Ministry of Transport
TE MANATŪ WAKA

Legislated Ban on Importing Light Vehicles Powered by Fossil Fuels

Preliminary Cost Benefit Analysis

October 2018

Preface

This report documents the preliminary cost/benefit analysis of legislating a ban on importing light vehicles powered by fossil fuels. The types of vehicles currently meeting this requirement are pure EVs, hydrogen fuel cell vehicles, and vehicles capable of being driven purely on alternative fuels like biofuels. This is one of the proposed policy options that aim to reduce greenhouse gas emissions from road transport and to contribute towards New Zealand's efforts to transition to a net zero carbon economy.

Acknowledgments

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Due to lack of information, time and resources, this cost benefit analysis does not include the following items:

1. Supply-side impacts on the availability of electric vehicles, the choice of vehicle models made available by importers and the battery range of these vehicle types.
2. Potential negative impacts on mobility and accessibility due to supply-side constraints in the availability of electric vehicles.
3. Possible impacts on electricity prices from investments in the charging infrastructure required to accommodate an accelerated uptake of electric vehicles.
4. Road safety impacts associated with changes in vehicle mixes, new technologies, driving behavioural changes and scrappage rates.
5. Health benefits from lower noise pollution due to the accelerated uptake of electric vehicles.
6. Changes in vehicle maintenance costs due to different vehicle technology of electric vehicles, their engine size and powertrain.
7. Any wider economic or distributional impacts by region or by income cohort.

Where possible and appropriate, a sensitivity analysis has been carried out to understand the materiality of varying some of the key inputs on the model results.

Disclaimer

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GLOSSARY OF TERMS AND ABBREVIATIONS

BCR	Benefit-cost ratio
CBA	Cost-benefit analysis
CO_2	Carbon Dioxide
CRF	Common Reporting Framework
EEM	Economic Evaluation Manual
EPA	Environmental Protection Agency
ETS	Emissions Trading Scheme
EV	Electric Vehicle
GHG	Greenhouse Gas
GST	Goods and services tax
ICE	Internal Combustion Engine
MAC	Marginal Abatement Cost
NPV	Net Present Value
PV	Present value
SUV	Sports Utility Vehicle
UNFCCC	United Nations Framework Convention on Climate Change
VFEM	Vehicle Fleet Emissions Model
VKT	Vehicle Kilometres Travelled

1. *Executive Summary*

Legislating a ban on importing light vehicles powered by fossil fuels is expected to lower the average emissions of the imported light vehicle fleet to a maximum of 15 grams of CO_2 emitted per kilometre travelled (gCO_2/km) by 2035. It assumes that all vehicle purchasers would change their behaviour in response to the announcement of this intervention in 2020 by importing an electric vehicle sometime during the 15 year period between 2020 and 2035.

A 15gCO_2/km figure reflects the current (2017) average emissions from the generation of the electricity required to power a pure Battery Electric Vehicle [1]. If in the future, the generation of electricity is wholly sourced from renewable sources, than the average emissions from operating an electric vehicle will effectively be zero (excluding embedded emissions).

In 2017, the average CO_2 emissions of **light vehicle imports** stood at 182 gCO_2/km [2]. Projections undertaken by the MoT as part of the Vehicle Fleet Emissions Model (VFEM) [2] indicate that the average CO_2 emissions of light vehicle imports are expected to decrease to 161 gCO_2/km by 2035 under the Slow EV Growth Scenario while this figure would be 89 gCO_2/km under the Base Case Scenario.

The majority of the (discounted) benefits (91%) are from fuel cost savings to vehicle users and 0.7% in ownership cost savings. Societal benefits in terms of lower GHG emissions amount to 7.7% and 0.4% are from health benefits obtained from lower air pollution concentrations. The total net benefits from the implementation of a legislated ban in 2035 are estimated to be $2.26 billion (in present value) and would save 27 million tonnes of CO_2 emissions over the evaluation period.

The majority of the (discounted) costs (60%) consist of the welfare impact borne by consumers who opt to buy a vehicle which is different from their preferred one or whose mobility is restricted because they are unable to afford a (more expensive) electric vehicle. This impact also includes the premium added to the EV price to represent the non-price factors that influence the consumers' buying behaviour. The capital cost incurred by vehicle buyers due to the higher upfront cost to buy an EV as compared to a fossil fuel vehicle, makes up 40% of total discounted costs. This cost is at it's highest in the initial years following the announcement of the legislated ban because the EV price differential would at it's widest. However, this is expected to narrow substantially by the year when the ban comes into force (2035). Less than 1% of the costs are incurred by the Government and its agencies to cover the implementation costs of this policy intervention.

A Monte Carlo simulation was carried out to test the viability of the legislated ban by changing a number of parameters independently or jointly. The estimated Net Present Value ranges from -$14.75 billion and $8.36 billion and the corresponding estimated BCR ranges from 0.45 and 2.74 at the 90% confidence interval, as shown in Table 1 below.

Table 1: Summary of the costs and benefits of a Ban on Importing Fossil Fuel Light Vehicles in 2035

All dollar estimates are expressed in present values at a 6% discount rate and cover the years 2020 to 2051	Mid-Range	Minimum	Maximum	Confidence Level	
				5%	95%
Benefits:					
Fuel Cost Savings ($ billion)	17.60	2.30	28.63	5.79	17.60
Other Operating Cost Savings ($ billion)	0.56	-0.12	1.39	0.08	0.56
GHG Emissions Savings ($ billion)	1.46	0.15	2.68	0.40	1.46
Health Benefits from Air Pollution Reduction ($ billion)	0.06	0.01	0.07	0.02	0.06
Costs:					
Capital Cost ($ billion)	15.99	0.16	37.58	1.54	15.99
Welfare Cost ($ billion)	13.51	0.61	28.02	2.19	13.51
Implementation Cost ($ billion)	0.03	0.01	0.03	0.01	0.03
Economic Viability Indicators:					
Net Present Value ($ billion)	8.36	-44.28	19.50	-14.75	8.36
Benefit-Cost Ratio	2.74	0.22	10.42	0.45	2.74
Marginal Abatement Cost ($/tCO2)	366.37	-406.09	899.65	-222.15	366.37

The legislated ban is expected to contribute towards reducing emissions from the transport sector and contribute to New Zealand's long term GHG mitigation targets, as further detailed in Section 8. To appreciate the scale of the CO_2 reduction potential from the policy intervention, Section 9 provides estimates of equivalent CO_2 savings in other sectors, such as from electricity generation and tree planting.

2. Background

2.1. Overview

This report provides a preliminary assessment of the benefits and costs accruing to society associated with a legislated ban on importing vehicles powered by fossil fuels [henceforth referred to as a "***legislated ban***" or **"ban"**]. The types of vehicles currently meeting this requirement are battery electric vehicles (BeV or EV), hydrogen fuel cell vehicles, and vehicles capable of being driven purely on biofuels.

This intervention is expected to discourage investment in fossil-fuel vehicles and accelerate the move to a low emissions light vehicle fleet. It would also mitigate the risk of New Zealand becoming a market for left-over fossil-fuel vehicles as major countries phase them out. This assessment provides the economic viability and the emissions reduction potential from legislating a ban effective 1st January 2035.

This assessment does not include any other additional policy interventions currently being considered such as a vehicle fuel efficiency standard, a feebate scheme or a vehicle scrappage scheme in Auckland. Notwithstanding, it is expected that these three interventions, as well as existing ones such as the ETS price, will reinforce and facilitate the transition towards a fossil-fuel free light vehicle fleet.

The benefits considered in this report are the monetary gains by private users in the form of vehicle ownership cost savings, including fuel savings, and benefits obtained by the wider society through lower greenhouse gas emissions and health benefits from lower concentrations of air pollution.

The bulk of the monetary costs are associated with the potentially higher purchase price of EVs and the associated welfare cost to vehicle buyers. This analysis also includes the costs incurred by Government entities, mainly the New Zealand Transport Agency (NZTA) and New Zealand Customs, which are responsible for the implementation and enforcement of a legislated ban. The costs include market monitoring, additional compliance costs, a wide stakeholder consultation and ongoing awareness-raising campaigns.

2.2. The Policy Problem and Objective

Under the Paris Agreement on Climate Change, New Zealand committed to reduce greenhouse gas (GHG) emissions by 30% below 2005 levels by 2030 [3]. To ensure that New Zealand joins with international leading countries to combat climate change, the Government has set a goal for New Zealand to be a net zero emissions economy by 2050 [4]. Transport accounts for 18% of New Zealand's GHG emissions, with light vehicles contributing to around 66% percent [2].

The Ministry of Transport is currently investigating a range of policy interventions to supplement existing policy settings, such as the emissions trading scheme (ETS) and the Electric Vehicles (EV) programme implemented in 2016, to help reduce New Zealand's GHG emissions from light vehicles. The policy options range from awareness-raising programmes to incentive-based or performance-based measures to increase the uptake of more fuel-efficient light vehicles entering the New Zealand fleet. This report focuses only on legislating a ban on importing light vehicles powered by fossil fuels, effective on 1st January 2035 and announced in 2020.

2.3. Policy Description

The legislated ban will be applied to all light passenger and light commercial vehicles powered by fossil fuels and having a gross vehicle mass of 3.5 tonnes or less and which are first registered in New Zealand from 1st January 2035. It will therefore encompass passenger cars, sports utility vehicles (SUVs), people movers, utes and light commercial vehicles (LCVs), including pickups and mini buses. It will also apply equally to both new and used vehicle imports. The ban will not apply to BeVs, hydrogen fuel cell vehicles, or vehicles operating on biofuels only.

This intervention aims to reduce the average emissions of the imported vehicle fleet to a maximum of 15 gCO_2/km by 2035. Thus, it is implicitly assumed that vehicle purchasers wishing to import a vehicle would have changed their behaviour in response to the announcement of this intervention in 2020 by importing an EV at some point during this 15 year period.

The 15 gCO_2/km figure reflects the average emissions from the generation of the electricity required to power an EV. If in future, the generation of electricity is wholly sourced from renewable sources, than the emissions from operating an EV will effectively be zero (excluding embedded emissions). Hence, this intervention intends to substantially lower the average CO_2 emissions from the base year value of 2019.

In 2017, the average CO_2 emissions of **light vehicle imports** stood at 182 gCO_2/km. Projections undertaken by the MoT as part of the Vehicle Fleet Emissions Model (VFEM) [2] indicate that the average CO_2 emissions of light vehicle imports are expected to decrease to 161 gCO_2/km by 2035 under the Slow EV Growth Scenario while this figure would be 89 gCO_2/km under the Base Case Scenario.

2.4. Description of Costs & Benefits

The main benefits from the implementation of a legislated ban are CO_2 emissions savings, vehicle ownership cost savings, including fuel cost savings, and health benefits from lower concentrations of air pollution. Due to data limitations, this report excludes health benefits from lower noise pollution obtained from a greater prevalence of EVs.

The main costs incurred from the implementation of a legislated ban mainly relate to the incremental difference in the projected purchase price of an EV as compared to a fossil-fuel vehicle. The expected trend in relative prices is highly uncertain and various studies point to different dates when price parity will be achieved. In this assessment, it was assumed that new EV prices will decrease by 2.6% per year while two alternative EV price scenarios have been modelled as part of the sensitivity analysis detailed in Section 7 and as further described in Section 4.1.1. These two scenarios assume a 'slow' price decrease in new EV prices of 1% per year and a 'fast' price decrease of 4.3% per year.

Another cost identified in this report relates to the welfare impact (measured by the deadweight loss) borne by consumers due to the change in their vehicle purchasing decisions as a result of changes in the prices or availability of their preferred vehicles. In other words, if consumers opt to buy a vehicle that is different from their preferred one, or if they are unable to afford a more expensive vehicle (during the period before price parity is reached), then this would have an adverse impact on their utility or on their mobility needs.

Another component contributing to the adverse welfare impact is the premium that is added to the EV price to 'monetise' a number of non-price factors that create disutility if consumers were to buy an EV. These factors include limited driving range and short battery life, availability (or lack thereof) of charging points and slow or inconvenient charge times. In this assessment, these non-price factors were monetised and summed up as a 'premium' that is added to the price of both new and used EVs.

This premium was assumed to narrow over-time until it is eliminated by 2035, meaning that these non-price factors would have improved to the extent that consumers no longer perceive them as a barrier to buying and operating an EV. Given the uncertainties around the future development of these non-price factors, three scenarios were modelled, as further detailed in Section 4.1.2 below.

The implementation costs incurred by the Government and its agencies in the run-up to the implementation of the legislated ban are estimated. These include a wide stakeholder consultation, ongoing information campaigns, compliance costs and *ex post* market monitoring. These costs are highly uncertain and a wide margin was assumed in the sensitivity analysis.

3. The Baseline Scenario

3.1. Baseline Description

To assess the impact of a legislated ban, it is necessary to first define the counterfactual or the baseline scenario for comparative purposes. In this scenario, it is assumed that there will be no additional policy intervention apart from those already implemented (such as the emission trading scheme) to alter the predicted trend in the average CO_2 emissions of the light vehicle imports. Thus, the 'baseline' average CO_2 emission level would only reflect the changes in the number and type of vehicle imports and the travel distances made by vehicle age and other characteristics[1].

3.2. Baseline Methodological Approach

Data on the light vehicles imported in New Zealand for the period 2019-2040 was obtained from the VFEM [2]. Since this CBA encompasses a longer time period, the post-2040 figures were estimated using a three-year moving linear trend starting from 2041[2]. The 2020 figures obtained from the VFEM were used as the starting point for the estimation of costs and benefits in this CBA.

The VFEM projects the composition of the vehicle fleet, vehicle travel, energy use (fuel and electricity) and greenhouse gas emissions from road transport. The projections are based on assumed economic, demographic and technological trends, including the rate of EV uptake and fuel efficiency improvements of fossil-fuel vehicles.

For the purposes of this CBA, the vehicle projections are obtained from the **'Base Case'** scenario. In this scenario, the annual growth rates in vehicle registrations differ depending on the vehicle's fuel type. For EVs and hybrid vehicles, the growth rates are projected to be faster than that of conventional vehicles over the policy period. Table 2 below shows the projected annual growth rates of vehicle registrations by fuel type.

[1] These travel needs are reflected in the annual average vehicle kilometres travelled. In turn, these are influenced by the driving preferences of vehicle users, the average age of the vehicle fleet and the retail fuel price.
[2] The Ministry of Transport is in the process of upgrading the VFEM to extend out to 2055.

Table 2: Annual growth rates in vehicle registrations – Baseline Scenario

	Diesel	Petrol	Electric	Hybrid
2018	-32%	-16%	51%	23%
2019	-6%	-6%	94%	27%
2020	-2%	-3%	74%	25%
2021	-4%	-1%	34%	12%
2022	-3%	-3%	34%	11%
2023	-7%	-11%	22%	12%
2024	-7%	-11%	17%	7%
2025	-2%	-5%	23%	5%
2026	-10%	-5%	18%	14%
2027	-11%	-6%	16%	13%
2028	-14%	-8%	13%	10%
2029	-17%	-9%	11%	8%
2030	-20%	-9%	11%	9%
2031	-8%	-10%	11%	0%
2032	-9%	-11%	10%	0%
2033	-11%	-14%	8%	-2%
2034	-13%	-17%	7%	-2%
2035	-14%	-18%	8%	0%
2036	-9%	-3%	2%	1%
2037	-10%	-4%	2%	1%
2038	-11%	-4%	2%	0%
2039	-13%	-5%	2%	0%
2040	-17%	-5%	2%	0%

The projected increase in EVs in the VFEM's Base Case scenario will improve the average CO_2 emission level of the fleet of the new and used light vehicle imports from the current (2017) average of 182 gCO_2/km to 89 gCO_2/km by 2035. The policy intervention intends to accelerate this improvement to 15gCO_2/km by 2035. Figure 1 shows the projected average CO_2 emission level in the baseline.

Figure 1: Projected average CO_2 emission level of vehicle registrations – Baseline Scenario

4. Modelling the Impact of a Legislated Ban

4.1. Key assumptions

The modelling approach to assess the impact of a legislated ban compared to the counterfactual described in Section 7 rests on a number of key assumptions, as listed below. These assumptions are discussed in further detail in the following sub-sections.

1. The projected trend in EVs prices;
2. The premium added to the EV price to monetise non-price factors and its trajectory;
3. How vehicle importers and suppliers will adapt their vehicle fleets in terms of availability, range of models and vehicle prices following the announcement of a legislated ban and/or following parliamentary approval of the relevant legislation;
4. The rate of investment in charging infrastructure to cater for an accelerated EV uptake.

A number of additional 'implicit' assumptions have been made in order to obtain robust projections, namely:

1. Consumer preferences between used and new vehicles will be maintained at the ratio indicated in the VFEM projections. In 2017, the share of new light vehicle imports was 47% of total imports [5].
2. The average economic life of a brand new vehicle is 17 years and that of a used vehicles is 7 years (i.e. the average age for a used import is 10 years when it enters the fleet) [6].
3. Historic data on the average annual VKT are based on the Vehicle Fleet Statistics published by the Ministry of Transport [5] while the projections of these figures are based on the Slow EV growth scenario [2]. An annual reduction of 4% in the average annual VKT is then applied to account for reduced travel as the vehicle ages [6].
4. The average annual VKT are assumed to be higher in the case of EVs due to the 'rebound effect'[3].
5. It is assumed that the VKT driven by EVs will not be constrained by battery range or charging locations. Moreover, the increase in VKT is assumed to have a negligible impact on congestion.
6. The share of total trips between different travel modes is unchanged throughout the time series, which means that commuters are assumed to maintain similar travel habits as those observed today.

[3] In general, the rebound effect refers to behavioural changes that offset the efficiency gains from adopting new technologies. This means that EVs will be driven more than fossil fuel vehicles because the electricity charging costs will be lower than the costs of fossil fuel.

4.1.1. Projected Trend in EV Prices

The upfront capital cost of buying an EV is the largest cost component incurred by the purchaser. As of 2017, the **average** price of a new EV was around $20,000 higher than that of a fossil-fuel vehicle and about $13,000 higher for a used EV [1]. The price difference varies according to a number of factors, including the make and model of the EV, its age and its condition when it is sold. In fact, the purchase price of some used EV models currently sold in New Zealand is already on par with that of a fossil fuel vehicle [1].

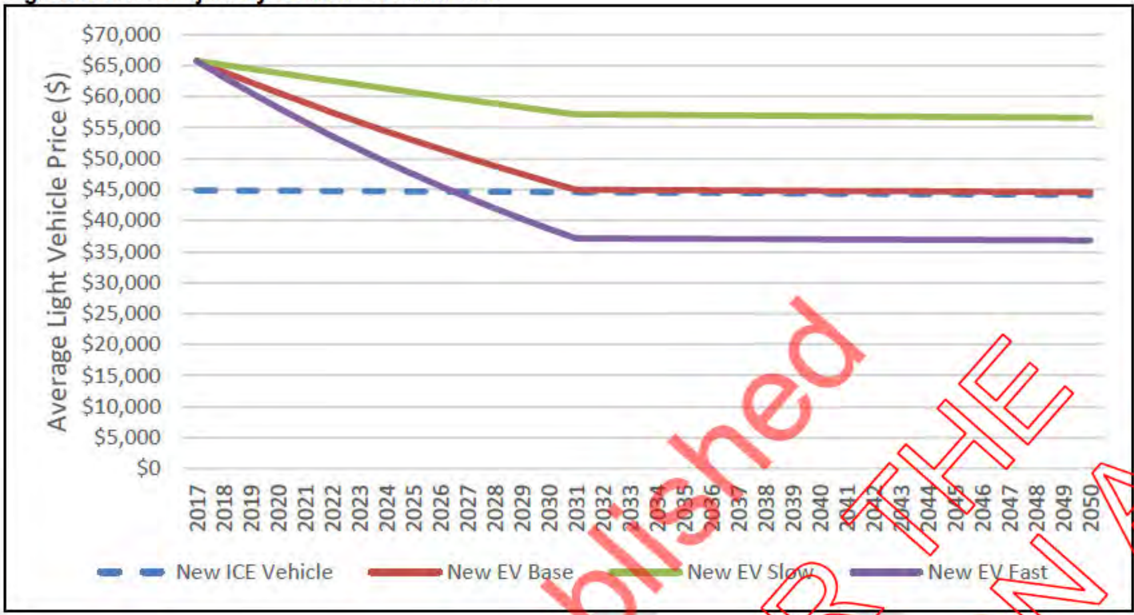
The price difference between EVs and fossil fuel vehicles is expected to decrease as EVs become more popular and their manufacturing costs decrease as a result of economies of scale, technical advances, 'learning' effects and deepening of the global EV supply market. In the VFEM's Base Case scenario, this trend will lead to price parity[4] around mid-2020[5].

Given the inherent uncertainty in future vehicle prices or on the price parity date, three scenarios were modelled in this assessment, as shown in Figure 2 below and as modelled in the sensitivity analysis detailed in Section 7. In general, the model shows that a faster EV price decrease will increase the benefits from legislating a ban because this intervention would incentivise consumers to buy an EV at an earlier date than would have otherwise been the case and thus, consumers and society would gain the resultant fuel savings and GHG emissions savings at an earlier date. Conversely, if EV price decline at a slower rate and the legislated ban would come into force, than consumers will be obliged to purchase a more expensive vehicle, leading to a larger adverse impact on personal utility.

[4] Price Parity refers to a specific point in time when the price of a good becomes equal to that of a potential substitute good. In this report, the parity point is when the average purchase price of an EV has sufficiently decreased to equate with that of a fossil fuel vehicle.

[5] The MoT is undertaking a detailed study on the EV uptake to incorporate the most recent developments in the EV and battery manufacturing sectors and the results of surveys on consumers' perceptions towards EVs. This report will feed into the VFEM and this model will be revised accordingly.

Figure 2: Price Trajectory for New EVs and ICEs



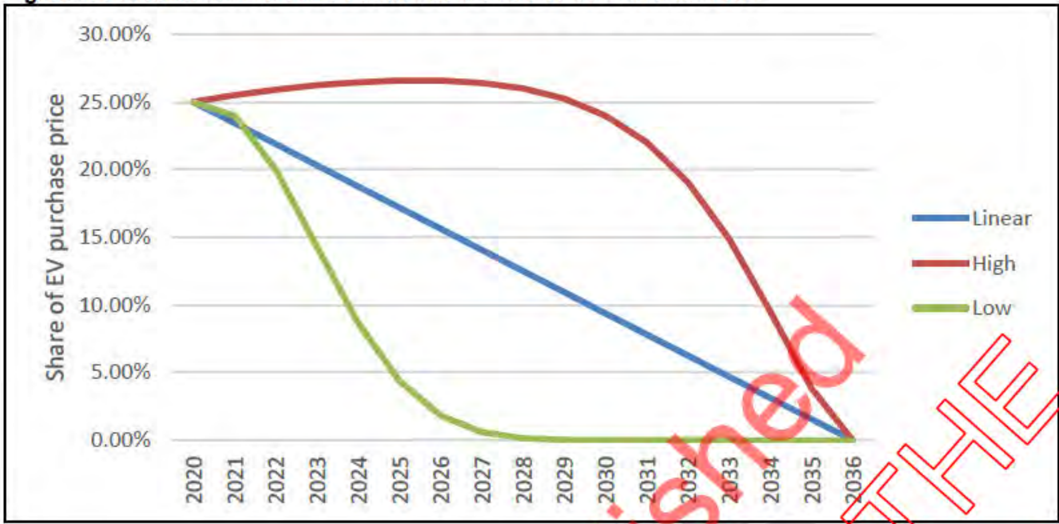
4.1.2. Premium on Non-Price Factors

The estimated impact of the legislated ban rests upon the assumption that the Government will announce this intervention in 2020 (or 15 years before the ban will come into force). From this assumption, it is inferred that potential vehicle purchasers will start to change their purchasing behaviour in favour of EVs from this year. The rate of behavioural change is reflected in an accelerated uptake of EVs as compared to the counterfactual.

Consumers' purchasing behaviour is influenced by both price and non-price factors. The latter may include the range or choice availability of EV models, their driving range, the expected battery life, the availability (or lack thereof) of charging points and the time taken to charge the EV battery.

In order to fully capture the welfare impact from the expected change in consumers' purchasing behaviour in favour of an EV **as a result of the legislated ban**, these non-price factors have been 'monetised' as a premium added to the EV price. Subsequently, this premium was assumed to decline overtime until becoming negligible by 2035. Given the uncertainties around the future development of these non-price factors, three scenarios were modelled, as shown in Figure 3 and as further detailed in the sensitivity analysis in Section 7.

Figure 3: Premium on Non-Price Factors as a share of EV Purchase Price



In reality, consumers' preferences could substantially differ from any one of these scenarios and the importance given to each of these non-price factors by different individuals is also subject to a wide uncertainty. Some consumers may assign a very high importance to all of these factors and which would have a greater influence on their behaviour than the higher EV price. In this case, the assigned premium would be very high. Conversely, some consumers, such as early adopters, would not be overtly concerned about these non-price factors and hence, the premium would be very low.

4.1.3. Vehicle Importers & Charging Infrastructure Investments

As stated in the previous section, it is assumed that the Government's announcement of its intention to legislate a ban on the importation of fossil fuel vehicles will accelerate the demand for EVs as compared to the counterfactual. For modelling purposes, it is assumed that importers will react accordingly and will increase the supply of EVs and broaden the range of models available. **Thus, it is assumed that there will be no supply constraints.**

Apart from making more choices of EVs available to the New Zealand market, it is also assumed that **importers will not raise the price of EVs** in response to a greater demand for these vehicles. Notwithstanding, it is highly recommended that extensive consultation with vehicle importers is undertaken to better understand, and possibly pre-empt, any supply-side issues that a legislated ban might induce.

It is also assumed that the Government and private sector will install the required charging infrastructure to cater for the accelerated EV uptake. **It is assumed that this increased infrastructural investment will not increase electricity prices.** Again, it is recommended that the private sector, such as electricity companies and petroleum filling stations, are extensively consulted to better understand any potential constraints in rolling out the required charging infrastructure.

In the sensitivity analysis detailed in Section 7, three electricity price projections have been modelled [7]. In the 'high' electricity price scenario, electricity prices are projected to be around 5% higher than the reference (mid-point) scenario. If one assumes this high electricity price scenario, the NPV from implementing a legislated ban would decrease by around 1% as compared to the NPV figure obtained using the reference electricity prices.

5. *Cost-benefit Analysis - Methodology*

5.1. Quantified Benefits

The vehicle ownership cost savings (including fuel savings), CO_2 emissions savings and health benefits from lower concentrations of air pollution have been quantified and valued in monetary terms[6]. Potential benefits from reduced noise pollution have not been quantified due to data limitations.

The benefits are estimated for the period 2020-2035, effectively incorporating the behavioural change of consumers with respect to their vehicle purchase decision following the announcement of the legislated ban. It excludes any benefits that are obtained beyond 2035, which is the year when the legislated ban comes into force. Hence, the benefits from the policy itself, and any other legacy effects from an earlier switch to EVs, are excluded.

5.1.1. CO_2 Emissions Savings

It is expected that a legislated ban would greatly accelerate the reduction in average CO_2 emissions of light vehicle imports – from a projected average of 180 gCO_2 /km in 2019 (or 182 gCO_2 /km in 2017) to a maximum of 15gCO_2 /km in the medium to long term, depending on the rate of acceleration in EV take-up.

The annual CO_2 savings are estimated by multiplying the improvement in the average annual CO_2 level of the imported vehicles (in gCO_2/km) as compared to the counterfactual by the number of vehicles imported in each year. These annual improvements are multiplied by the average VKT driven while reducing the latter as the vehicle gets older. An average lifetime of 17 years was assumed for a new vehicle and a 10 year lifetime was assumed for a used vehicle. These estimated annual CO_2 savings are summed up and converted into tonnes of CO_2 emissions to obtain the **gross** annual emissions savings from the legislated ban.

In order to obtain the **net** CO_2 emissions savings, the emissions generated from the electricity needed to power the additional EVs must be subtracted from the gross CO_2 emissions savings. These additional emissions are estimated in a similar fashion to the CO_2 emissions savings, namely by multiplying the number of additional EVs by the average annual VKT, with the latter assumed to decrease as the vehicle gets older, and hence, is driven fewer kilometres in a year.

[6] All cost/price values are in 2017 New Zealand dollars, unless otherwise specified.

It was also assumed that the driving behaviour of EV users will be subject to the 'rebound effect'. In general, this refers to behavioural changes that partly offsets the efficiency gains from adopting new technologies. This means that EVs will be driven more than fossil fuel vehicles because the electricity charging costs will be lower than the costs of fossil fuel.

In this analysis, the rebound effect has been accounted for by increasing the kilowatt-hours (kwh) needed to operate the EVs by 10% throughout the time series. Given the lack of data on the rebound effect, wide margins were assumed in the sensitivity analysis to gauge the impact on the net benefits of this intervention, as discussed in Section 7.

The net CO_2 savings are monetised by multiplying the tonnes of emissions savings by the projected price of carbon as published in the Productivity Commission's 'Low Emissions Economy' report [8]. The present value of the monetary net CO_2 savings are then estimated using a real discount rate of 6% p.a. [9].

The Productivity Commission's report presents three carbon price projections: the *'Policy Driven'* scenario, the *'Disruptive Decarbonisation'* scenario and *'Stabilising Decarbonisation'* scenario. These three carbon price scenarios are shown in Figure 4 below while Annex 3 provides a detailed commentary of different carbon values that may be found in local and foreign publications. These three scenarios were simulated in the sensitivity analysis detailed in Section 7.

Figure 4: Carbon Price Projections

These carbon prices are not the same as, or equal to, the social cost of carbon (SCC). The latter reflects the true cost borne by society from CO_2 emissions. In New Zealand, the SCC is estimated at $40/ton as stated in the Economic Evaluation Manual (EEM) published by New Zealand Transport Agency (NZTA) [9]. However, no projections or high/low scenarios are provided in this publication and it would not be realistic to hold this figure constant throughout the time period (2020-2051) covered by this assessment.

Hence, the carbon prices modelled by the Productivity Commission have been used as a proxy to the SCC while recognising that the latter could be much higher in a future were climate change is causing large negative impacts on social welfare.

5.1.2. Fuel Cost Savings

The fuel cost is normally the second largest component of owning (and operating) a fossil fuel vehicle and is much higher than the cost of the electricity needed to travel the same distance with an EV. Hence, consumers can reap substantial financial savings over the useful life of an EV. In this report, the electricity price projections were sourced from MBIE [7] with a 'low price' and a 'high price' scenario simulated in the sensitivity analysis detailed in Section 7 below. Figure 5 below illustrates these three electricity price scenarios.

Figure 5: Electricity Price Projections

The extent of these fuel savings depends on a range of factors, including the difference between the retail fuel price and the retail electricity price, the user's travel needs and the type of vehicle purchased, which in turn depends on preferences and choice availability.

For modelling purposes, the fuel cost savings are a function of the CO_2 savings, relative to the counterfactual, from having more EVs in the vehicle fleet multiplied by the fuel emission factor. The estimated fuel cost savings are then multiplied by the projected fuel prices (exclusive of GST and ETS) [7].

Given the uncertain nature of future fuel prices, two additional scenarios have been modelled in the sensitivity analysis to reflect a 'high price' and 'low price' projections, as further detailed in Section 7. The projected prices of petrol and diesel were sourced from MBIE and are shown in Figure 6 and Figure 7, respectively.

Figure 6: Average Retail Petrol Price exclusive of Taxes & Carbon

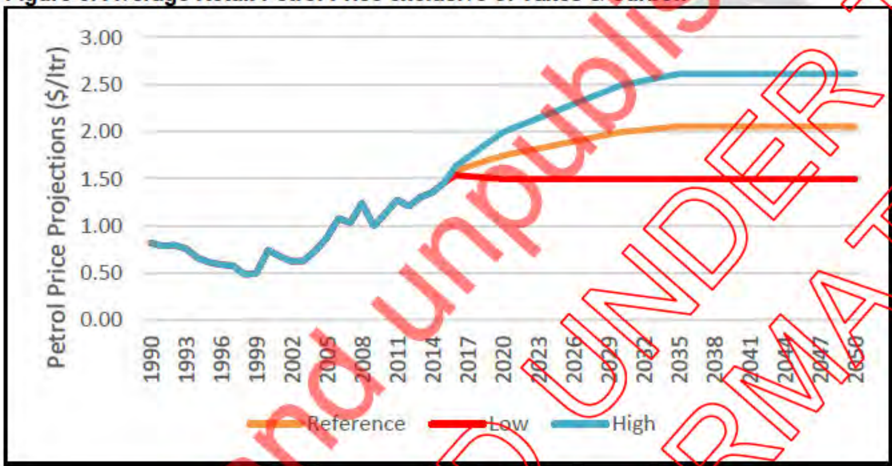
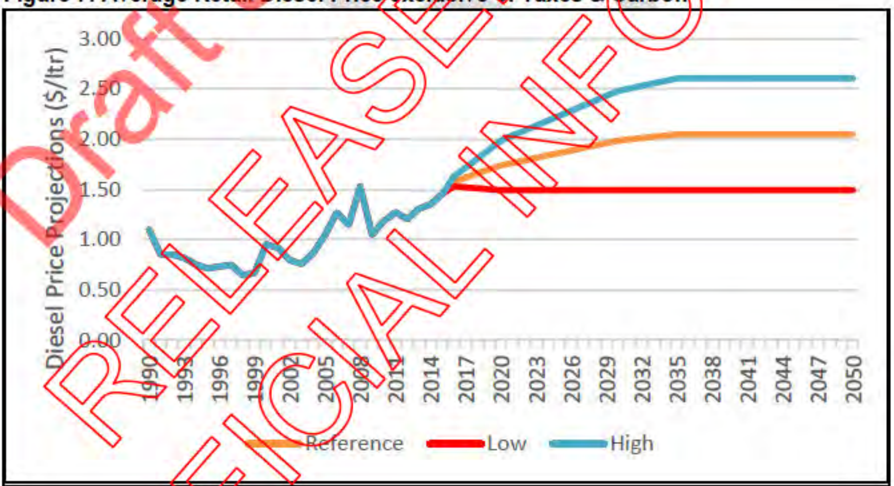


Figure 7: Average Retail Diesel Price exclusive of Taxes & Carbon



5.1.3. Ownership Cost Savings

Ownership cost savings from switching to an EV are obtained from the lower cost of maintenance and scheduled servicing, including downtime, as compared to a fossil fuel vehicle. Road user charges are also not applied to EVs but these are considered to be transfer payments and hence, have been excluded from this assessment. The ownership costs for both EVs and ICEs was obtained from EECA [1] and amortised over the average effective lifetime of the vehicle (which varies from an average of 17 years for a new vehicle to 10 years for a used one).

The ownership cost *savings* were estimated by multiplying the difference between the ownership cost of a fossil fuel vehicle and that of an EV by the number of additional EVs imported in each year as compared with the counterfactual. These savings were summed up over the average effective lifetime of the vehicle and subsequently summed up for the whole policy period (2020-2035).

5.1.4. Health Benefits from Lower Concentrations of Air Pollution

The implementation of a legislated ban is expected to lead to substantial improvements in air quality in those regions where the concentration of exhaust emissions is relatively high, such as the CBD of Auckland, Christchurch and Wellington. The HAPINZ report estimated the social cost of air pollution from motor vehicles as $934 million in 2010 [10]. Converting this figure to 2018 prices [11] would increase it to $1.02 billion. These health costs are attributed to premature mortality and restricted activity days, as shown in Table 3.

Table 3: Social Cost of Air Pollution by Motor Vehicles in 2010 (in 2018 prices)

Premature Mortality ($million)	998
Restricted Activity Days ($million)	24
Total Costs attributed to the Transport Sector ($million)	**1,022**

In the absence of data on the health costs of air pollution attributed to vehicle imports in any given year, a proxy was used as the share of total CO_2 emissions from light vehicle imports as a percentage of the total fleet in 2019. This figure is projected to be approximately 5% in 2019 [2]. Hence, the social cost of air pollution attributed to light vehicle imports was estimated at $46.6 million in 2019.

This social cost was projected to decrease in-tandem with the improvement in the average emissions of the imported fleet due to a greater uptake of EVs. In the year when the ban comes into force, the social cost of air pollution from light vehicle imports would be completely eliminated (since no fossil fuel vehicles would be imported after this year). However, air pollution would still be generated by the fossil fuel vehicles that will remain in operation after 2035.

5.2. Quantified Costs

5.2.1. Incremental Capital Costs

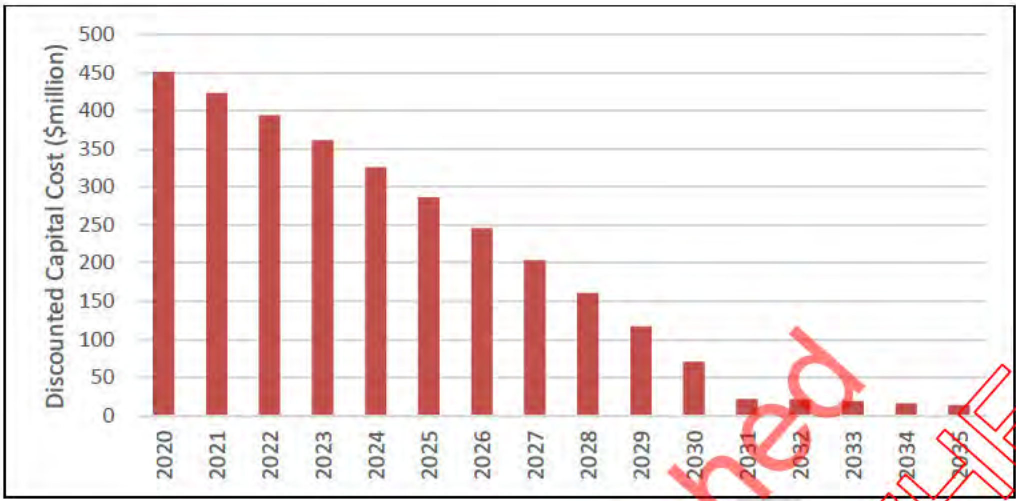
The main cost associated with this policy intervention is the higher purchase price of EVs compared with fossil fuel vehicles. The EV price is influenced by a number of factors including the long run 'technology' costs incurred by vehicle manufacturers to further develop and produce EVs for the mass market.

The operating costs of using an EV include the electricity to power the vehicle, the replacement cost of batteries and general servicing costs but these are generally lower than the operating costs of a fossil fuel vehicle over its useful life.

As of 2017, the **average price** of a new EV was around $65,000 [1] including the present value of the annualised cost of battery replacement every 10 years [12]. In the case of a used EV, the **average price** in 2017 was around $20,000 or about three times the average price of a used fossil fuel vehicle. However, the price of some used EV models is already on par with the purchase price of fossil fuel vehicles [1].

The incremental capital cost was estimated by multiplying the change in the EV imports from the counterfactual with the price differential of EVs and fossil fuel vehicles for each year. These annual cost figures were subsequently summed up and discounted using a real discount rate of 6% p.a. [9]. The annual incremental capital costs are expected to gradually decrease as the price of EVs declines, even as the rate of EV uptake increases, as shown in Figure 8 below.

Figure 8: Discounted Incremental Capital Costs



5.2.2. Welfare Costs

The incremental cost of the legislated ban is measured in social welfare terms as the 'deadweight loss'. This cost consists of two components; the price differential between an EV and a fossil fuel vehicle and the added 'premium' monetizing a number of non-price factors that create disutility for consumers, as described in Section 4.1.2.

Together, these costs lead to a net loss of consumer surplus due to the change in vehicle purchase preferences, or possibly, in the preferred choice of transport mode. The implementation of a legislated ban is expected to induce behavioural changes in consumers' purchase decisions, as some consumers will purchase a vehicle that is different from their preferred one (in terms of vehicle brand, vehicle type, engine size etc.) or they may be unable to afford the higher upfront cost of an EV, thus being constrained to use a mode of transport that is not their preferred one. Either way, this behavioural change will lead to a loss in consumer welfare. The extent of these losses will depend on a number of factors, including consumers' response to vehicle price and non-price changes and how importers adapt their fleets to meet the demand changes brought about by this intervention.

In this analysis, the consumer welfare impacts have been estimated by multiplying the projected change in EV imports with the incremental capital cost of EVs and the premium representing the monetised non-price factors. This calculation implicitly assumes that consumers are price-takers and that vehicle importers will fully pass on the incremental cost to consumers. It also implies that the non-price factors will have the same perceived 'monetary' impact on all consumers.

The estimated impact on consumer welfare is difficult to establish due to the inherent uncertainty in key variables, particularly related to consumer preferences, importers' selling strategies and vehicle costs and prices. Further research is required to reduce these uncertainties, although the comprehensive sensitivity analysis detailed in Section 7 provides information on the impact of these uncertainties on the economic viability indicators shown in Section 6.4.

5.2.3. Implementation Costs

The implementation of this policy intervention will require an extensive stakeholder consultation, ongoing awareness-raising campaigns and market monitoring. These implementation costs are estimated at $2 million per year, starting in 2020 and ending in 2035. The total discounted implementation costs amount to $20.2 million for the duration of this intervention. These costs are highly uncertain and wide margins have been assumed in the sensitivity analysis in Section 7.

5.2.4. Other Costs

The implementation of a legislated ban is expected to have wide-ranging and long-term impacts on the light vehicle fleet and it is difficult to foresee the full system-wide impacts of this intervention, in particular on specific cohorts and their mobility needs. For example, the wider use of EVs may induce users to drive more often and/or for longer distances (as inferred by the rebound effect). This behavioural change will, in turn, worsen congestion and increase travel time, and possibly increase traffic accidents. Hence, it is important that the policymaker keeps a close eye on developments, both in terms of the global supply market for EVs, and on the driving behavioural changes that a legislated ban may induce.

6. Cost-benefit Analysis – Results

6.1. Introduction

The base year and price level have been set to 2019 and the evaluation period covers 2020 to 2051 to include the impact from the purchase of a new vehicle in 2035 over its expected lifetime (17 years). A real discount rate of 6% p.a. was used to convert cost and benefit estimates to present values [9].

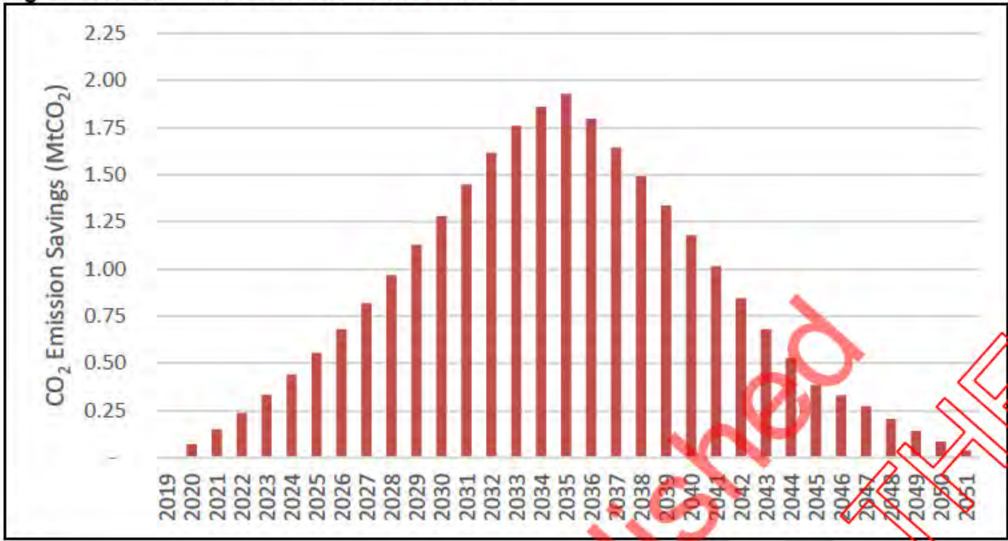
6.2. Vehicle Import Fleet Composition & Emissions Savings

A legislated ban is expected to have a significant impact on the composition of vehicles imported in New Zealand, as shown in Figure 9. Imports of EVs will increase year-on-year at an increasing rate while light petrol and diesel vehicles will decrease in-tandem.

Figure 9: Composition of Light Vehicle Imports with a Legislated Ban in 2035

This shift in favour of EVs will significantly reduce CO_2 emissions from light vehicle imports. In this assessment, a legislated ban applied on 1st January 2035 is expected to result in a reduction of 27 million tons of CO_2 emissions over the policy period (2020-2051). The annual emissions reductions vary with the changes in uptake of EVs compared to the counterfactual, as shown in Figure 10 below.

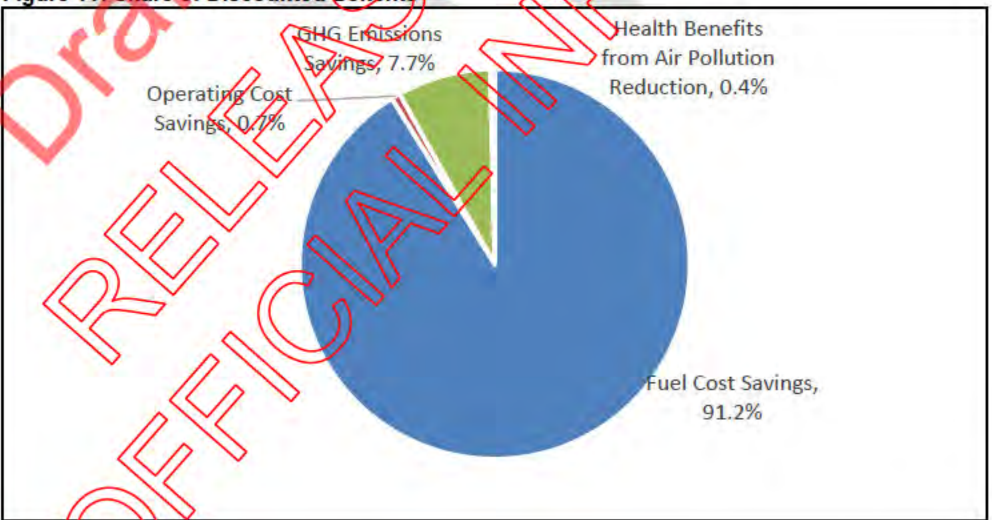
Figure 10: Annual Emissions Reduction Potential



6.3. Net Benefits

The total net benefits from the implementation of a legislated ban in 2035 are estimated to be $2.26 billion (in PV) and would save 27 million tonnes of CO_2 emissions over the evaluation period. The majority of the (discounted) benefits (91%) are from fuel cost savings to vehicle users and 0.7% in ownership cost savings. Societal benefits in terms of lower GHG emissions amount to 7.7% and only 0.4% are from health benefits obtained from lower air pollution concentrations. These relative shares in net benefits are shown in Figure 11 below.

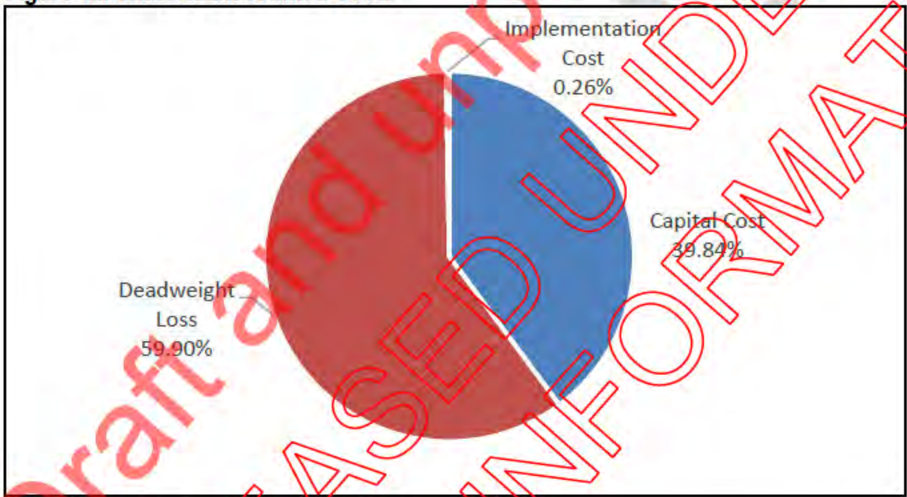
Figure 11: Share of Discounted Benefits



The majority of the (discounted) costs (60%) consist of the welfare impact borne by consumers who opt to buy a vehicle which is different from their preferred one or whose mobility is restricted because they are unable to afford a (more expensive) electric vehicle. This impact also includes the premium added to the EV price to represent the non-price factors that influence the consumers' buying behaviour.

The capital cost incurred by vehicle buyers due to the higher upfront cost to buy an EV as compared to a fossil fuel vehicle, makes up 40% of total discounted costs. This cost is at it's highest in the initial years following the announcement of the legislated ban because the EV price differential would still be wide. However, this is expected to narrow substantially by the year when the ban comes into force (2035). As shown in Figure 12 below, the implementation costs consist of less than 1% of the total discounted costs.

Figure 12: Share of Discounted Costs



The annual discounted costs and benefits are shown in Figure 13 and these reflect the interplay between the uptake of EVs at a higher incremental capital cost in the earlier years and the increasing benefits obtained, particularly in fuel cost savings, from an accelerated EV uptake in the later years of this policy intervention. Further detail on the breakdown of costs and benefits is provided Annex 1.

Figure 13: Annual Costs & Benefits

6.4. Economic viability

The main indicators of economic viability are the Benefit/Cost Ratio (BCR), the Net Present Value (NPV) and the Marginal Abatement Cost (MAC). The MAC is one way of ranking different options based on the relative marginal costs and benefits. When there is a net cost to reduce an additional tonne of CO_2 emission, the MAC has a positive value and vice versa. The indicators obtained from implementing the legislated ban are shown Table 4 below.

Table 4: Results of the Main Indicators for Economic Viability

BCR	1.29
NPV	$2.26 billion
MAC	-83/tCO_2

The above table indicates that for every dollar that is spent on this intervention, society in general would obtain around 1.3 dollars of benefits in return, as indicated by the BCR. In monetary terms, this net benefit would amount to around $2.26 billion over the whole period, as shown by the NPV. The MAC is negative and substantial, meaning that the marginal cost of abating an additional tonne of CO_2 would result in a net social benefit of $83 per tonne.

Apart from these significant net benefits to society, it is also important to ascertain the distributional impacts of this intervention. This will require a separate Social Impact Assessment to provide a better picture of how the intervention would impact on different population segments, particularly vulnerable groups.

7. Sensitivity Analysis

A comprehensive sensitivity analysis was carried out to account for the inherent uncertainties in key parameters and to identify which ones have a significant impact on the economic viability of this intervention. A sensitivity analysis also provides an indication of the robustness of the results subject to alternative parameter values and scenarios. Table 5 lists the key parameters that have been simulated.

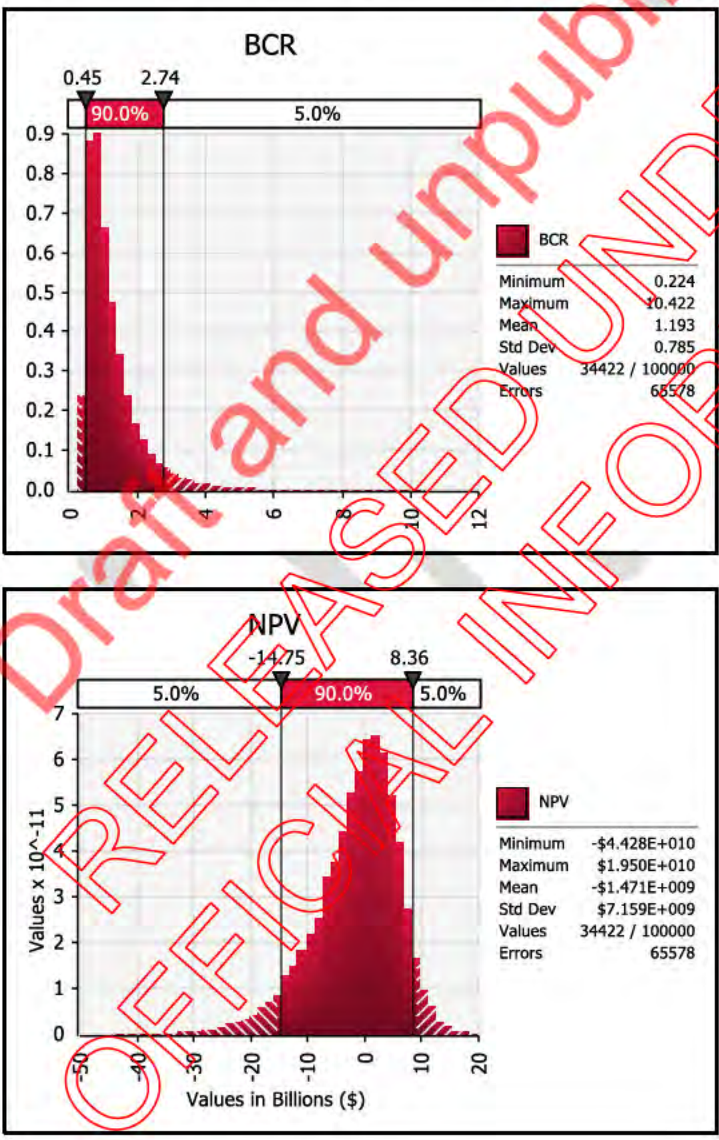
Table 5: Key parameters simulated in the sensitivity analysis

1	Average lifetime of a new vehicle
2	Average lifetime of a used vehicle
3	Annual decrease in VKT driven
4	Rebound Effect
5	Implementation cost
6	Discount Rate (Policy)
7	Discount Rate (Market)
8	Carbon Price
9	Fuel Price
10	Electricity Price
11	Average New Vehicle Price in 2017
12	Average Used Vehicle Price in 2017
13	Annual Price Change in New Vehicles (including EVs)
14	Annual Price Change in Used Vehicles (including EVs)
15	New Vehicle Registrations in 2017
16	Used Vehicle Registrations in 2017
17	Vehicle Ownership Cost
18	EV Battery Replacement Cost
19	EV Battery Annual Cost Decrease
20	Premium on Non-Price Factors (New Vehicles)
21	Annual Decrease in Premium on Non-Price Factors (New Vehicles)
22	Premium on Non-Price Factors (Used Vehicles)
23	Annual Decrease in Premium on Non-Price Factors (Used Vehicles)
24	Average EV Rating (kwh/100km)
25	Electricity Emissions Factor
26	Fossil Fuel Emissions Factor
27	Share of Health costs attributed to Imports
28	New ICEV Imports in the Counterfactual
29	Used ICEV Imports in the Counterfactual
30	New EV Imports in the Counterfactual
31	Used EV Imports in the Counterfactual

A Monte Carlo simulation was carried out to test the impact on the economic viability indicators (shown in Table 4) when changing the key parameters (listed in Table 5). The minimum and maximum variation simulated for each key parameter, including at the 5% and 95% confidence level, are listed in Annex 2.

The results of the sensitivity analysis indicate a range of uncertainty in the viability of the legislated ban, as attested by a BCR that varies between 0.45 and 2.74 at a 90% confidence interval. Similarly, the NPV ranges from -$14.75 billion and $8.36 billion when applying the uncertainty margins of each key parameter simultaneously. The results are shown in Figure 14 below.

Figure 14: Results of the Monte Carlo Simulation on Key Parameters



The key parameters that have the greatest impact on the BCR and NPV are shown in Table 6 below. Unsurprisingly, the rate of decrease in the price of both new and used EV have the largest impact on the BCR followed by the replacement cost of batteries. The same three parameters also have the largest impact on the NPV, although the battery replacement cost exceed the impact from the price decrease of used EVs. The large uncertainty in these key parameters leads to a wide range in the economic viability indicators.

Table 6: Top 10 Key Parameters

Change in Output Statistic for BCR			
Rank	**Name**	**Lower**	**Upper**
1	Annual Price Change in New Vehicles (including EVs)	0.67	1.81
2	Annual Price Change in Used Vehicles (including EVs)	0.81	1.62
3	EV Battery Replacement Cost	0.83	1.59
4	Fuel Price	0.99	1.34
5	Premium on Non-Price Factors (New Vehicles)	1.03	1.33
6	Discount Rate (Market)	1.05	1.30
7	Discount Rate (Policy)	1.07	1.31
8	Average lifetime of a used vehicle	1.11	1.29
9	EV Battery Annual Cost Decrease	1.11	1.28
10	Fossil Fuel Emissions Factor	1.10	1.26
Change in Output Statistic for NPV ($billion)			
Rank	**Name**	**Lower**	**Upper**
1	Annual Price Change in New Vehicles (including EVs)	-$8.24	$3.81
2	EV Battery Replacement Cost	-$5.32	$1.56
3	Annual Price Change in Used Vehicles (including EVs)	-$4.96	$1.50
4	Fuel Price	-$3.47	$0.00
5	Discount Rate (Market)	-$3.25	-$0.38
6	Premium on Non-Price Factors (New Vehicles)	-$2.94	-$0.36
7	New EV Imports in the Counterfactual	-$2.47	-$0.38
8	Discount Rate (Policy)	-$2.52	-$0.61
9	Average lifetime of a used vehicle	-$2.36	-$0.47
10	EV Battery Annual Cost Decrease	-$2.39	-$0.58

8. Contribution to New Zealand's GHG Emissions Reduction Targets

In 2020, the projected emissions from road transport are expected to reach 14.1 million tonnes of CO_2 equivalent ($MtCO_2e$) with 10.3 $MtCO_2e$ emitted by light vehicles. The latter are projected to decrease to 5 $MtCO_2e$ by 2040[7] [2].

New Zealand's current GHG reduction targets [13] apply at the national level and are not sector-specific. **Hence, there is currently no specific target for the transport sector.** The national GHG reduction targets are the following:

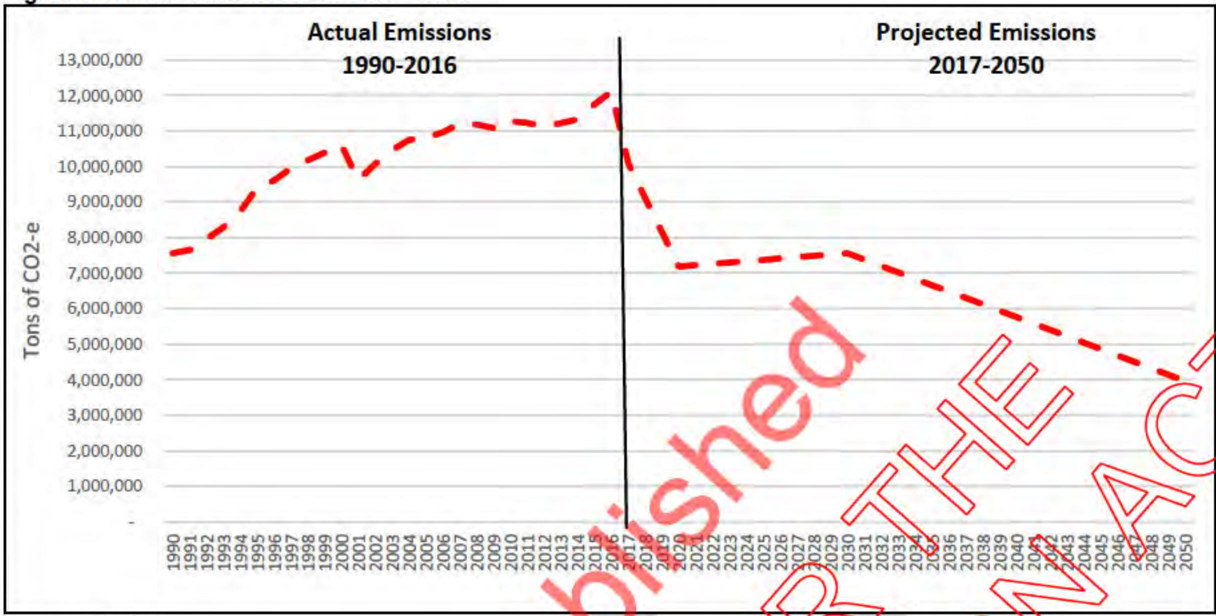
(1) 5% below 1990 levels by 2020
(2) 30% below 2005 levels by 2030 (equivalent to 11% below 1990 levels)
(3) 50% below 1990 by 2050

For the purposes of this analysis, these national level targets were applied to the road transport emissions[8] and a target trajectory was calculated for the period 2020 to 2050. A linear interpolation was used to obtain annual figures for the interim years.

To obtain a comprehensive time series of historic and projected emissions specifically from light vehicles, the historic emissions (1990-2016) from light vehicles were included with the target trajectory (2017-2050). These historic emissions were obtained from the National Inventory Submission under the Common Reporting Framework (CRF) as reported to the United Nations Framework Convention on Climate Change (UNFCCC) [14]. The resultant time series of road emissions covering 1990-2050 is shown in Figure 15.

[7] The Ministry models a number of scenarios in the Future Outlook report. The figures reflect the Base Case scenario.
[8] In theory, a sector-specific target should be based on the cost-effective mitigation potential of the particular sector.

Figure 15: Road Emissions from 1990 – 2050



source: [2], [14]

Superimposing the projected emissions from light vehicles as estimated in the Base Case scenario [2] shows the 'target gap' between the projected scenario and the target trajectory. This gap shows where New Zealand is expected to stand in relation to its GHG reduction targets at any given year and the effort needed to attain these targets.

The annual CO_2 savings from the legislated ban are compared with both the emissions projections and with the observed target gap. In the latter case, this comparison provides an indication of how much this measure can help New Zealand remain within its annual carbon budget. Figure 16 below compares the target trajectory, the baseline emissions projections (as per Base Case scenario) and the emissions trajectory with the legislated ban.

Figure 16: Comparison of the Target Trajectory with the Base Case scenario projections

Table 7 shows the contribution from the annual CO_2 savings from the legislated ban for each 5 year period. It indicates that the legislated ban would reduce the projected emissions from light vehicles by 24% in 2035.

Table 7: Contribution to Target Trajectory

	Emissions from Light Vehicles (A)	Annual Emissions Savings (B)	Share of Emissions Savings from Light Vehicles emissions (B)/(A)
	MtCO2-e	MtCO2-e	
2020	10.29	0.07	1%
2025	9.97	0.55	6%
2030	8.77	1.28	15%
2035	6.92	1.93	28%
2040	5.07	1.18	23%
2045	3.32	0.39	12%
2050	1.22	0.04	3%

9. *Equivalent Value of the Cumulative Emissions Savings*

An 'equivalent value' compares the emissions savings from implementing a GHG reduction measure with an equivalent source that would need to be reduced or to an equivalent sink that would need to be introduced to offset CO_2 emissions. This comparative exercise provides a sense of the scale of CO_2 savings from implementing a GHG reduction measure. In this analysis, the CO_2 savings are compared to the following equivalent sources or sinks:

(1) Power stations that would be taken off-line
(2) Vehicles that would be scrapped
(3) Lifetime emissions from the three most popular light vehicles
(4) Trees that would need to be planted

9.1. Equivalent Value in terms of Power Stations Taken Off-Line

The MBIE reports the GHG emissions from the energy sector [15] on an annual basis. A subset of this sector is electricity generation and the annual GHG emissions for 2011 to 2015 are shown in Table 8.

Table 8: GHG emissions from electricity generation

	kt CO_2-e
2011	5,012
2012	6,417
2013	5,198
2014	4,231
2015	4,041
Average	**4,980**

A legislated ban in 2035 is expected to save 27 million tonnes of CO_2 equivalent over its lifetime and therefore, it is equivalent to preventing 5 and a half years of emissions that occur from electricity generation in New Zealand. A similar comparison with a large (750MW) coal fired power station operating for most of the year would amount to 5 years worth of emissions saved.

9.2. Equivalent Value in terms of Scrapped Vehicles

A preliminary CBA carried out by the MoT on the implementation of a vehicle scrappage scheme in Auckland indicates that, on average, scrapping a vehicle (between 10 to 18 years) would save approximately 11 tonnes of CO_2 per vehicle (weighted by the average travel distance by vehicle age). This figure is based on a number of assumptions including the characteristics of the scrapped vehicle such as it's age, fuel type, emissions rating, etc. In general, this figure was estimated using historic data on the types of vehicles scrapped.

The legislated ban is expected to affect all vehicle imports over the 2020-2035 period and it's expected to save around 27 million tonnes of CO_2 equivalent. The estimated CO_2 savings is therefore equivalent to scrapping 2.4 million vehicles between 10 and 18 years of age from the existing fleet (excluding the emission effects from the purchase of any replacement vehicles).

9.3. Equivalent Value in terms of Most Popular Vehicles

Another approach is to base the equivalent value on the number of new fossil fuel vehicles that are imported in New Zealand. In 2017, the three most popular vehicles were the Ford Ranger, Toyota Hilux and Holden Colorado [16]. Their average emissions range from 191 gCO_2/km for a single cab to 223 gCO_2/km for a double cab. Taking the average of these two figures and the expected VKT driven over their economic lifetime (17 years), the CO_2 savings from the legislated ban would be equivalent to lifetime emissions from 885,000 such vehicles.

9.4. Equivalent Value in terms of Planted Trees

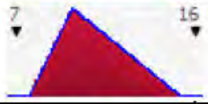
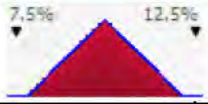
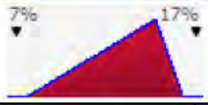
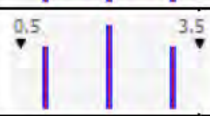
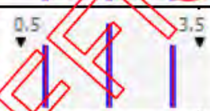
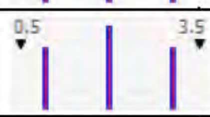
A report published by the Parliamentary Commissioner for the Environment [17] indicates that a hectare of pine trees would offset 31 tonnes of CO_2 emissions per year in the first 20 years of the tree's life. To retain the storage of 600 tonnes of CO_2 per hectare, the rotations need to continue indefinitely or an equivalent area will need to be planted. A hectare of pine trees can accommodate between 1,000 to 2,500 individual trees, depending on the number of rows and spacing in between the rows, amongst others. The **annualised** savings from the legislated ban are expected to be 851,000 tons of CO_2 equivalent, and hence, these savings are equivalent to planting around 27.4 million trees every 20 years. This is equivalent to planting an area of 27 square kilometres (if a spacing of 1,000 trees per hectare is assumed).

Annex 1 – Annual Costs and Benefits

Table 9: Annual Costs and Benefits

Financial Year	Implementation Year	Undiscounted Cash Flow										Discounting Factor @	Discounted Cash Flow									
		Costs ($ millions)				Benefits ($ millions)					Net Benefit ($m)		Costs ($ millions)				Benefits ($ millions)					Net Benefit ($)
		Capital Cost	Deadweight Loss	Implementation Cost	Total Cost	Fuel Cost Savings	Operating Cost Savings	GHG Emissions Savings	Health Benefits from Air Pollution Reduction	Total Benefits		6%	Capital Cost	Deadweight Loss	Implementation Cost	Total Cost	Fuel Cost Savings	Operating Cost Savings	GHG Emissions Savings	Health Benefits from Air Pollution Reduction	Total Benefits	
2019	0	-	-	-	-	-	-	-	-	-	-	1.00	-	-	-	-	-	-	-	-	-	-
2020	1	477.87	462.35	2.00	942.22	48.86	0.53	1.42	7.21	58.03	(884.19)	0.94	450.82	436.18	1.89	888.89	46.10	0.50	1.34	6.80	54.74	(834.14)
2021	2	475.84	480.99	2.00	958.83	104.76	1.13	3.52	6.95	116.36	(842.47)	0.89	423.50	428.08	1.78	853.35	93.24	1.00	3.14	6.18	103.56	(749.80)
2022	3	468.95	497.58	2.00	968.52	168.92	1.77	6.42	6.49	183.60	(784.92)	0.84	393.74	417.77	1.68	813.19	141.83	1.49	5.39	5.45	154.16	(659.03)
2023	4	456.03	511.18	2.00	969.20	240.85	2.49	10.19	6.26	259.80	(709.41)	0.79	361.22	404.90	1.58	767.70	190.77	1.97	8.07	4.96	205.78	(561.92)
2024	5	435.30	520.37	2.00	957.67	321.28	3.30	14.94	5.70	345.22	(612.45)	0.75	325.28	388.85	1.49	715.63	240.08	2.47	11.16	4.26	257.97	(457.66)
2025	6	406.47	524.31	2.00	932.79	410.92	4.16	20.78	4.50	440.36	(492.43)	0.70	286.55	369.62	1.41	657.58	289.68	2.93	14.65	3.17	310.43	(347.14)
2026	7	369.60	523.47	2.00	895.07	512.47	5.06	27.87	3.37	548.77	(346.30)	0.67	245.81	348.14	1.33	595.27	340.82	3.37	18.53	2.24	364.96	(230.31)
2027	8	324.73	517.80	2.00	844.52	623.61	6.02	36.35	2.37	668.35	(176.18)	0.63	203.74	324.87	1.25	529.86	391.26	3.77	22.81	1.49	419.33	(110.53)
2028	9	271.53	507.22	2.00	780.75	747.34	7.04	46.38	1.58	802.34	21.60	0.59	160.72	300.22	1.18	462.12	442.35	4.17	27.45	0.94	474.91	12.78
2029	10	208.87	490.28	2.00	701.15	885.64	8.15	58.18	0.96	952.93	251.78	0.56	116.63	273.77	1.12	391.52	494.54	4.55	32.49	0.53	532.11	140.59
2030	11	134.25	463.84	2.00	600.09	1,017.20	8.96	70.39	0.49	1,097.05	496.96	0.53	70.72	244.34	1.05	316.12	535.85	4.72	37.08	0.26	577.91	261.79
2031	12	43.01	421.71	2.00	466.72	1,157.76	9.71	85.87	0.22	1,253.55	786.83	0.50	21.38	209.58	0.99	231.94	575.37	4.83	42.67	0.11	622.98	391.03
2032	13	45.03	417.53	2.00	464.56	1,301.88	10.36	102.87	0.06	1,415.18	950.62	0.47	21.11	195.76	0.94	217.80	610.37	4.86	48.23	0.03	663.49	445.69
2033	14	42.64	386.64	2.00	431.28	1,426.18	11.02	119.60	0.01	1,556.81	1,125.53	0.44	18.86	171.01	0.88	190.75	630.80	4.87	52.90	0.00	688.58	497.82
2034	15	38.52	304.53	2.00	345.05	1,519.31	11.77	134.69	0.00	1,665.78	1,320.73	0.42	16.07	127.07	0.83	143.98	633.96	4.91	56.20	0.00	695.07	551.09
2035	16	34.95	165.45	2.00	202.40	1,583.98	12.65	148.01	0.00	1,744.63	1,542.24	0.39	13.76	65.13	0.79	79.67	623.53	4.98	58.26	0.00	686.77	607.10
2036	17	-	-	-	-	1,474.96	11.68	145.54	-	1,632.19	1,632.19	0.37	-	-	-	-	547.75	4.34	54.05	-	606.14	606.14
2037	18	-	-	-	-	1,350.74	10.51	140.51	-	1,501.76	1,501.76	0.35	-	-	-	-	473.22	3.68	49.23	-	526.13	526.13
2038	19	-	-	-	-	1,225.93	9.25	134.00	-	1,369.18	1,369.18	0.33	-	-	-	-	405.19	3.06	44.29	-	452.53	452.53
2039	20	-	-	-	-	1,098.60	7.91	125.90	-	1,232.41	1,232.41	0.31	-	-	-	-	342.55	2.47	39.26	-	384.27	384.27
2040	21	-	-	-	-	967.40	6.49	116.10	-	1,089.98	1,089.98	0.29	-	-	-	-	284.57	1.91	34.15	-	320.62	320.62
2041	22	-	-	-	-	833.04	5.10	104.31	-	942.44	942.44	0.28	-	-	-	-	231.17	1.41	28.95	-	261.53	261.53
2042	23	-	-	-	-	694.65	3.78	90.59	-	789.02	789.02	0.26	-	-	-	-	181.86	0.99	23.72	-	206.56	206.56
2043	24	-	-	-	-	559.27	2.48	75.81	-	637.57	637.57	0.25	-	-	-	-	138.13	0.61	18.72	-	157.47	157.47
2044	25	-	-	-	-	434.66	1.13	61.12	-	496.90	496.90	0.23	-	-	-	-	101.27	0.26	14.24	-	115.78	115.78
2045	26	-	-	-	-	318.33	(0.28)	46.30	-	364.36	364.36	0.22	-	-	-	-	69.97	(0.06)	10.18	-	80.09	80.09
2046	27	-	-	-	-	272.61	(0.13)	41.12	-	313.60	313.60	0.21	-	-	-	-	56.53	(0.03)	8.53	-	65.03	65.03
2047	28	-	-	-	-	223.04	0.03	34.85	-	257.93	257.93	0.20	-	-	-	-	43.63	0.01	6.82	-	50.46	50.46
2048	29	-	-	-	-	168.61	0.17	27.28	-	196.06	196.06	0.18	-	-	-	-	31.12	0.03	5.03	-	36.18	36.18
2049	30	-	-	-	-	115.23	0.28	19.30	-	134.81	134.81	0.17	-	-	-	-	20.06	0.05	3.36	-	23.47	23.47
2050	31	-	-	-	-	69.26	0.30	12.01	-	81.57	81.57	0.16	-	-	-	-	11.38	0.05	1.97	-	13.40	13.40
2051	32	-	-	-	-	31.08	0.21	5.41	-	36.70	36.70	0.15	-	-	-	-	4.82	0.03	0.84	-	5.69	5.69
Total		4,233.58	7,195.24	32.00	11,460.82	21,908.38	163.05	2,067.62	46.18	24,185.23	12,724.42		3,129.89	4,705.29	20.21	7,855.39	9,223.75	74.21	783.71	36.43	10,118.11	2,262.72

Annex 2 – Monte Carlo Simulation: Key Input Parameters

Name	Graph	Min	Mean	Max	5%	95%
Average lifetime of a new vehicle		15	17	20	16	19
Average lifetime of a used vehicle		8	11	15	9	14
Annual decrease in VKT driven		3%	4%	4%	3%	4%
Rebound Effect		8%	10%	12%	9%	11%
Implementation cost		1,003,933	2,000,000	2,997,826	1,316,225	2,683,762
Discount Rate (Policy)		4%	6%	8%	5%	7%
Discount Rate (Market)		8.0%	12.9%	16.0%	9.6%	15.3%
Premium on Non-Price Factors (New Vehicles)		1	2	3	1	3
Annual Decrease in Premium on Non-Price Factors (New Vehicles)		1	2	3	1	3
Premium on Non-Price Factors (Used Vehicles)		1	2	3	1	3
Annual Decrease in Premium on Non-Price Factors (Used Vehicles)		1	2	3	1	3
Carbon Price		1	2	3	1	3
Fuel Price		1	2	3	1	3
New Vehicle Price in 2017		1	2	3	1	3
Used Vehicle Price in 2017		1	2	3	1	3
Annual New Vehicle Price Decrease		1	2	3	1	3
Annual Used Vehicle Price Decrease		1	2	3	1	3
New Vehicles Registrations in 2017		1	2	3	1	3
Used Vehicles Registrations in 2017		1	2	3	1	3
New ICEV Imports in the Counterfactual		1	2	3	1	3
Used ICEV Imports in the Counterfactual		1	2	3	1	3
New EV Imports in the Counterfactual		1	2	3	1	3
Used EV Imports in the Counterfactual		1	2	3	1	3
EV Battery Replacement Cost		1	2	3	1	3

Name	Graph	Min	Mean	Max	5%	95%
EV Battery Annual Cost Decrease	0.5 3.5	1	2	3	1	3
Vehicle Ownership Cost	0.5 3.5	1	2	3	1	3
Share of Health costs attributed to Imports	0.5 3.5	1	2	3	1	3
Average EV Rating (kWh/100km)	0.5 3.5	1	2	3	1	3
Electricity Emissions Factor (kgCO2/kWh)	0.5 3.5	1	2	3	1	3
Electricity Retail Price ($/kwh)	0.5 3.5	1	2	3	1	3
Fossil Fuel Emissions Factor (kgCO2/ltr)	0.5 3.5	1	2	3	1	3

Annex 3 – Comparison of Carbon Values

The monetary benefits from CO_2 savings depend on the social cost of carbon that is used to convert the estimated impacts from tonnes to the dollar values. This social cost represents the true cost borne by society from CO_2 emissions.

However, various 'carbon values' exist both in New Zealand publications and from literature around the world. In NZTA's Economic Evaluation Manual (EEM), a social cost of $40/tonne [9] is recommended while the current NZ Emissions Trading Scheme (ETS) price is $21.50/tonne [18] and is expected to increase to around $27/tonne by 2023 [18]. The recently published NZ Productivity Commission report [8] models three Options that estimate a carbon price ranging from $55-80/tonne in 2030 to $150-250/tonne in 2050. The Ministry for the Environment (MfE) reported a carbon price of $20/tonne in 2020 and increasing to $25/tonne by 2030 in the 7th National Communication to the UNFCCC [19].

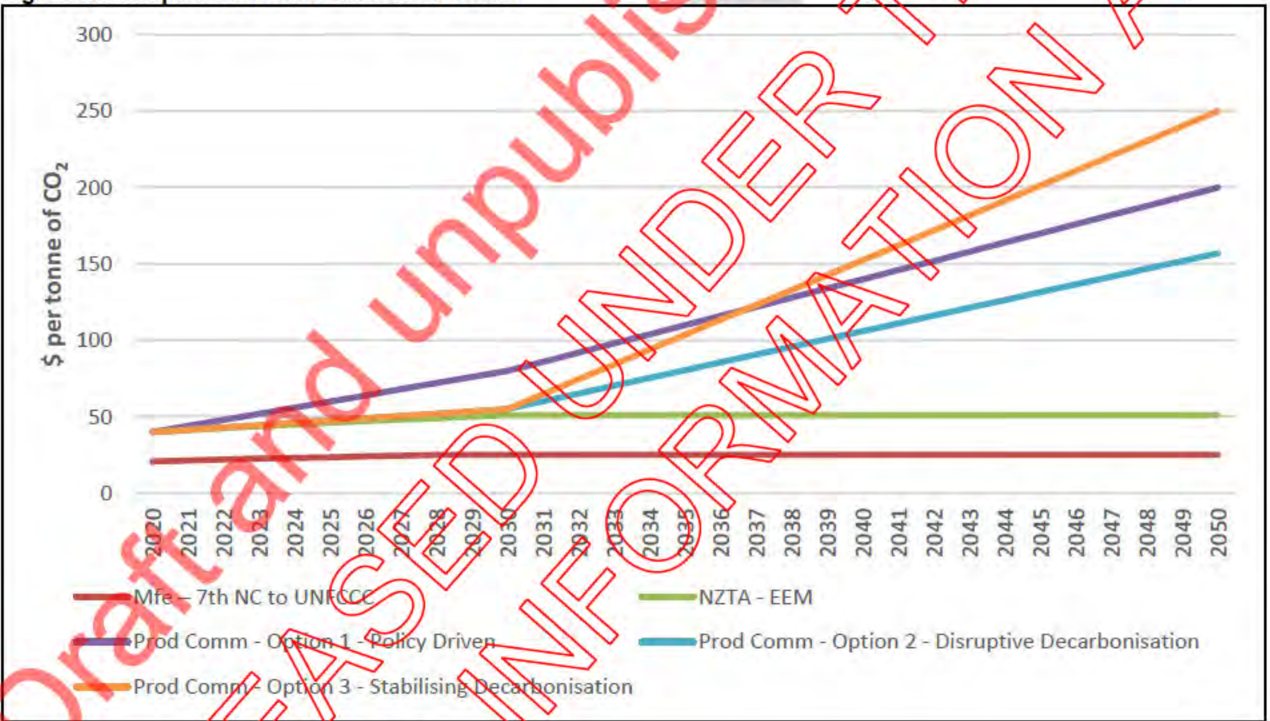
In the EU, the traded ETS price is €13/tonne ($22/tonne @ 0.58 exchange rate) [20] while the EPA recommends a price of US$105 ($150/tonne @ 0.71 exchange rate) [21]. The carbon prices are shown in Table 10 and Figure 17, with a linear interpolation being used to estimate the interim (annual) values.

Table 10: Comparison of Carbon Values ($/tCO2)

	MfE (7th NC to UNFCCC)	NZTA (EEM)	Prod Comm (Policy Driven)	Prod Comm (Disruptive Decarbonisation)	Prod Comm (Stabilising Decarbonisation)
2020	20.77	40.00	40.00	40.00	40.00
2021	21.38	41.23	44.00	41.50	41.50
2022	21.98	42.46	48.00	43.00	43.00
2023	22.58	43.69	52.00	44.50	44.50
2024	23.06	44.92	56.00	46.00	46.00
2025	23.55	46.15	60.00	47.50	47.50
2026	24.03	47.14	64.00	49.00	49.00
2027	24.52	48.13	68.00	50.50	50.50
2028	25.00	49.12	72.00	52.00	52.00
2029	25.00	50.11	76.00	53.50	53.50
2030	25.00	51.10	80.00	55.00	55.00
2031	25.00	51.10	86.00	60.10	64.75
2032	25.00	51.10	92.00	65.20	74.50
2033	25.00	51.10	98.00	70.30	84.25
2034	25.00	51.10	104.00	75.40	94.00
2035	25.00	51.10	110.00	80.50	103.75
2036	25.00	51.10	116.00	85.60	113.50
2037	25.00	51.10	122.00	90.70	123.25
2038	25.00	51.10	128.00	95.80	133.00
2039	25.00	51.10	134.00	100.90	142.75
2040	25.00	51.10	140.00	106.00	152.50
2041	25.00	51.10	146.00	111.10	162.25

	MfE (7th NC to UNFCCC)	NZTA (EEM)	Prod Comm (Policy Driven)	Prod Comm (Disruptive Decarbonisation)	Prod Comm (Stabilising Decarbonisation)
2042	25.00	51.10	152.00	116.20	172.00
2043	25.00	51.10	158.00	121.30	181.75
2044	25.00	51.10	164.00	126.40	191.50
2045	25.00	51.10	170.00	131.50	201.25
2046	25.00	51.10	176.00	136.60	211.00
2047	25.00	51.10	182.00	141.70	220.75
2048	25.00	51.10	188.00	146.80	230.50
2049	25.00	51.10	194.00	151.90	240.25
2050	25.00	51.10	200.00	157.00	250.00

Figure 17: Comparison of different Carbon Values



Annex 4 – Additional Information on the Marginal Abatement Cost

A marginal abatement cost is a measure of the cost-effectiveness of the policy measure in reducing GHG emissions. It is calculated by dividing the net present value (NPV) of the measure with its GHG abatement potential i.e. the expected reduction in emissions that this measure would achieve if it is implemented as intended. The calculation may be shown by the following notation.

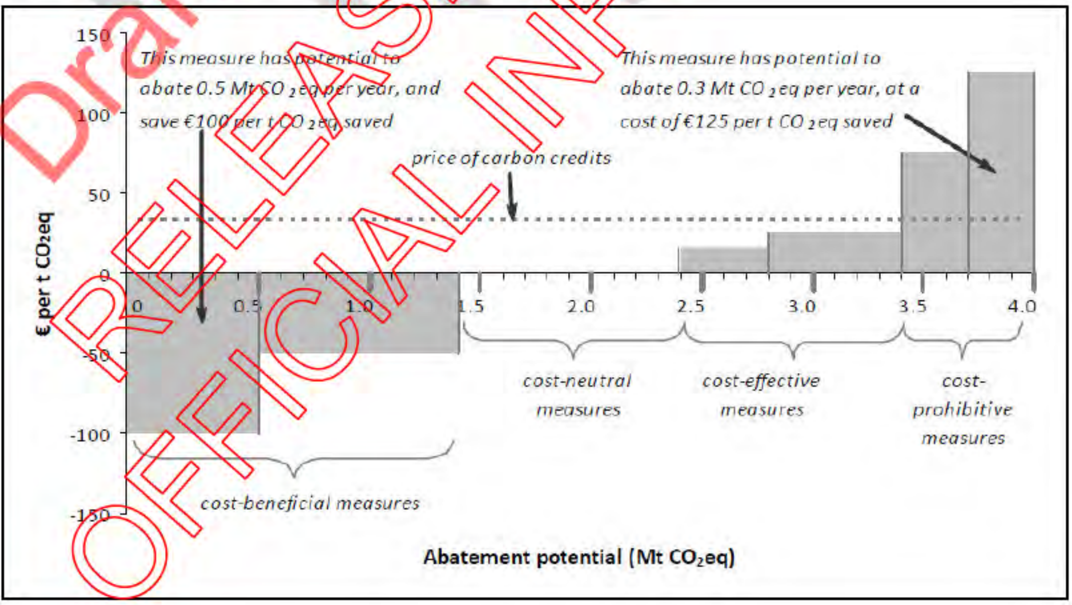
$$NPV_m = \sum_{t=0}^{n} \frac{(b-c)_{m,n}}{(1+r)} \quad \textbf{(1)}$$

$$MAC_m = \frac{-NPV_{m,n}}{CO_{2\ m,n}} \quad \textbf{(2)}$$

Where **(1)** NPV_m is the net present value from implementing the measure (m), b denotes the benefits derived from implementing the measure (m) whilst c denotes the costs incurred from implementing measure (m). 1+r denotes the discount rate, n represents the lifetime of measure (m) and t represents the implementation year. **(2)** MAC_m is the marginal abatement cost from implementing measure (m), NPV_m is the net present value from implementing measure (m) and CO_{2m} represents the emissions in CO_2 equivalent saved from implementing measure (m) over n years.

The MAC of different measures may be ranked in ascending order from the least expensive to the most expensive in terms of GHG reductions to create a marginal abatement cost curve (MACC)[9], as stylised in Figure 18 below [22] [23].

Figure 18: Stylised Marginal Abatement Cost Curve



[9] A MACC represents the relationship between the quantity of abated emissions and the [incremental] price of CO_2 through the implementation of abatement measures.

The 'low hanging fruit' are those measures on the left hand side and below the horizontal axis since these measures save both money and emissions[10]. Moving to the right of the horizontal axis would represent more costly measures. To determine which of the measures situated above the horizontal axis are still worthwhile to implement, a 'social cost of carbon' (SCC) is used as a benchmark [24]. Any measure whose bar is higher than the SCC line would be deemed to be too expensive to undertake and, in theory, it would be cheaper to buy carbon allowances.

The total cost and emissions savings from the implementation of the measures are based on a number of underlying assumptions, including the emissions reduction potential, the behavioural changes that the measure might induce and the time period over which it would be effective. For example, an energy saving awareness campaign may be expected to induce a behavioural change in 10% of households which would subsequently reduce their energy consumption (and hence emissions) by 1% per year over the next 5 years. These assumptions are therefore crucial to obtain a meaningful MAC and a careful analysis is required when calculating the emissions saving potential and the cost of each measure. These estimations need to be sufficiently robust in the face of the uncertainties inherent in any analysis that requires some form of projections.

Moreover, the measures being considered are likely to have an impact on one or more, of the other measures. These multi-measure interactions can be quite complex and it may be difficult to assess their overall effect. Hence, a careful examination of these interactions is required and detailed caveats would have to be made when drawing conclusions through the use of the bottom-up approach.

[10] As denoted by a positive NPV

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