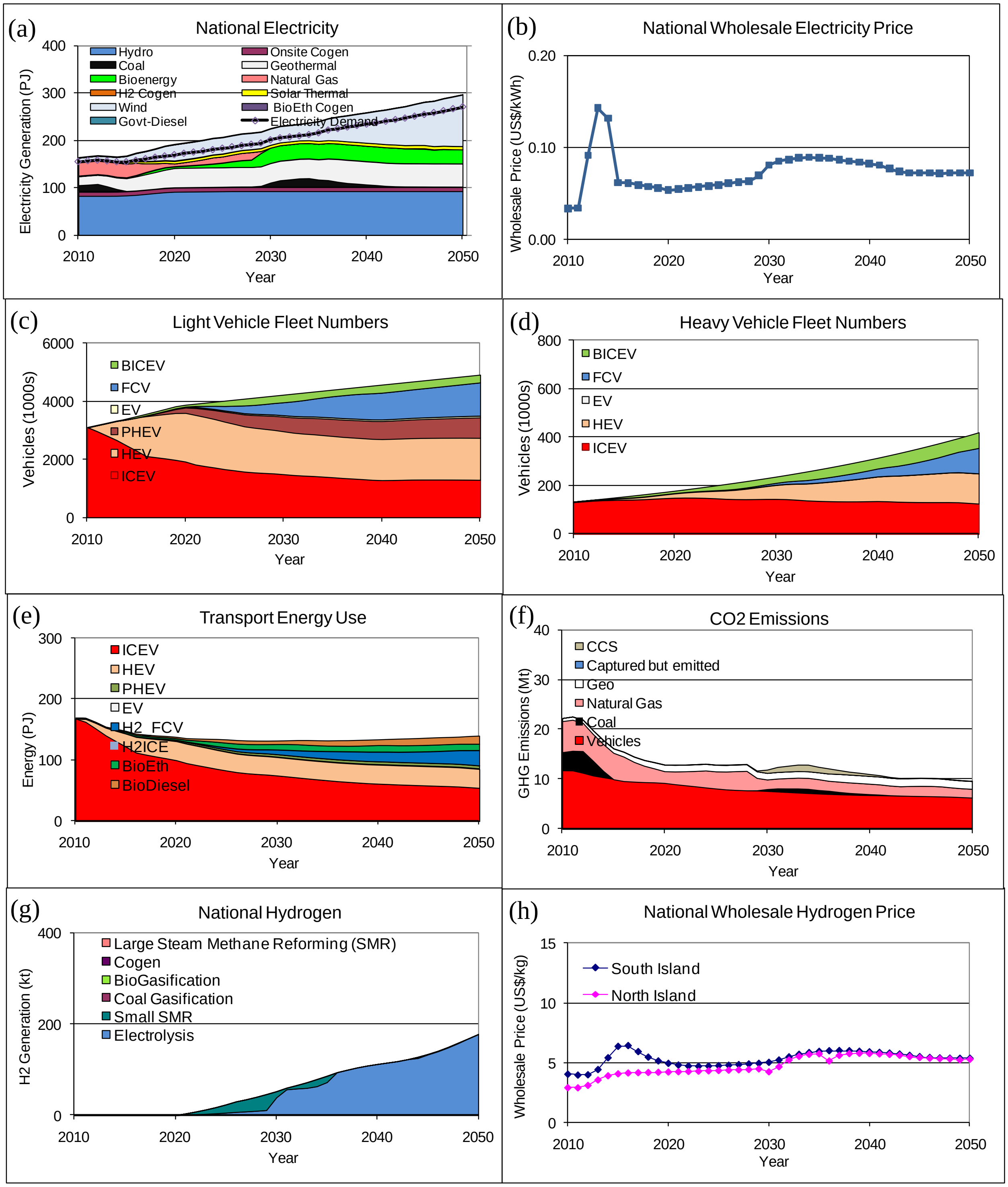

Figure 3. HCTSL scenario from 2010 to 2050. (a) National electricity supply and demand (b) Wholesale electricity price (c) Light vehicle fleet share (d) Heavy vehicle fleet share (e) Total transport energy use (f) GHG emissions (g) National hydrogen supply (h) Wholesale hydrogen price.

DISCUSSION

The standard logit model gives the same weighting to capital, depreciation, fuel and maintenance costs. This is equivalent to assuming a zero percentage discount rate. The use of the conditional logit in modelling the electricity generation and transport sectors to 2050 in the BAUCL scenario resulted in a reduction in the adoption of alternative fuelled vehicles from 42% under the standard logit scenario of BAUSL to 26%. The principal drivers for the reduction are the utility weightings in the conditional logit that are based on consumer feedback for fuel cost, purchase price, driving range, refuelling infrastructure availability and a desire to drive an alternative vehicle. Of these factors the purchase price is the most significant. When this data is used in the logit it inhibits the uptake of these new technologies. This is an important effect as the conditional logit is more likely to represent the realities of the vehicle retail market as it quantifies a wider range of factors that impact on market share such as driving range, accessibility to both medium and long distance destinations and reluctance to drive conventional vehicles (CV).

The HCTSL scenario (in which the carbon tax increased from US$15/t-$CO_{2eq}$ to US$120/t-$CO_{2eq}$) resulted in a 54% reduction in GHG emissions by 2050 compared to 2010 levels. Using data from [3] this is equivalent to an 8% increase on 1990 levels. The reason that the decrease in GHG emissions is not larger is due to low level of GHG emissions from the electricity sector in 1990 and 2010 when 81% and 74% respectively of New Zealand's electricity generation was from renewable sources. [14].

Under all three scenarios the availability of large cost effective wind, geothermal and hydro resources in New Zealand ensures that by 2050 the electricity generation sector consists of at least 93% renewables. This study did not factor in real-time meteorological constraints for the wind and rainfall or the cost of backup generation to cater for dry or calm periods, hence the predicted percentage of renewable generation is likely to be an upper bound. The extent to which this upper bound can be reached will be dependent on three main factors. The first factor is the ability of New Zealand to use other renewable generation such as hydro, biomass and geothermal to supplement wind generation in periods of low wind. The second factor is the extent to which natural gas and other renewable energy that are directly used in industry can be diverted at strategically important times to provide peak load support for the electricity network. The third factor is the extent to which demand side management such as ripple control of hot water heaters can be used to reduce peak demand.

Notwithstanding the constraints of the oil price and carbon tax as specified in the three scenarios, the degree to which the model results match the real future are dependent on a level economic playing field where the New Zealand energy economy is free of taxes and incentives. The results also assume the gradual provision of refuelling infrastructure when alternative fuelled vehicles become competitive with conventional vehicles. Other assumptions such as the rate of natural gas discoveries also impact on results. Despite these conditions the results give useful insights into the implications of energy policy.

CONCLUSIONS

A comparison of results from the standard (BAUSL) and conditional logit (BAUCL) scenarios shows that vehicle market consumer choice behavior is a significant factor in determining the rate of reduction in greenhouse gases. Vehicle costs and driving range when weighted to reflect consumer choice can result in a 38% reduction in the penetration of alternative fuelled light vehicles by 2050. The market share of alternative fuelled vehicles in the vehicle fleet by 2050 is likely to be between 26% and 42% depending primarily on retail strategy and infrastructure availability. For the model conditions specified in the scenarios the range of the vehicle technology mix in 2050 is predicted to be PHEVs 7-12%, FCVs 10-22%, BICEVs 6-8% and EVs 1%.

A high carbon tax of US\$120/t-CO_{2eq} eliminated the use of fossil fuels from the electricity generation mix. Under this regime GHG emissions in the electricity and transport sector in 2050 were reduced by 54% from 2010 but remained at 8% above 1990 levels. Reductions in emissions below this level are likely to require government policy interventions to limit the use of petroleum based transport fuels.

REFERENCES

[1] The New Zealand Vehicle Fleet: Annual Fleet Statistics 2009, Ministry of Transport, Wellington. ISBN978-0-478-07228-0, 2010.

[2] The Climate Change Response (2050 Emissions Target) Notice 2011(987). New Zealand Gazette Notice Number 2067, New Zealand Department of Internal Affairs, Wellington. http://www.dia.govt.nz/MSOS118/On-line/NZGazette.nsf/; 31 March.

[3] New Zealand's Greenhouse Gas Inventory 1990–2009. New Zealand Ministry for the Environment, Wellington. ISSN: 1179-223X, April 2011, p. 415.

[4] Parker D. 2008. The way forward on biofuels and electric vehicles. In: biofuels and electric vehicles conference, Wellington. Energy Efficiency and Conservation Authority (EECA), http://www.beehive.govt.nz/speech/way+forward+biofuels+and+electric+vehicles; 2 April.

[5] New Zealand Energy Strategy to 2050, Ministry of Economic Development, Wellington. http://www.med.govt.nz/upload/52164/nzes.pdf; October 2007.

[6] Leaver, J.D., and Gillingham, K.T., 2010. Economic impact of the integration of alternative vehicle technologies into the New Zealand vehicle fleet. Journal of Cleaner Production, 18, 908-916.

[7] Leaver, J.D., Gillingham, K.T., and Leaver, L.H.T., 2009. Assessment of primary impacts of a hydrogen economy in New Zealand using UniSyD. International Journal of Hydrogen Energy, 34 (7), 2855-2865.

[8] Connolly D, Lund H, Mathiesen BV, Leahy M., 2010. A review of computer tools for analysing the integration of renewable energy into various energy systems. Applied Energy, 87(4):1059-1082.

[9] Bioenergy Options for New Zealand: Situation Analysis, Scion, Rotorua, ISBN 0-478-11019-7, 2007, p. 83.

[10] Train, KE. EM Algorithms for nonparametric estimation of mixing distributions. Journal of Choice Modelling, 1(1), 40-69.

[11] Santini, D.J. and Vyas, A.D., 2005. Suggestions for a new vehicle choice model simulating advanced vehicles introduction decisions (Avid): Structure and Coefficients, Center for Transportation Research, Argonne National Laboratory, Illinois, USA p. 170.

[12] Hoffman, S.D. and Duncan, G.J., 1988. Multinomial and conditional logit discrete-choice models in demography, Demography, 25(3), 415-427.

[13] IPCC, 2007: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, New York, ISBN 978-0-521-70598-1, p. 852.

[14] New Zealand Ministry of Economic Development, New Zealand Energy Data File: 2011, ISSN 1177-6676, p. 68.