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**Battery Electric Vehicles in Cities:
Measurement of some impacts on
traffic and government revenue
recovery**

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ABSTRACT: We are told that electric vehicles, cars in particular, will be good for the environment. But what exactly might this mean? It is true that end use emissions will be significantly reduced when we move from fossil fuels to green energy sources? Assuming that the demand for such cars, including battery electric vehicles (BEVs) in particular will grow, we can expect a significant number of such vehicles manufactured in future years. Given the potentially relatively lower cost (fewer moving parts) compared to the internal combustion engine vehicles (ICEs) as well as the significantly lower usage costs per kilometre, we would expect a level of uptake that could impact on the performance of the road network (perhaps increased congestion) but also a concomitant reduced use of public transport and fuel excise loss. In this paper we apply the MetroScan modelling system in the Greater Sydney Metropolitan Area (GSMA) over the period 2021-2056 to identify the likely impact that the growth in BEV ownership and use will have on vehicle kilometres, modal shares, government revenues, levels of CO₂ emissions and other impacts. Moreover, we investigate the introduction of a BEV usage charge proposed in Australia to see what it might do to these key performance indicators and whether it can offset the adverse effects during BEV uptake such as government fuel excise revenue loss and increased congestion.

KEY WORDS: *Electric cars, MetroScan, car use, fuel excise, congestion, CO₂ emissions, distance-based charge, Sydney*

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Introduction

We are told that electric vehicles, cars in particular, will be good for the environment. But what exactly might this mean? End-use emissions will indeed be significantly reduced when we move from fossil fuels to green energy sources. With a substantial (hopefully total) switch to battery electric vehicles (BEVs), the general position of experts is that the cost of a BEV will be significantly less than a petrol or diesel car (the switching point is unclear, but many suggest in about 10 to 20 years) and that the cost of purchasing and using BEVs will decline. According to recent figures released by BloombergNEF¹, the price parity between BEVs and ICEs may even be achieved as early as 2023. The price parity-time will largely depend on whether the battery pack price can drop below \$US100/kWh (Schmidt 2020). The battery pack price was above \$US1000/kWh in 2010, and recent estimates indicate it is now closer to \$200/kWh, and likely to drop to as low as \$61/kWh in 2030². Falls in operating costs will accelerate BEVs' advancement and adoption. For example, a taxi driver of a fully electric taxi in London indicated that his fuel costs have dropped by one hundred pounds or \$AU178 per week, or close to \$AU 10000 per annum³. In Australia, the BEV Council⁴ suggests that a BEV's running cost will be equivalent to 5.15 cents per kilometre for a BEV compared to 14.39 cents per kilometre for an ICE, an average saving of \$1275 per annum on fuel costs alone for an average user annual car kilometres.

Simple economics suggests that the private car will become more affordable and hence more attractive to use. With all other things being equal, it is possible that there will be a notable increase in car kilometres travelled. However, if 'all other things being equal' is modified to include the reform of road use charges, such that government introduces a re-pricing of road use that reflects a position that 'those who benefit' should pay an efficient (and equitable) charge for using the roads, then we may be able to contain this expected growth in car use. Fossil fuel excise accounts for about 37% of government road-related expenses in Australia (IPA 2019). As this fuel excise is expected to decline, governments are already contemplating ways to compensate for this loss, including potentially new charges for electric vehicles. In addition, road pricing reform may be part of the response. If, for example, we have a 5c/km peak period distance-based charge (DBC), with an average annual peak kilometres travelled of 4,000, out of the typical 12,000 kms per annum for a privately registered car in Australia this amounts to \$200, which is still well below the annual savings in fuel on a BEV and will be able to compensate the loss in government revenue. Moreover, if there was a surplus from the combined DBC and fuel excise under this proposed reform, the extra revenue can be redistributed to install the charging network and technology, and even subsidise the purchase price of vehicles.

Road pricing reform may have another important role to play in BEV adoption. Given lower operating costs, BEV adoption runs the real risk of increasing car use and so congestion significantly in some urban areas. The amount of money committed in Australia to new public transport investment is arguably inadequate to make a significant difference to the continuing dominance of the private car, made worse during the COVID-19 pandemic, despite it being a major objective of many governments. For example, even a new Metro rail system in North West Sydney has resulted in a significant loss of bus patronage (21% on the long haul tolled M2 services) while achieving just a 2% reduction in car use. This illustrates that even new rail services are unlikely to have a significant impact on car use as it grows in popularity as lower costs drive BEV uptake. Congestion is expected to increase and even though some car users may reduce using their car under these conditions, we speculate that this

¹<https://www.bloomberg.com/opinion/articles/2019-04-12/electric-vehicle-battery-shrinks-and-so-does-the-total-cost>

² <https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-2019/>

³ At the time of writing \$1AUD=\$US0.67 and €0.62.

⁴ <https://electricvehiclecouncil.com.au/>

reduction will not be enough to control congestion without road pricing reform, desirably on both cars and trucks (as shown in Hensher et al. 2020a).

This paper addresses a range of future scenarios as follows. We begin with a review of the benefits and costs of battery electric vehicle adoption as documented in the literature, followed by a more detailed review of past research on battery electric vehicles. We then discuss the idea of a proposal, growing in interest in Australia, for a road usage charge of BEVs. We then set out the framework within which we investigate the implications of such a charging regime for some key performance indicators, notably government revenue as fuel excise decreases, car kilometres travelled and CO₂ emissions from a mixed fleet of ICEs and BEVs. We conclude the paper with a summary of the main findings and caveats to be attached to the evidence from this study. Importantly, although the focus is on the Australian context, the approach and findings have a much greater geographical relevance as many countries are investigating ways, in particular, to recover lost fuel excise.

The Benefits and Costs of Battery Electric Vehicle Adoption

Commonly known benefits of BEVs include more vehicles with zero tailpipe emissions, the storage capacity of a BEV helping to stabilise the electricity grid ((Hartmann 2021)), transitioning to power battery electric vehicles by renewable energy, and reduced reliance on petrol and oil.

Fuel excise is historically the primary source of funding for road infrastructure and maintenance, and as vehicles shift from internal combustion engines (ICEs) to BEVs, there will be a growing hole in government budgets. Without a replacement source of revenue, road funding will increasingly have to be drawn from the broader tax base, taking away resources from critical services such as health and education. As argued by Infrastructure Partnerships Australia (IPA 2019), battery electric cars ‘do not float’; they will still use roads, so we need to keep paying for road construction and maintenance. All motorists should pay their fair share⁵. Without reform, fewer road users – particularly those who cannot afford a new vehicle or motorists in regional areas who drive vast distances – will increasingly subsidise BEV motorists. In response to the impending revenue shortfall, a growing number of governments are looking to get a system in place that enables some level of charge for road use, be it on all vehicles or just BEVs, and which enables governments to manage their networks and sustainably fund their maintenance and upgrades over time while still making the purchase and use on a BEV attractive to the consumer.

In the Australian context, IPA (2019) encourages the introduction of road use charging for EVs to be resolved sooner rather than later. Although current BEVs form only a tiny part (around 0.076%) of Australia's light vehicle fleet, with a substantial (hopefully total) switch to BEVs, the cost of BEV's will be significantly less than a petrol or diesel car making the private car more affordable to use. So all other things being equal, we can expect a notable increase in car kilometres travelled. Thus, moving to green energy to reduce (if not eliminate) end use vehicle emissions runs the genuine risk of increasing congestion significantly if governments continue to reject road pricing reform.

Australian BEV strategy has become more evident in recent times with the Australian federal government's announcement ruling out giving subsidies to BEV purchases for many reasons including those listed above (Harris 2021, Whitehead et al. 2021). Although criticised for not following the EU and the US strategies to incentivise BEVs, the government strategy of improving the electrification of business fleets and developing technology and infrastructure for BEVs is well-positioned. The question

⁵ The Committee for Sydney 2021 survey of 1000 Sydneysiders asked a question on introducing a road user levy on electric vehicles to begin a gradual transition away from petrol taxes in anticipation of widespread adoption of BEVs and obtained 49% supporting it and 31% opposed.

remains as to which fund the government can draw on to support these movements. Before further addressing this question, we examine what has been documented in past research.

Past Research on the impact of Battery Electric Vehicles in the Passenger Transport Sector

Research on BEVs in the transport and energy literature has primarily focused on the incentives to support adoption of BEVs or electrification. The incentives include fiscal policy, typically tax exemption, and ways to reduce BEV usage costs. These incentives apply to all stages of BEV production, purchase, and use. Little research has been undertaken on the adverse effects of BEVs or incentives on BEVs, and even less systematic research to systematically examine the adverse impact on public revenues. In this review, we discuss both aspects to provide a background for the later discussion on a proposed distance-based charge for BEVs.

The incentives on BEVs include the incentives offered at the time of purchase and at the time of use. These incentives have been widely studied in different countries. Using Norway as an example, which has the highest BEV penetration per capita, Figenbaum et al. (2015) review and assess the effectiveness of including fiscal incentives to reduce the purchase price and yearly costs, direct subsidies to reduce users' usage costs, financial support for charging stations, and extra access to a bus lane and free parking for BEVs. They found three incentives were most efficient: 1) exemption from the value-added tax (VAT); 2) free toll roads for BEVs; and 3) access to bus lanes for BEVs. These assessments are partially supported by Zheng et al. (2016) who study both consumers and business buyers in their BEV choices using revealed preference data and estimated discrete choice models in Norway. They find that free toll roads have a positive effect on BEV adoption. However, their results also show that giving BEVs access to a bus lane has a negative effect, most likely due to the congestion it can cause.

Tax exemptions and charges are found to be very useful in promoting BEVs in different countries. Morton et al. (2017) use the London Congestion Charge scheme as an example to show that the uptake of BEVs is positively associated with the exemption from congestion charges. Yan (2018) studied data for ten pairs of BEVs with their ICE counterparts across 28 EU countries. The results show that a 10% increase in tax incentives can drive a 3% increase in BEVs' sales share. They also found that the costs associated with converting ICEs to large BEVs are higher than converting ICEs to smaller BEVs. More importantly, the study concluded that using tax incentives to reduce emissions by converting ICEs to BEVs is not cost-effective with this level of conversion.

The research by Zhang et al. (2016) found that the most effective measures to improve BEV adoption are technology and infrastructure related, the position preferred in Australia by governments, including BEV battery technology and capacity, and density of charging stations. A fast charging time was found to be an effective trade-off feature to offset the high purchase costs of BEVs. This phenomenon was observed by a study in Belgium (Lebeau et al. 2016). A similar finding was also supported by research by Arslan et al. (2014) in Turkey where they find that by offering fast charging facilities combined with larger battery capacities, BEV drivers are more likely to take longer trips and overcome their stopping intolerance. Extending trip lengths that BEV users are willing to travel positively impacts positively in achieving emission targets and improving BEV adoption.

Contestabile et al. (2017) suggest that the current BEV policies that are leaning towards government regulations expediting BEVs' adoption, may not be sustainable cost-wise in the mid-term. They suggested a lower-cost approach as a balance between plug-in hybrid electric vehicle (PHEVs) and BEVs, with small BEVs to cover short-range trips in urban areas and PHEVs to cover long-range trips in other areas. They argue that this approach will reduce the mid-term adoption costs to allow gradual improvement in BEV technology until it becomes more affordable. For adopting PHEVs, Fritz et al. (2019) examined car sales data in the EU from 2010 to 2016 and specifically tested the relationship between emission targets and PHEV sales. They concluded that a more ambitious CO₂ fleet regulation

target would lead to more PHEV sales, noting that the current target set by the EU is below the targets set by car manufacturers.

Although the incentive feature of BEV adoption has been studied by many researchers, the BEV cost aspect associated with its adoption and use, has rarely been discussed and examined. In assessing the environmental and economic impact of different transport fuels, Sharma and Strezov (2017) show that the total economic cost, including the capital and operation costs, is the highest for electric fuel on a cost per kilometre basis among all fuel types. The fuel types assessed include diesel, gasoline, biodiesel, ethanol, LPG, CNG, hydrogen and electric fuel.

In addition to capital and operation costs for electric fuel, the BEV adoption cost applies to both the purchase and usage stage. Incentives at the purchase stage target government revenues which apply to ICEs, such as purchase VAT (or referred to as a Goods and Services Tax (GST) in Australia GST), vehicle excise duty and extra purchase fees. Incentives at the usage stage target government revenues obtained by instruments such as a carbon tax, fuel excise duties, fuel VAT (GST), and annual road charges (i.e., registrations). The contribution of electricity in transport fuel demand has historically relied heavily on government providing ongoing incentives (Shafiei et al. 2018); however, whether supporting such fiscal-induced demand is sustainable at the expense of government revenue is questionable. According to Shafiei et al. (2018), based on their study in Iceland, government revenues will likely shrink by 28% to 35% if the fiscal policies above are implemented.

Similar concerns have been raised in research in other countries. In the US, on State Gas Taxes alone, the aggregated revenue raised in recent years is \$35 billion. Different States charge gas taxes from 5c to 40c per gallon. With increasing mileage from BEVs, a BEVs' cost-effectiveness will improve and further establish BEV growth. The loss of State Gas Taxes with increased mileage by BEVs and reduced mileage by ICEs will be huge. In California alone, the loss of 1c per gallon on the gas tax is equivalent to \$149 million of government revenue (Ratner 2018). In Canada, the fiscal impact for BEV adoption to replace ICEs was also examined. The significant loss of revenue comes from the excise rate on fuels, GST on sales of gasoline and provincial "Carbon Tax" charged on per litre of gasoline (Wong 2017).

In Australia, according to Infrastructure Partnerships Australia (IPA 2019), total revenue for road vehicles that government used for paying for road-related expenses during the FY 2017 to FY 2018 was about \$31 billion, of which 37% came from fuel excise, 9% from tolls, 23% from registration, and the rest from other items such as stamp duty and license fees. BEV adoption has a direct impact on fuel excise revenue. If the government further introduces incentives for BEVs on tolls, registration fees and other items, more revenue loss will incur, making road funding for current sources unsustainable. The reform suggested by IPA aims not to deter the uptake of BEVs but to offset the revenue loss of BEV adoption by other methods such as road user charges for BEVs (IPA 2019).

In summary, past research on BEVs has displayed two opposing views. One view is that BEVs should be incentivised to fast track their adoption with policies such as tax exemptions. The primary motivation is to achieve ambitious emission targets. The opposing view is that BEVs should be charged to offset the governments' and public's ongoing revenue loss, with a potential by-product of managing road congestion. Only by doing so, the growth in BEV technology can be made sustainable⁶.

⁶ Australia is a small part of the international new vehicle sales market, roughly 1m of 65m. Plus we are a RHD market which is the minority. The manufacturers therefore will not prioritise investment to engineer new RHD product to Australia if it not going to be profitable and with solid demand. In 2021 the policy environment in Australia provides neither and we need both. Profitability and demand should be addressed with financial incentives to reduce the sticker price. Additionally, the government should pull-ahead stricter emissions legislation in line with global best practices such as Europe, China, and California. Australia also needs legislative certainty as seen in Europe, China and California, as the manufacturers need this certainty to make the long-term investment/business planning decisions for future vehicle engineering programs.

A Proposed Electric Car Usage Charge Reform

Victoria and South Australia, and more recently NSW, have proposed a 2.5 cents per km user charge on kilometres of electric vehicle usage. In deciding if this is a good idea, there are two conflicting agendas - one that argues that those who use the roads should pay for the benefit received, and the other to incentivise a young industry to grow its product given its environmental advantages over ICEs. Overlaying these two agendas is a growing concern that a switch out of petrol and diesel increasingly threatens the flow of fuel excise revenue collected by the Federal government and is a tax that is avoided by BEVs.

In this paper, we look at all the current charges, fees and taxes such as car registration, driving licence, GST on car related outlays, fuel excise, and tolls as road specific charges in Australia, and ask how we might price the use of roads more efficiently and equitably. This is not a new debate, but now we overlay an alternative energy technology. If, however, BEVs scale up, as is the hope more generally in the population, then from a transportation point of view (in contrast to a manufacturing interest) we know they will cost less to purchase and far less to run (Hensher 2020).

The way forward ideally is not to just assume a new charge on electric cars but to revise all charges and align them with efficient user pays. Pundits have been arguing for many years, before the exploding debate on the proposed BEV user charge, that we should reduce fixed charges and introduce a distance-based charge; but to do it in a way get buy-in to ensure it passes the 'hip pocket test' so that people are not financially worse off, but that their outlays reflect the benefit better through the use of the roads (Hensher and Bliemer 2014, Hensher and Mulley 2014). We can do this by reducing or eliminating vehicle registration charges, introducing, for example, a distance-based charge in peak times (as Hensher and Mulley have shown) such as 5c/ km in congested areas plus 1c/km for emissions that occur regardless of congestion. This could be adjusted to reflect the fact that BEVs are likely to grow in use given the lower cost of owning and using them compared to ICE cars, threatening the viability of public transport. We also need to ensure that while emissions might be lower if not eliminated per car and per kilometre, there will be other negative externalities such as worsening congestion in some settings, and hence BEVs should pay according to the benefit received. The proposed 2.5c per km on BEVs in Victoria offers a way to achieve this; however, it is unclear what the overall net benefit will be in terms of congestion, emissions, and revenue changes⁷. In March 2021, the South Australian state government decided to put their DBC plan on hold for a year to monitor the Victorian tax initiative and then to work out details in implementing the tax⁸. We investigate this matter in the following sections where we focus on the Greater Sydney Metropolitan Area (GSMA) and introduce BEVs in the mix or in totality, in the presence and absence of road user charging reforms on all fuel classes and just BEVs or ICEs.

Developing a suite of charging reform scenarios for Sydney

We provide details of a series of scenarios implemented within a strategic transport and land modelling setting, with and without a projection of the future BEV adoption rate from 2021 to 2056 under various assumptions of a distance based charging (DBC) regime. In comparing the impact of a base reference scenario without pricing reform in the absence and presence of BEV projections, against a number of DBC regimes, we present evidence on what this means for vehicle kilometres, government revenue, CO₂ emissions, generalised cost of car use, and modal shares. These outcomes are critical indicators for transport policy consideration.

⁷ Given it is unlikely that governments will listen and act this way, then the best we can hope for is that the 2.5c per km might be hypothesized to a sufficient extent to support both a young industry and some amount of road improvement. This seems sensible since fuel excise has never anyway been enough to fund road maintenance and investment fully.

⁸ According to the news from ABC, the SA government will monitor the tax implications of other states such as Victoria. The Victorian state government plans to introduce the road user charge from 1 July 2020.

We have applied these scenarios in the MetroScan system for the GSMA. MetroScan is a strategic planning tool to forecast passenger movement, freight movement, work location choice, firm location and other transport and land-use outcomes (Figure 1). MetroScan integrates demand and supply-side models, origin-destination databases, transport data, socio-demographic data and other sources and uses them to obtain transport related forecasts and other outputs associated with specific transport policies and projects (Hensher et al. 2020). We run a base scenario and a series of application scenarios to obtain forecasts of likely impacts of moving to a green car fleet on revenue, CO₂ emissions and kilometres of car use. A more detailed overview of the framework of the MetroScan system is given in Hensher et al. (2020) and other papers published in the Journal of Transport Geography (Ho et al 2016, Hensher et al. 2019, Hensher and Teye 2019). The specific parts of MetroScan that were modified to account for BEV assumptions are summarised in Figure 2.

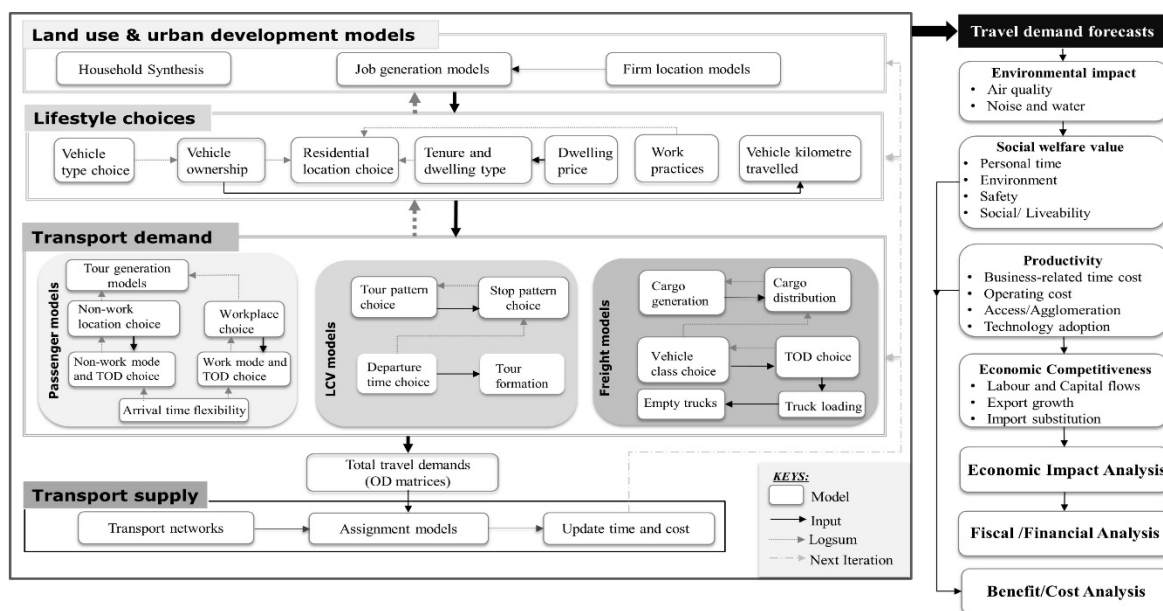


Figure 1. MetroScan framework.

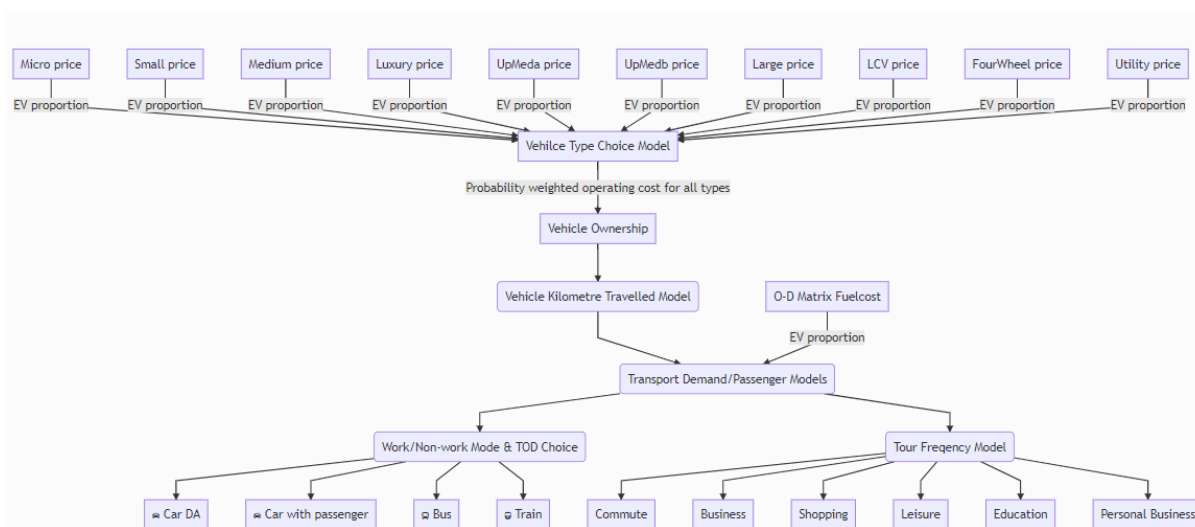


Figure 2. MetroScan elements linked directly to BEVs

Several prerequisite assumptions on key inputs are required to establish the base scenario used to forecast the collective impact of BEV adoption and DBC. Using available data and forecasts such as

the proportion of BEVs out of the total car fleet for each year, on-road emissions for ICE and BEV vehicles, and the fuel consumption of petrol and electric cars, the base scenario can be used as the benchmark to compare the outcomes of different scenarios/policies.

The proportion of BEVs in future years

Various online sources forecast new car sales of BEVs in Australia for different markets, but the forecasts of the annual proportion of BEV out of the total car fleet over the next thirty years are rare. For the Australian market, we use forecasts by Energeia (a consulting firm specialising in energy and transport) in a report to the Australian Renewable Energy Agency (ARENA) and the Clean Energy Finance Corporation (CEFC), as shown in Table 1 (Energeia 2018).

Table 1. The forecast of BEV adoption in Australia

Year	The proportion of BEV in the total car fleet
2020	0.2%
2025	1.1%
2030	4.5%
2035	11.6%
2040	23.7%
2045	41.8%
2050	61.3%
2055	87.9%

From 2050 to 2056, a rapid increase of BEVs is predicted to occur (i.e., from 61.3% to 94% of cars), provided there is a concerted effort by government to support this outcome through appropriate incentives. Given that many countries and regions such as the EU, UK, and Japan have all set a net-zero emission target by 2050, it is expected that some government policy interventions would occur in Australia to achieve the total conversion from ICEs to BEVs around that time. The projected increase of BEV penetration is shown in Figure 3.

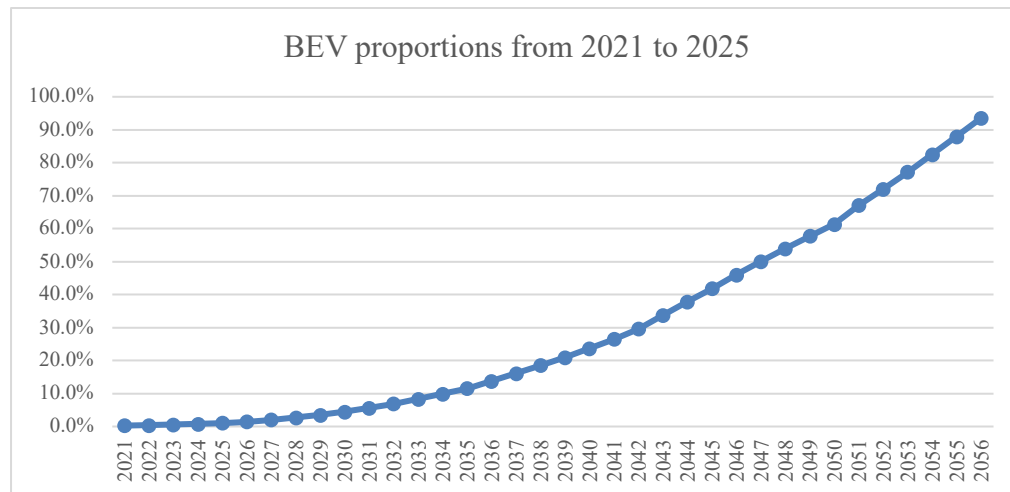


Figure 3. The forecast for BEV adoption in Australia

Purchase prices of BEVs

Forecasts of the average purchase prices of BEVs for 10 vehicle class sizes over future years are based on the projected proportions of BEVs and elasticities presented in recent research by Fridstrøm and Østli (Fridstrøm and Østli 2021). Appendix A includes further details.

On-road CO₂ emissions

We focus on the on-road emissions to allow direct comparisons of the use of ICEs and BEVs, although we recognise that there are also emissions relating to the generation of electricity and production of vehicles in the life cycle of a BEV. We apply the average figures for CO₂ emissions for different vehicle classes noting that BEVs produce zero end use emissions. On average, ICE passenger cars emit 0.172 kilograms per kilometre of CO₂ (Almond 2020; Grigoratos et al. 2019; NIC 2019; Transport & Environment 2015). The EU standard of 0.12 kg/km for new vehicles is lower than the figures applied in Australia for on-road vehicles.

Fuel consumption for ICEs and BEVs

Transport for NSW (2020) provides detailed fuel consumption parameters for different vehicle classes from small to large vehicles running on petrol and diesel. The average figure across all types of cars coincides with fuel consumption numbers given by Budget Direct (2020), a car rental company. On average, ICEs consume 10.8 litres of petrol per 100 km and 18.4 litres of diesel per 100 km. The passenger vehicle fleet is 79.9% petrol (Australian Bureau of Statistics 2020). For BEVs, although varied by different brands and makes, the typical average fuel consumption per 100km is approximately 18 kWh, or 0.18 kWh/km (Gaton 2019).

Fuel excise rate

The current fuel excise for unleaded petrol (regular or premium grades) and diesel is set by the Australian Government at 42.3 cents per litre (Australian Competition & Consumer Commission 2021). As discussed earlier, this revenue is the primary source of road maintenance and infrastructure spending on transport facilities (IPA 2019).

Generalised cost of car use

The operating cost (\$/trip) and toll cost (\$/trip), as well as peak and off-peak travel times for each of the O-D travel pairs, are built into MetroScan (Hensher et al., 2020). The generalised cost per person trip for cars for all purpose of trips (peak/offpeak) is equal to:

$VTTS \cdot \text{in-vehicle time} + \text{VoR} \cdot \text{buffer time} + \text{operating cost (\$/trip)} + \text{tollcost (\$/trip)}$.

VTTS is the value of travel time savings, equal to \$17.72 per person hour as the recommended value by Transport for NSW (TfNSW). The value of reliability (or travel time variability over repeated trips) is set at \$30.14/person hour.

Fuel price on the demand for car travel

The fuel price tends historically to have little impact on the demand for car travel at an elasticity of -0.075 (Hensher et al. 1992). This matches with the demand elasticity figures recommended by TfNSW (2020, p. 45). The direct elasticity of petrol price change on travel demand for car use is between -0.014 and -0.8, with the lower end -0.014 the recommended value by TfNSW (TfNSW 2020, p.45). For train, the direct elasticity of fare on train trip demand is -0.25, and for bus, the elasticity is -0.383.

Given the low elasticity of fuel price impact on car trip demand, the changes in total vehicle kilometres (VKM) for ICE and BEV cars are primarily due to the BEV adoption level and levels of the DBC. Adjustments to overall demand for car travel (i.e., vehicle kilometres) associated with fuel price changes are assumed to be negligible.

Results and Discussion

We have designed two base scenarios and twelve policy scenarios and tested them using MetroScan, as summarised in Table 2. The first base scenario (Scenario 1) is the forecast for 2021 to 2056 without any BEV adoption projection or DBC policies. The status quo assumes that the current state of ICE vehicle dominance in the car fleet will for the next thirty years. The second base scenario (Scenario 2) is the

forecast for 2021 to 2056 with the BEV projection rate included, as shown in Figure 3. There are no DBC policies for this base, so it represents the likely outcomes without policy adjustments by a DBC.

Designing the base and policy scenarios

In designing DBC policy scenarios, we consider DBC applied to the entire fleet versus ICE only and BEV only. There are implications for this differentiation since it represents different views in the public debate on which vehicles should be subject to a DBC. For example, one argument is that instead of BEV owners paying the DBC, ICE owners should pay the DBC to incentivise emission reduction through switching to BEVs. An important focus of our research is to identify the extent to which government can recover the loss of revenue from fuel excise obtained from ICE cars in order to maintain adequate funding from car use charges (or taxes) for road and infrastructure maintenance and investment by imposing a DBC on BEVs. The scenarios we have assessed investigate varying levels of a DBC on ICEs only, BEVs only, and all cars.

In designing DBC scenarios, we have chosen 2040 as the first year to test the DBC policy given that the projections suggest that electric cars would have achieved a reasonable market share of more than 20% of the total fleet size by then. Scenarios 1a to 1c are scenarios with DBC applied to all cars from 5c/km to 15c/km without the BEV projection. We compare the results for these three scenarios with Scenario 1 to show the impact of a DBC alone without BEV adoption. Scenarios 2a to 2c are the same scenarios as Scenario 1a to 1c but include the influence of BEV adoption. These three scenarios' outcomes show the mixed impact of BEV adoption and DBC on the fiscal and other outputs of interest.

Scenarios 2d to 2f and Scenarios 2g to 2i represent the two opposing views in thinking about a DBC. Scenarios 2d and 2f forecast the outcomes of imposing a DBC on ICEs only, from 5c/km to 15c/km with the BEV adoption. These scenarios represent a view in using a DBC as a tool to incentivise a faster pace of electrification to cut emissions. In contrast, Scenarios 2g to 2i forecast the outcomes of imposing a DBC on BEVs only, from 5c/km to 15c/km. These scenarios represent a position that BEV owners should contribute, as beneficiaries, to the cost of transport services and road infrastructure. Even with a DBC, BEVs will still have lower running costs compared to an ICE without a DBC, and hence the argument that this is an impost on BEV users that is greater than for ICE users is not valid. Table 2 provides a summary of these scenarios.

Table 2 The base and policy scenarios tested in MetroScan

Scenario No	Scenarios	BEV projection included from 2021 to 2056
1	Base 1	No
2	Base 2	Yes
1a	DBC 5c all ICE	No
1b	DBC 5c all ICE	No
1c	DBC 15c all ICE	No
2a	DBC 5c all car (BEV+ICE)	Yes
2b	DBC 10c all car (BEV+ICE)	Yes
2c	DBC 15c all car (BEV+ICE)	Yes
2d	DBC 5c ICE only	Yes
2e	DBC 10c ICE only	Yes
2f	DBC 15c ICE only	Yes
2g	DBC 5c BEV only	Yes
2h	DBC 10c BEV only	Yes
2i	DBC 15c BEV only	Yes

Comparing the two base scenarios

We first compare the outcomes of the two base scenarios with and without the BEV adoption projections, as shown in Table 3. 2041 is chosen to show the immediate impact of the policy change following the starting year of 2040.

Table 3 The outcomes of two base scenarios for 2041 (no DBC)

	Base 1	Base 2	Differences (Scenario 2 vs 1)
Year		2041	
BEV proportion	0%	26.50%	26.5%
Scenario Number	1	2	
Total daily car kilometres	243,445,930	246,798,380	1.4%
<i>Mode Shares (%) all trips purposes:</i>			
Car as driver	47.85	47.97	0.2%
Car as passenger	44.29	43.89	-0.9%
Bus	3.44	3.55	3.3%
Train	4.43	4.60	3.9%
Generalised cost of car use (\$/person trip)	\$23.62	\$21.46	-9.1%
CO ₂ daily emissions (tonnes)	41,873	32,389	-22.6%
<i>Government revenue:</i>			
Total daily fuel excise (A\$)	\$11,121,584	\$8,286,932	-25.5%

The results suggest that with BEVs accounting for 26.5% of the total fleet, the total VKM will increase by 1.4%, adding to traffic levels and congestion risk. There is some modal switching with an increase of 3.3% to bus and 3.9% to train in modal shares, most likely due to increased congestion; however coming off a small base this is negligible. CO₂ emissions will reduce by 22.6%; however, there is also a significant loss of fuel excise revenue, by 25.5%.

The outcomes demonstrate the positive aspect of electrification in CO₂ reduction, but with significant fuel excise revenue loss. These estimates are based on a relatively low level of take up of BEVs in 2041 of only 26.5%. By 2051, when the BEV proportion is over 60%, the loss of government fuel excise revenue will be around 66% (see Table 8). To find a way to recover some or all of this loss in fuel excise, a policy intervention will be needed.

The DBC impact without BEV adoption

Table 4 summarises the comparison of Scenarios 1a, 1b and 1c with Scenario 1. The DBC is applied to all cars that are ICE only (i.e., BEVs are set to zero). There is a significant reduction of VKM due to the DBC and a noticeable shift to public transport, suggesting, as expected, that a DBC is an effective method to switch transport mode from car to public transport. Even with only a 5c/km DBC, the daily car kilometres are forecast to reduce by 7.6%⁹, with the increase of the modal share of bus and train increasing by 45.8% and 66.8% (off a very low base), respectively. Such a shift is much more significant if the DBC increases to 10c/km and 15c/km.

On the other hand, the increase in total revenue from both the fuel excise and DBC is substantial¹⁰. If the DBC is implemented in 2040, government revenue in 2041 will increase by 93.5%, 168.6% and 231% if the DBC is 5c/km, 10c/km and 15c/km, respectively. Such significant growth in government revenue without evidence of significant user benefit (such as improved travel times and investment upgrades in roads and public transport) risks a backlash from the public. With the introduction of BEVs, and a more targeted DBC focussed on recovering fuel excise levels and no more, there may be greater support. We now turn to consider these options.

Table 4 The outcomes of three scenarios with DBC imposed on all cars (with no BEVs in the mix)

	Base 1	DBC 5c/km on ICE	DBC 10c/km ICE	DBC 15c/km ICE	Differences (Scenario 1a vs 1)	Differences (Scenario 1b vs 1)	Differences (Scenario 1c vs 1)
Year	2041	2041	2041	2041			
BEV proportion	0%	0%	0%	0%			
Scenario Number	1	1a	1b	1c			

⁹ Interestingly, this is close to returning peak traffic to school holiday levels.

¹⁰ Although not the focus of this paper, we know that this will also result in improved travel times in the road network and hence an additional contribution to reduced levels of traffic congestion.

Total daily car kilometres	243,445,930	224,894,418	205,078,371	188,128,534	-7.6%	-15.8%	-22.7%
<i>Mode Shares (%) all trips purposes:</i>							
Car as driver	47.85	44.89	40.14	35.57	-6.2%	-16.1%	-25.7%
Car as passenger	44.29	42.73	42.33	40.76	-3.5%	-4.4%	-8.0%
Bus	3.44	4.99	6.67	8.92	45.3%	94.1%	159.7%
Train	4.43	7.38	10.87	14.75	66.8%	145.5%	233.3%
Generalised cost of car use (\$/person trip)	\$23.62	\$21.28	\$20.92	\$20.65	-9.9%	-11.4%	-12.6%
CO ₂ daily emissions (tonnes)	41,873	38,682	35,273	32,358	-7.6%	-15.8%	-22.7%
<i>Government revenue:</i>							
Total daily fuel excise (A\$)	\$11,121,584	\$10,274,077	\$9,368,800	\$8,594,464	-7.6%	-15.8%	-22.7%
Total daily DBC (A\$)	\$0	\$11,244,721	\$20,507,837	\$28,219,280	--	--	--
Sum of excise and DBC	\$11,121,584	\$21,518,797	\$29,876,637	\$36,813,744	93.5%	168.6%	231.0%

The DBC impact with BEV adoption

With BEV adoption as per Table 1, Scenarios 2a to 2c forecast the outcomes if a DBC is applied to all cars, covering both ICEs and BEVs. Scenarios 2d to 2f forecast the outcomes if a DBC only applies to ICEs, and Scenario 2g to 2i forecast the consequences if DBC only applies to BEVs. The results for 2041 are summarised in Tables 5, 6 and 7.

Table 5 The outcomes of three scenarios with DBC imposed on all cars (with BEV adoption)

	Base 2	DBC 5c/km on BEV & ICE	DBC 10c/km on BEV & ICE	DBC 15c/km on BEV & ICE	Differences (Scenario 2a vs 2)	Differences (Scenario 2b vs 2)	Differences (Scenario 2c vs 2)
Year	2041	2041	2041	2041			
BEV proportion	26.5%	26.5%	26.5%	26.5%			
Scenario Number	2	2a	2b	2c			
Total daily car kilometres	246,798,380	241,680,415	222,802,395	204,255,062	-2.1%	-9.7%	-17.2%
<i>Mode Shares (%) all trips purposes:</i>							
Car as driver	47.97	45.42	42.30	39.79	-5.3%	-11.8%	-17.0%
Car as passenger	43.89	43.24	42.78	41.40	-1.5%	-2.5%	-5.7%
Bus	3.55	4.64	5.92	7.47	30.7%	66.8%	110.5%
Train	4.60	6.71	9.00	11.34	45.8%	95.7%	146.4%
Generalised cost of car use (\$/person trip)	\$21.46	\$21.19	\$20.56	\$20.15	-1.2%	-4.2%	-6.1%
CO ₂ daily emissions (tonnes)	32,389	30,553	28,167	25,822	-5.7%	-13.0%	-20.3%
<i>Government revenue:</i>							
Total daily fuel excise (A\$)	\$8,286,932	\$8,115,082	\$7,481,201	\$6,858,423	-2.1%	-9.7%	-17.2%
Total daily DBC (A\$)	\$0	\$12,084,021	\$22,280,240	\$30,638,259	--	--	--
Sum of excise and DBC	\$8,286,932	\$20,199,103	\$29,761,440	\$37,496,683	143.7%	259.1%	352.5%

When a DBC applies to both ICEs and BEVs (Table 5), the 5c/km charge will reduce daily VKM by 2.1%. When the DBC is raised to 15c/km, the daily VKM will decrease by 17.2%. Consistent with this change, the modal shares for public transport modes will increase considerably. Even with a 5c/km DBC, the bus share will increase by 30.7%, and the train share will increase by 45.8%. Both the generalised cost of car use and CO₂ emissions will decrease.

A 5c/km DBC will generate a 143.7% revenue increase combining fuel excise and the DBC, with \$12 million out of 20 million dollars of revenue obtained from the daily DBC. The revenue will increase even more with 10c/km and 15c/km. If we compare these outcomes with Scenarios 1a to 1c without the BEV projection in Table 4, the level of revenue increase is more significant because the base level is smaller for Base Scenario 2.

Table 6 The outcomes of three scenarios with DBC imposed on ICEs only (with BEV adoption)

	Base 2	DBC 5c/km on ICE	DBC 10c/km on ICE	DBC 15c/km on ICE	Differences (Scenario 2d vs 2)	Differences (Scenario 2e vs 2)	Differences (Scenario 2f vs 2)
Year	2041	2041	2041	2041			

BEV proportion	26.5%	26.5%	26.5%	26.5%			
Scenario Number	2	2d	2e	2f			
Total daily car kilometres	246,798,380	245,194,662	231,425,077	230,744,647	-0.6%	-6.2%	-6.5%
<i>Mode Shares (%) all trips</i>							
<i>purposes:</i>							
Car as driver	47.97	47.31	47.27	45.59	-1.4%	-1.5%	-4.9%
Car as passenger	43.89	43.12	43.14	43.08	-1.7%	-1.7%	-1.8%
Bus	3.55	4.04	4.05	4.59	13.9%	14.2%	29.4%
Train	4.60	5.52	5.54	6.73	20.1%	20.5%	46.3%
Generalised cost of car use (\$/person trip)	\$21.46	\$21.39	\$20.80	\$20.22	-0.3%	-3.1%	-5.8%
CO ₂ daily emissions (tonnes)	32,389	30,998	29,257	29,171	-4.3%	-9.7%	-9.9%
<i>Government revenue:</i>							
Total daily fuel excise (A\$)	\$8,286,932	\$8,233,083	\$7,770,731	\$7,747,884	-0.6%	-6.2%	-6.5%
Total daily DBC (A\$)	\$0	\$9,010,904	\$17,009,743	\$25,439,597	--	--	--
Sum of excise and DBC	\$8,286,932	\$17,243,986	\$24,780,474	\$33,187,481	108.1%	199.0%	300.5%

If the DBC only applies to ICEs (with 26.5% of BEVs in the fleet for 2041) (Table 6), the 5c/km will reduce daily VKM slightly by 0.6% (lower than the 2.1% for all cars in Table 4) given that BEV users will not need to pay the DBC and hence are unlikely to reduce car use. When the DBC increases to 15c/km, the daily VKM will reduce by 6.5% but again only for ICE owners¹¹. The shift to public transport is moderate, with a 20% increase in train share and a 14% increase in bus share, for both the 5c/km and 10c/km DBC. When the DBC increases to 15c/km, the shift becomes more significant at a 40% and 29% increase in train and bus shares. The moderate decrease also applies to both the generalised cost and CO₂ emissions.

For the revenue impact, a 5c/km DBC will generate a 108% revenue increase when combining fuel excise and the DBC on ICEs, with \$9 million out of 17 million dollars of revenue from the DBC on ICEs. The revenue will increase further with 10c/km and 15c/km, by 199% and 300% respectively. Again, raising this level of revenue from ICE owners while also paying for fuel excise risks being criticised unless the benefits are clear and supported (what we refer to as the buy in strategy – see Hensher and Mulley 2014). Moreover, as shown in Figure 3 and discussed in the next section, the revenue will decline fast with the increasing adoption of BEVs relative to ICEs in the fleet.

Table 7 The outcomes of three scenarios with DBC imposed on BEVs only (with BEV adoption)

	Base 2	DBC 5c/km on BEV	DBC 10c/km on BEV	DBC 15c/km on BEV	Differences (Scenario 2g vs 2)	Differences (Scenario 2h vs 2)	Differences (Scenario 2i vs 2)
Year	2041	2041	2041	2041			
BEV proportion	26.5%	26.5%	26.5%	26.5%			
Scenario Number	2	2g	2h	2i			
Total daily car kilometres	246,798,380	242,523,028	238,216,757	234,398,808	-1.7%	-3.5%	-5.0%
<i>Mode Shares (%) all trips</i>							
<i>purposes:</i>							
Car as driver	47.97	47.59	45.76	45.30	-0.8%	-4.6%	-5.6%
Car as passenger	43.89	43.25	46.65	44.18	-1.4%	6.3%	0.7%
Bus	3.55	3.91	3.35	4.38	10.1%	-5.6%	23.3%
Train	4.60	5.25	4.25	6.15	14.2%	-7.7%	33.6%
Generalised cost of car use (\$/person trip)	\$21.46	\$21.13	\$20.88	\$20.69	-1.5%	-2.7%	-3.6%
CO ₂ daily emissions (tonnes)	32,389	30,660	30,115	29,633	-5.3%	-7.0%	-8.5%
<i>Government revenue:</i>							
Total daily fuel excise (A\$)	\$8,286,932	\$8,143,375	\$7,998,780	\$7,870,582	-1.7%	-3.5%	-5.0%
Total daily DBC (A\$)	\$0	\$3,213,430	\$6,312,744	\$9,317,353	--	--	--
Sum of excise and DBC	\$8,286,932	\$11,356,805	\$14,311,524	\$17,187,935	37.0%	72.7%	107.4%

¹¹ Although not considered in this paper, the reduced kilometres of ICEs will release road space through improved travel times that might attract greater uptake and use of BEVs.

If the DBC only applies to BEVs (Table 7), the 5c/km charge will reduce daily VKM slightly by 1.7% but more than when the same level of a DBC is only applied to ICEs. When the DBC increases to 10c/km and 15c/km, the daily VKM will reduce, respectively, by 3.5% and 5.0%. The shift to public transport is moderate for all three scenarios 2g to 2i. There is also a similar level of reduction in generalised cost and CO₂ emissions.

On revenue, a 5c/km DBC on BEVs will increase total government revenue by 37%. The 3 million dollars loss of revenue in fuel excise in Base Scenario 2 compared to Base Scenario 1 can be fully recovered from the 5c/km DBC charged on BEVs. When the DBC increases to 10c/m and 15c/km, the total revenue will increase by 72% and 107% compared to Scenario 2.

A comparison of total revenue for all base and policy scenarios

Table 8 summarises the total revenue for both 2041 and 2051 for all base and policy scenarios. Scenario 2g (5c/km DBC on BEV only), as highlighted in grey, will generate the closest match with the revenue stream from fuel excise when BEV adoption is not considered (Base Scenario 1), both at about \$11m daily for 2041 and maintaining a close match until 2056. This pattern is shown in both Table 8 and Figure 4. It is noteworthy that the proposed 2.5c/km on BEVs by NSW, Victoria and South Australia is insufficient to recoup the loss of fuel excise.

On the other hand, different policy scenarios, especially charging a DBC on all cars, including ICEs and BEVs (Scenario 1a to 1c and Scenario 2a to 2c), will generate substantial surplus revenue for road maintenance, construction, building new electric charging stations, or developing new energy sources and methods such as hydrogen. However, if the purpose is to maintain the current revenue level without increasing future spending, it is not necessary to adopt a broad based DBC (which may be justified for other reasons).

While imposing a 5c/km DBC on BEVs only can maintain the current level of revenue from fuel excise, as in Scenario 2g, having a DBC on ICEs only (Scenario 2d to Scenario 2f) will result in a decreasing level of government revenue over the years because the share of ICEs will keep declining until such time when it reaches 0%. Although such a policy has been mentioned in the media and public debate in Australia to encourage electric vehicles' fast growth, it appears, on our evidence, not to be a financially sustainable transport policy.

Table 8 The total revenue associated with each scenario in 2041 and 2051

Scenario No	Scenarios	BEV projection	Total daily revenue (Excise + DBC)	
			2041	2051
1	Base 1	No	\$11,121,584	\$11,167,696
2	Base 2	Yes	\$8,286,932	\$3,777,674
1a	DBC 5c all ICE	No	\$21,518,797	\$12,545,190
1b	DBC 5c all ICE	No	\$29,876,637	\$14,655,788
1c	DBC 15c all ICE	No	\$36,813,744	\$17,531,271
2a	DBC 5c all car (BEV+ICE)	Yes	\$20,199,103	\$14,620,613
2b	DBC 10c all car (BEV+ICE)	Yes	\$29,761,440	\$20,377,878
2c	DBC 15c all car (BEV+ICE)	Yes	\$37,496,683	\$24,388,391
2d	DBC 5c ICE only	Yes	\$17,243,986	\$7,804,027
2e	DBC 10c ICE only	Yes	\$24,780,474	\$10,643,426
2f	DBC 15c ICE only	Yes	\$33,187,481	\$14,986,226
2g	DBC 5c BEV only	Yes	\$11,356,805	\$11,852,330
2h	DBC 10c BEV only	Yes	\$14,311,524	\$19,997,017
2i	DBC 15c BEV only	Yes	\$17,187,935	\$28,141,621

Figures 4 to 6 highlight the changes in daily VKM, fuel excise and the total revenue for Scenarios 2g, 2d and 2a, comparing a 5c/km DBC charge on BEV only, ICE only and both BEVs and ICEs. Figure 4 suggests that total government revenue will remain stable from 2041 to 2056. The revenue loss from excise can be offset by the combined influence of a DBC and increasing levels of BEV proportions in

the overall car fleet. The total daily VKM remains stable at about 250 million kilometres, from 2040 to 2056, without contributing to an overall increase in levels of road congestion.

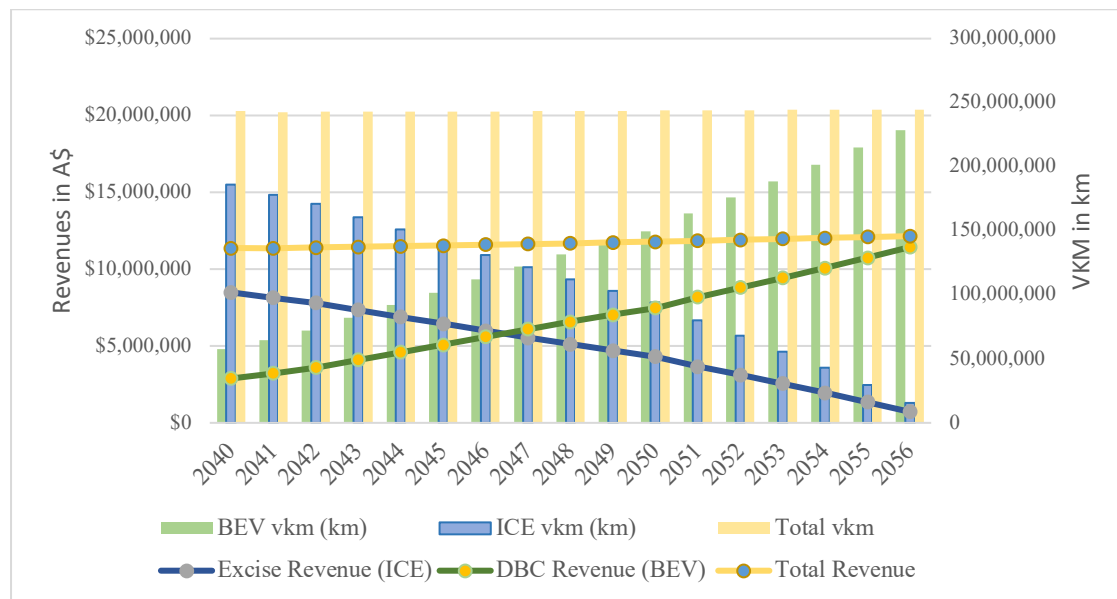


Figure 4. Daily VKM & Revenue for Scenario 2g - DBC 5c/km on BEV Only

Figure 5 shows the fast decline of total revenue if a DBC applies to ICEs only. With the adoption of BEVs and declining ICEs, both fuel excise and DBC charged on ICEs will gradually diminish to a low level and eventually become zero when there are no more ICE vehicles. The total daily VKM is relatively stable at 250 million kilometres, with some small variations.

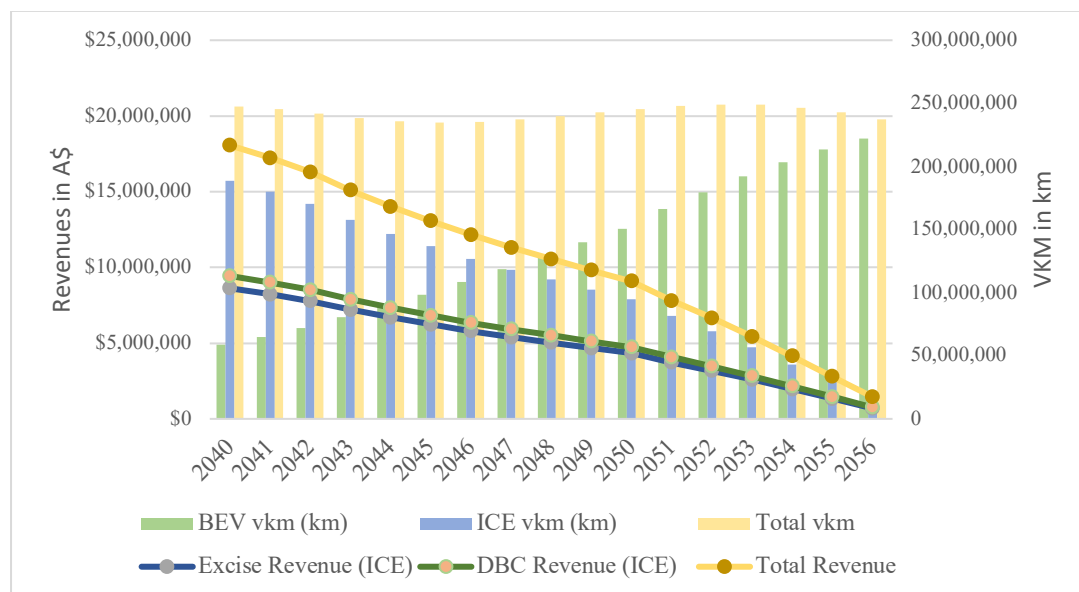


Figure 5. Daily VKM & Revenue for Scenario 2d - DBC 5c/km on ICE Only

Regardless of a declining trend, if the DBC applies to both ICEs and BEVs, a substantial revenue surplus will be obtained from 2040 to 2056, above the 11 million dollars daily at the base level. Figure 6 shows the significant rate of decline of fuel excise revenue while the DBC will be maintained at a similar level. Total daily VKM will first decline from 2040 up to 2048 with an across the board DBC, then start rising from 2049 onwards due to the rapid increase of BEVs, which comes with much lower running costs for cars using batteries instead of petrol and diesel.

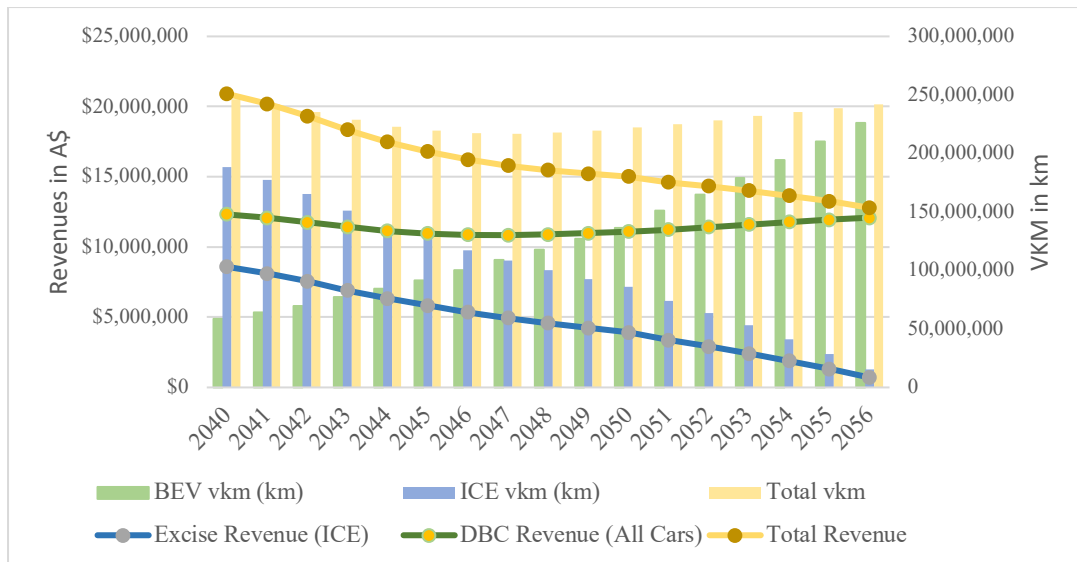


Figure 6. Daily VKM & Revenue for Scenario 2a - DBC 5c/km on All Cars (ICE + BEV)

If a policy objective is to maintain government revenue during BEV adoption, then a 5c/km DBC on BEVs only seems to be an appropriate policy to achieve this objective. Applying a DBC on BEVs only seems to be an appropriate policy to achieve this objective. Applying a DBC on all cars may serve as an alternative approach for a certain period if there is buy in that is linked to having government revenue in excess of the fuel excise associated with a 100% ICEs fleet used to improve the performance of the transport network in ways that users find acceptable. The focus on a DBC on BEV's only is promoted as a way of beginning the journey to move towards an efficient road user charging scheme on all road-based vehicles, and that with a relatively low usage cost per kilometre compared to ICEs , BEV users will still be financially better off.

Conclusions

This paper has investigated a topic that is growing in interest, especially by governments who are increasingly concerned about the loss of fuel excise as cars switch from a dependence on petrol and diesel to clean end-use energy sources, notably battery electric cars (although this would also apply to battery fuel cell (hydrogen) cars). To minimise the loss of fuel excise as battery electric cars come on stream and are scalable with attractive purchase prices and costs of usage, a 'tax' on battery electric car usage has been suggested in Australia by three State governments. Specifically, a 2.5c/km distance based charge has been chosen as an appropriate charge, although we are not aware of the justification for identifying this specific level of a DBC.

Given that BEVs are almost certainly going to be dominant in the future in the car fleet in Australia, and indeed in many countries, the challenge is to gain a better understanding on what this will mean for some of the critical indicators that matter to government, especially revenue changes, CO₂ emissions, car kilometres and hence congestion, and switching potential in favour of public transport. With reduced purchase prices and usage costs per kilometre we might expect BEVs to be very popular and to result in additional daily travel kilometres and impacts on the performance of the road network.

One way to 'contain' negative externalities is to consider the introduction of a distance based charge. This is not a new idea at all, and one aligned with many years of arguments by economists for road pricing reform designed to internalise the negative externalities such as congestion and more recently CO₂ emissions, associated with under-priced road use. The proposal to introduce a DBC on BEVs as a transition strategy raises new prospects that finally governments might show a greater interest in road

use pricing reform. We doubt, however, that the current interest is aligned with a renewed interest in efficient pricing but rather a concern about significant loss of revenue from fuel excise.

To gain new insights into what these proposals might mean, we have introduced projections over time in the switch away from ICEs to BEVs, adjusting the purchase prices and usage costs of cars in the ICE and BEV mix based on available best information. We have assessed what this might mean for the recovery of revenue under reduced fuel excise when we add in a DBC for BEVs, considering a range of charging rates (from 5c/km to 15 c/km), noting that the proposed State government DBC rate of 2.5c/km in Australia will result in a significant drop in overall government revenue unless it is also applied to ICEs. To place the findings in a broader context, we have also considered a DBC on all cars, both ICE and BEV, and also what it might have looked like in a fleet that is 100% ICE. The main finding associated with revenue is that a 5c/km DBC on BEVs only is forecast to reinstate government revenue to the level associated with fuel excise in a future period after 2040 when we have a significant switch to electric cars. This also comes close to containing any additional growth in car use associated with a switch to BEVs.

There are caveats, as always. The evidence is dependent on assumptions made about the penetration rate of BEVs and hence the reduced incidence of ICEs, as well as the expected purchase price and usage cost of BEVs. Our findings are contingent on the best information available on these influential factors as well as the current view in Australia in support of BEVs in contrast to hydrogen. As further information becomes available that may impact of the assumptions in the paper, it is very easy to modify the assumptions and implement additional analysis in MetroScan to obtain revised forecasts.

Appendix A. Battery Electric Vehicle Price Projections

This appendix includes the projected prices for ten vehicle classes with ICE and BEV proportions. In determining the prices for BEVs for future years, we began with the average prices for current available BEVs in 2021. We then applied price elasticities for BEVs identified in recent research in the Norwegian market (Fridstrøm and Østli 2021). Their study identified the direct price elasticities for BEVs as -1.27. We then built the projected prices into the MetroScan system.

Table A1. Purchase price of BEVs by class type and year (LCV = light commercial vehicle)

Year	Micro	Small	Med	Luxury	UpMeda	UpMedb	Large	LCV	FourWheel	Utility
2021	\$17,281	\$21,035	\$31,256	\$83,453	\$47,733	\$28,910	\$45,173	\$22,384	\$39,352	\$39,352
2022	\$17,283	\$21,064	\$31,279	\$83,524	\$47,256	\$28,621	\$44,721	\$22,160	\$38,958	\$38,958
2023	\$17,286	\$21,110	\$31,313	\$83,634	\$46,783	\$28,335	\$44,274	\$21,939	\$38,569	\$38,569
2024	\$17,288	\$21,155	\$31,344	\$83,739	\$46,315	\$28,051	\$43,831	\$21,719	\$38,183	\$38,183
2025	\$17,288	\$21,203	\$31,375	\$83,846	\$45,852	\$27,771	\$43,393	\$21,502	\$37,801	\$37,801
2026	\$17,286	\$21,270	\$31,415	\$83,988	\$45,394	\$27,493	\$42,959	\$21,287	\$37,423	\$37,423
2027	\$17,278	\$21,349	\$31,456	\$84,148	\$44,940	\$27,218	\$42,529	\$21,074	\$37,049	\$37,049
2028	\$17,263	\$21,439	\$31,496	\$84,316	\$44,490	\$26,946	\$42,104	\$20,863	\$36,679	\$36,679
2029	\$17,240	\$21,534	\$31,530	\$84,478	\$44,045	\$26,677	\$41,683	\$20,655	\$36,312	\$36,312
2030	\$17,206	\$21,630	\$31,555	\$84,625	\$43,605	\$26,410	\$41,266	\$20,448	\$35,949	\$35,949
2031	\$17,162	\$21,728	\$31,569	\$84,755	\$43,169	\$26,146	\$40,854	\$20,244	\$35,589	\$35,589
2032	\$17,103	\$21,830	\$31,571	\$84,866	\$42,737	\$25,884	\$40,445	\$20,041	\$35,233	\$35,233
2033	\$17,031	\$21,931	\$31,559	\$84,950	\$42,310	\$25,625	\$40,041	\$19,841	\$34,881	\$34,881
2034	\$16,946	\$22,027	\$31,531	\$85,000	\$41,887	\$25,369	\$39,640	\$19,642	\$34,532	\$34,532
2035	\$16,846	\$22,121	\$31,486	\$85,017	\$41,468	\$25,115	\$39,244	\$19,446	\$34,187	\$34,187
2036	\$16,710	\$22,225	\$31,412	\$84,989	\$41,053	\$24,864	\$38,851	\$19,252	\$33,845	\$33,845
2037	\$16,557	\$22,319	\$31,314	\$84,909	\$40,643	\$24,616	\$38,463	\$19,059	\$33,507	\$33,507
2038	\$16,397	\$22,400	\$31,201	\$84,784	\$40,236	\$24,369	\$38,078	\$18,868	\$33,172	\$33,172
2039	\$16,220	\$22,473	\$31,066	\$84,611	\$39,834	\$24,126	\$37,697	\$18,680	\$32,840	\$32,840
2040	\$16,024	\$22,538	\$30,907	\$84,386	\$39,436	\$23,885	\$37,321	\$18,493	\$32,511	\$32,511
2041	\$15,811	\$22,594	\$30,726	\$84,109	\$39,041	\$23,646	\$36,947	\$18,308	\$32,186	\$32,186
2042	\$15,570	\$22,643	\$30,511	\$83,763	\$38,651	\$23,409	\$36,578	\$18,125	\$31,864	\$31,864
2043	\$15,239	\$22,689	\$30,205	\$83,245	\$38,264	\$23,175	\$36,212	\$17,944	\$31,546	\$31,546
2044	\$14,910	\$22,717	\$29,888	\$82,686	\$37,882	\$22,943	\$35,850	\$17,764	\$31,230	\$31,230
2045	\$14,577	\$22,729	\$29,560	\$82,089	\$37,503	\$22,714	\$35,491	\$17,587	\$30,918	\$30,918
2046	\$14,216	\$22,728	\$29,194	\$81,407	\$37,128	\$22,487	\$35,137	\$17,411	\$30,609	\$30,609
2047	\$13,864	\$22,714	\$28,829	\$80,716	\$36,756	\$22,262	\$34,785	\$17,237	\$30,303	\$30,303
2048	\$13,523	\$22,690	\$28,470	\$80,023	\$36,389	\$22,039	\$34,437	\$17,064	\$30,000	\$30,000
2049	\$13,189	\$22,658	\$28,113	\$79,325	\$36,025	\$21,819	\$34,093	\$16,894	\$29,700	\$29,700
2050	\$12,866	\$22,621	\$27,764	\$78,636	\$35,665	\$21,601	\$33,752	\$16,725	\$29,403	\$29,403
2051	\$12,337	\$22,545	\$27,184	\$77,478	\$35,308	\$21,385	\$33,414	\$16,557	\$29,109	\$29,109
2052	\$11,880	\$22,469	\$26,674	\$76,448	\$34,955	\$21,171	\$33,080	\$16,392	\$28,818	\$28,818
2053	\$11,400	\$22,378	\$26,135	\$75,347	\$34,605	\$20,959	\$32,750	\$16,228	\$28,529	\$28,529
2054	\$10,899	\$22,273	\$25,564	\$74,173	\$34,259	\$20,750	\$32,422	\$16,066	\$28,244	\$28,244
2055	\$10,375	\$22,153	\$24,962	\$72,925	\$33,917	\$20,542	\$32,098	\$15,905	\$27,962	\$27,962
2056	\$9,830	\$22,018	\$24,329	\$71,603	\$33,578	\$20,337	\$31,777	\$15,746	\$27,682	\$27,682

Appendix B. Battery Electric Vehicle Daily Kilometre Projections

Table B1. Total daily car kilometres for each Scenario and year

			Total daily car kilometres (in million kilometres)																
Scenario No	Scenarios	EV Projection	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056
1	Base 1	No	243	243	244	244	244	244	244	244	244	244	244	244	244	244	244	244	244
2	Base 2	Yes	246	247	248	248	249	249	250	250	251	251	251	251	251	252	252	251	251
1a	DBC 5c all ICE	No	236	225	212	199	187	175	165	157	149	142	136	131	126	122	119	116	113
1b	DBC 5c all ICE	No	228	205	183	164	148	136	126	118	112	108	104	101	98	96	94	92	91
1c	DBC 15c all ICE	No	219	188	162	141	126	115	107	102	98	95	92	90	87	83	78	71	65
2a	DBC 5c all car	Yes	246	242	235	229	223	219	217	217	218	220	222	225	228	232	236	239	242
2b	DBC 10c all car	Yes	239	223	206	191	180	174	170	169	169	171	174	177	182	188	193	199	205
2c	DBC 15c all car	Yes	231	204	181	164	152	145	141	140	140	142	144	148	152	158	163	169	175
2d	DBC 5c ICE only	Yes	247	245	242	238	236	235	235	237	240	243	246	248	249	249	247	243	237
2e	DBC 10c ICE only	Yes	243	231	219	209	201	198	197	199	203	209	215	222	230	237	243	246	245
2f	DBC 15c ICE only	Yes	233	231	228	225	223	222	222	223	226	228	231	233	234	234	233	230	226
2g	DBC 5c BEV only	Yes	244	243	243	243	243	243	243	243	243	244	244	244	244	244	244	244	244
2h	DBC 10c BEV only	Yes	240	238	239	239	240	241	241	242	242	243	243	243	244	244	244	244	244
2i	DBC 15c BEV only	Yes	236	234	236	237	238	239	240	241	242	242	243	243	244	244	244	244	244

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Author Contributions

David A. Hensher: Conceptualization, Methodology, Analysis, Writing, Editing, Reviewing

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Wen Liu: Programming, Data outputs

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