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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 internal combustion engine vehicles 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 and crash risk) 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 CO_2 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.

1. 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, but there are a number of interrelated issues that surround BEV adoption and use.

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. 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 10,000 per annum.[1]

In Australia, the BEV Council[2] suggests that a BEV's running cost will be equivalent to 5.15 cents per kilometre compared to 14.39 cents per kilometre for an ICE, an average saving of $1400 per annum on fuel costs alone for the annual car kilometres of the average user. Other sources suggest slightly higher rates of operating costs but the percentage differences are almost identical, with electricity costing about 34% to 36% of the petrol price. Average electricity usage rates in different states in Australia are similar although higher in South Australia. Specifically, electricity prices are respectively 21.34 cents, 20.96 cents, 24.66 cents and 34.24 cents per kWh in Queensland, Victoria, New South Wales and South Australia based on May 2021 figures.[3] The average price for electricity is 30.25 cents per kWh.[4] Using the average fuel consumption for ICEs and BEVs, to travel 100 kms, the average cost of petrol is $16.20 at $1.50/l for 10.8 l and the average cost of electricity (from the grid) is $5.45 for 18 kWh of electricity and $0.3025 per kWh., a finding similar to the BEV Council. It is worth noting, however, that retail petrol prices change on a daily basis (often as much as 20%) while electricity usage rate remains stable, and with off-peak rates and factors, the actual savings can be much lower. On average, Australian cars registered as

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[1] At the time of writing $1AUD = $US0.67 and €0.62.

[2] https://electricvehiclecouncil.com.au/

[3] Numbers are from https://www.canstarblue.com.au/electricity/electricity-costs-kwh/.

[4] Number is from https://www.leadingedgeenergy.com.au/news/cost-of-electricity-in-australia-in-2020/.

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private or business, travel close to 15,000 km per annum, varying by states and territories (ABS, 2020). On a yearly basis, the saving in operating cost in the switch to a BEV is about $1600 for the above selected average scenario.

Simple economics suggests that the private BEV 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. Congestion is expected to increase and even though some car users may reduce using their car under these conditions, we speculate that this reduction will not be enough to control congestion without road pricing reform, desirably on both cars and trucks (as shown in Hensher et al., 2020c). We might also anticipate increased traffic crash risk, sprawl related costs, and non-tailpipe emissions such as tyre particulates (See Ahangari et al., 2014; Burke and Nishitateno, 2015, and OECD, 2020).

Another reason to consider road pricing reform is the impact of BEV use on Government revenue raised via fuel levies. Fossil fuel excise accounts for about 37% of government road- related revenue 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. If, for example, we have a 5c/km peak period distance-based charge (DBC), assuming an average annual peak kilometres travelled of 4000 (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 for a BEV user and compensates to some degree for the loss in government revenue.

These aspects show that BEV adoption and utilisation has complex and inter-dependant potential impacts that call for careful analysis. This paper addresses some potential impacts as follows. We begin with a short commentary on what battery electric car adoption is likely to mean for government revenue,[5] followed by a proposal, growing in interest in Australia, for a road usage charge on BEVs. We then 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 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 to address the concerns over BEV use that we address here.

2. Battery electric vehicle adoption and government revenue

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 share.[6] 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 managing a potential increase in congestion. This has to be done while still making the purchase and use of a BEV attractive.

The 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 (Harris, 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 remains as to which fund the government can draw on to support these movements.

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). This paper focuses on State government proposals to introduce a distance-based charge for BEVs in recognition that such vehicles obtain a benefit from road use which has in part been recouped through the fuel excise on petrol and diesel and which currently does not apply to electric vehicles.

3. 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. Although this is seen by some pundits as an environmentally bad policy, it nevertheless has been passed in legislation in Victoria[7] as a 2.5c/km charge. 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 license, 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.

Pundits have been arguing for many years, before the implications of BEV adoption became apparent, that we should reduce fixed charges and introduce a distance- based charge. Proponents agreed it needed to be done in a way to get buy-in to ensure it passes the ‘hip pocket test’ so that people are not financially worse off, but that they perceive their outlays to reflect a benefit through better use of the roads (Hensher and Bliemer, 2014; Hensher and Mulley, 2014). Research has shown that 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 a1c/km for

[5] Appendix C provides an overview of broader issues in the transport sector related to the switch to BEVs.

[6] 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.

[7] See https://www.innovationaus.com/victorian-parliament-passes-evs-tax/. It is expected to raise about $30 million over four years, with owners to pay an average of $300 per year. Electric vehicle owners will have to keep a log of their driving, with this information used to calculate how much extra they will have to pay when they renew their car registration. Photos of a vehicle's odometer will be provided to the state government via an online portal.

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. 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. We investigate these issues in the following sections where we focus on the Greater Sydney Metropolitan Area (GSMA) and introduce BEVs in the mix in the presence and absence of road user charging reforms on all fuel classes and just BEVs or ICEs.

4. Road charging reform scenarios in a transport and land use context

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, CO_2 emissions, generalised cost of car use, car operating cost per kilometre, and modal shares. These outcomes are critical indicators for transport policy consideration.

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 (Fig. 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., 2020b). 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, CO_2 emissions, operating costs, and kilometres of car use. A more detailed overview of the framework of the MetroScan system is given in Hensher et al. (2020b) and other papers published in the Journal of Transport Geography (Ho et al., 2017, Hensher et al., 2019, and Hensher and Teye, 2019). The specific parts of Metroscan that were modified to account for BEV assumptions are summarised in Fig. 2.

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, electricity charging rates, petrol and diesel prices, 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.

4.1. 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 in 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).

From 2050 to 2056, a rapid increase of BEVs is predicted to occur (i. e., from 61.3% to 94% of cars), assuming a concerted effort by government and manufacturers 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 Fig. 3.

4.1.1. 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.

4.1.2. On-road CO_2 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.[8] We apply the average figures for CO_2 emissions for different vehicle classes noting that BEVs produce zero end-use emissions. On average, ICE passenger cars emit 0.172 kg per kilometre of CO_2 (Almond, 2020; Grigoratos et al., 2019; NTC, 2019; Transport and 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.

4.1.3. 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 l of petrol per 100 km and 18.4 l 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 100 km is approximately 18 kWh, or 0.18 kWh/km (Gaton, 2019).[9]

4.1.4. 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 and Consumer Commission, 2021). As discussed earlier, this revenue is the primary source of road maintenance and infrastructure spending on transport facilities (IPA, 2019).

4.1.5. 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., 2020b). The generalised cost per person trip

[8] Although there is no exhaust emission from the tailpipe, the upstream emissions from the consumed electricity is often neglected and should be accounted for (see ITF, 2020; Hausfather, 2020). This is different to the emissions generated during the production of vehicles and batteries. Australia's electricity production has high fossil fuel intensity with 62% from coal, 9.9% from natural gas, 27.7% from renewable energy and 0.5% from other waste and mine gas, or other liquids according to Clean Energy Australia (2021). The emission factors are 1 kg $CO_{2\text{-}e}$/kWh for coal and 0.5 kg $CO_{2\text{-}e}$/kWh for gas, and only close to zero emissions from renewable energy. This matches with emission factors in the USA (NREL, 2016). The emission intensity is different by state. Except in Tasmania and South Australia with 60% to 99% of renewable energy used for electricity generation, other states especially large states such as New South Wales, Queensland and Victoria are still heavy fossil fuel reliant in power generation, so a kWh electricity in Australia will generate about 0.7 kg $CO_{2\text{-}e}$/kWh. The indirect emission factors for consumption of purchased electricity recommended by the Australian Government also align with this emission level but were higher (Department of Environment and Energy of the Australian Government, 2017), reflecting the improvement in using renewables in electricity generation.

[9] Given the assumptions made in Australia on the release of BEVs, we have used an average of 18 KwH/100 kms which aligns with the anticipated growth in small to medium affordable BEVs from 2040 onwards. We do not consider a breakdown by class of BEVs but note that there is an expectation that the majority of BEVs in Australia will be in the small to medium classes adopted by the ICE classification. The luxury brands when released in 2022 onwards are expected to cost of $AUD 140,000 (such as the BMW *iX*).

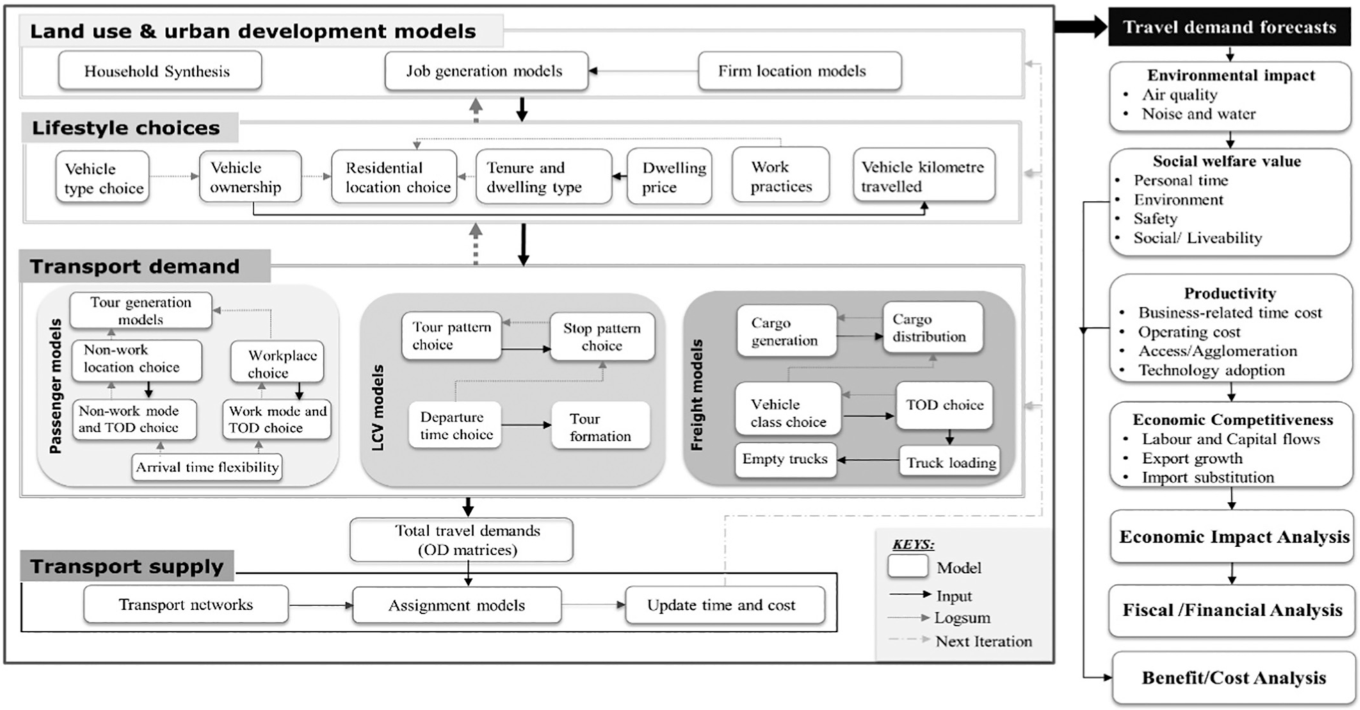

Fig. 1. MetroScan framework.

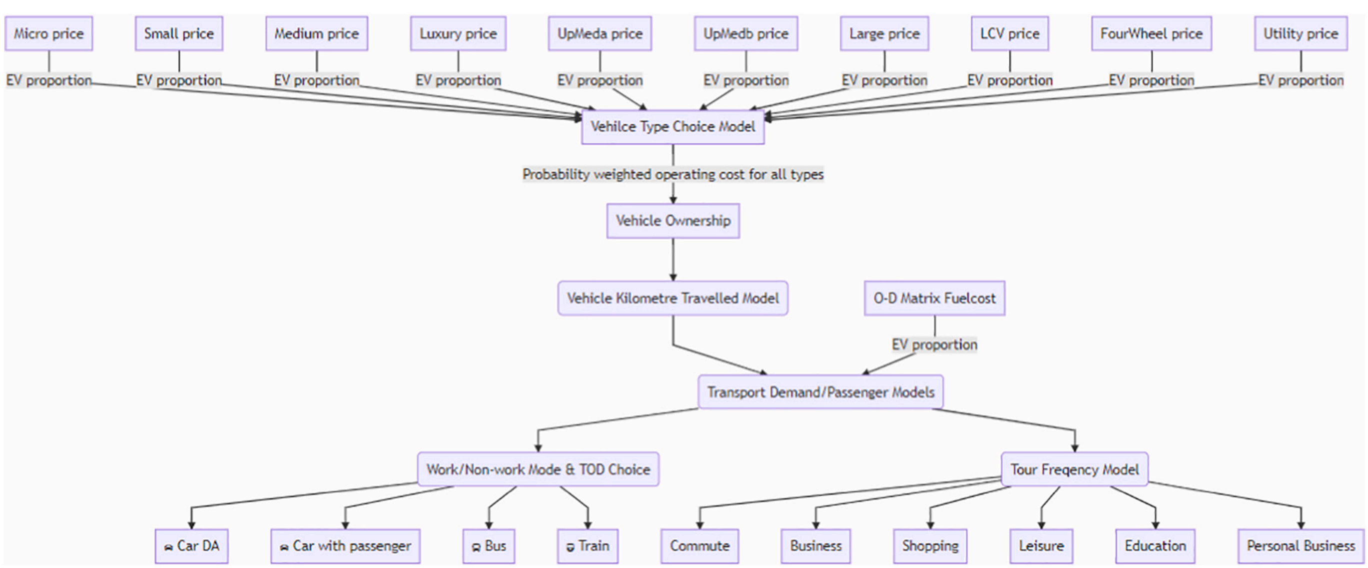

Fig. 2. MetroScan elements linked directly to BEVs.

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%

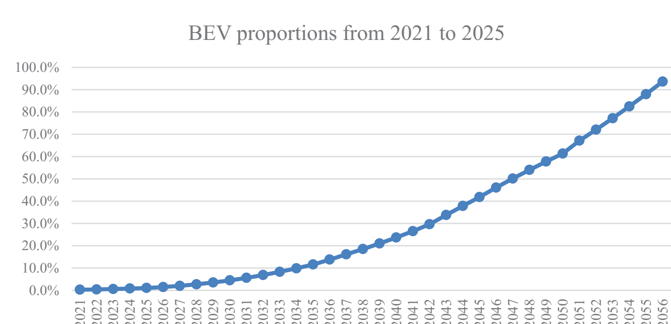

Fig. 3. The forecast for BEV adoption in Australia.

for cars for all purpose of trips (peak/offpeak) is equal to:

VTTS*in-vehicle time + VoR*buffer time + operating cost ($/trip) + tollcost ($/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, 2020). The value of reliability (or travel time variability over repeated trips) is set at $30.14/person hour.

5. 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 apply 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 Fig. 3. There are no DBC policies for this base, so it represents the likely outcomes without policy adjustments by a DBC.

5.1. 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. In addition, some commentators suggest that politically this is more acceptable when the presence of BEVs is starting to be ‘significant’. Scenarios 1a to 1c have 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 BEV	No
2	Base 2 BEV adoption	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

5.2. 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.

The results suggest that with BEVs accounting for 26.5% of the total fleet, the total VKM will increase by 1.4%, not adding much 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. CO_2 emissions will reduce by 22.6% as will the operating cost per kilometre; however, there is also a significant loss of fuel excise revenue, by 25.5%.

The outcomes demonstrate the positive aspect of electrification in CO_2 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.

5.3. Introducing a distance based charge

5.3.1. Without BEV adoption

The first step in the analysis of the impact of a DBC establishes a

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%
Mode Shares (%) all trips purposes:			
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	$21.46	−9.1%
Generalised cost per km ($/km)	$0.603	$0.683	13.3%
Op cost (petrol/ electricity+DBC) per km ($/km)	$0.162	$0.133	−17.6%
CO_2 daily emissions (tonnes)	41,873	32,389	−22.6%
Government revenue:			
Total daily fuel excise (A$)	$11,121,584	$8,286,932	−25.5%

version of a business-as-usual case where a DBC is applied to the car and truck fleet that remains totally ICE. Table 4 summarises the results for three levels of DBC charge (Scenarios 1a, 1b and 1c compared to Scenario 1). 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 demand 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 when the DBC increases to 10c/km and to 15c/km.

In these scenarios, the increase in total revenue from both the fuel excise and DBC is substantial.[10] If the DBC is implemented in 2041, 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. The implied mean direct elasticity of daily car kilometres with respect to operating cost per kilometre is around −0.25, varying slightly according to the level of DBC. We now turn to consider these options.

5.3.2. The DBC impact of 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.

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% off a very low base. The generalised cost of car use and CO_2 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.

If the DBC only applies to ICEs (with 26.5% of BEVs in the fleet for 2041), 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 only for ICE owners.[11] 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 CO_2 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 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 who are also paying for fuel excise risks public opposition 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 Fig. 3 and discussed in the next section, the revenue will decline fast with the increasing adoption of BEVs relative to ICEs in the fleet.

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 CO_2 emissions. On revenue, a 5c/km DBC on BEVs will increase total government revenue by 37%. The $3 million 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.

5.3.3. 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 current revenue stream from fuel excise on the ICE fleet (Base Scenario 1), both at about $Aus11m daily for 2041 and maintaining a close match until 2056. This pattern is shown in both Table 8 and Fig. 4. It is noteworthy that a currently proposed 2.5c/km on BEVs by NSW, Victoria and South Australia is insufficient to recoup the loss of fuel excise.

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, to have serious negative financial implications on transport expenditure, and seems an unsustainable policy option.

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, for example, hydrogen.

Figs. 4 to 6 highlight the changes in daily VKM, car operating costs per kilometre, 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. Fig. 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, suggesting no increase in levels of road congestion.

Fig. 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.

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 $Aud11 million daily at the base level. Fig. 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 per kilometre for cars using batteries instead

[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.

[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.

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

	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			
Total daily car kilometres	243,445,930	224,894,418	205,078,371	188,128,534	−7.6%	−15.8%	−22.7%
Mode Shares (%) all trips purposes:							
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	$20.65	−9.9%	−11.4%	−12.6%
Generalised cost per km ($/km)	$0.603	$0.852	$0.868	$0.875	41.3%	43.9%	45.1%
Op cost (petrol/electricity/ DBC) per km ($/km)	$0.162	$0.212	$0.262	$0.312	30.9%	61.7%	92.6%
CO_2 daily emissions (tonnes)	41,873	38,682	35,273	32,358	−7.6%	−15.8%	−22.7%
Government revenue:							
Total daily fuel excise (A$)	$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%

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%
Mode Shares (%) all trips purposes:							
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	$20.15	−1.2%	−4.2%	−6.1%
Generalised cost per km ($/km)	$0.683	$0.904	$0.979	$0.998	32.4%	43.3%	46.1%
Op cost (petrol/ electricity/DBC) per km ($/km)	$0.133	$0.184	$0.234	$0.286	38.3%	75.9%	115.0%
CO_2 daily emissions (tonnes)	32,389	30,553	28,167	25,822	−5.7%	−13.0%	−20.3%
Government revenue:							
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%

of petrol and diesel.

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 all cars may serve as an alternative approach for a certain period. This could be justified if the excess of the fuel excise was used to improve the performance of the transport network in ways that users find acceptable. The focus on a DBC on BEV's only could be seen as a way of beginning the journey towards an efficient road user charging scheme on all road-based vehicles, which could be politically acceptable as the relatively low usage cost per kilometre of a BEV means BEV users will still be financially better off. Such a position needs to be communicated to the wider public.

6. Conclusions

Given that BEVs are almost certainly going to be dominant in the

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%
Mode Shares (%) all trips purposes:							
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	$20.22	−0.3%	−3.1%	−5.8%
Generalised cost per km ($/km)	$0.683	$0.866	$0.945	$1.225	26.8%	38.4%	79.4%
Op cost (petrol/electricity/ DBC) per km ($/km)	$0.133	$0.170	$0.207	$0.243	27.8%	55.6%	82.7%
CO_2 daily emissions (tonnes)	32,389	30,998	29,257	29,171	−4.3%	−9.7%	−9.9%
Government revenue:							
Total daily fuel excise (A$)	$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%

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%
Mode Shares (%) all trips purposes:							
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	$20.69	−1.5%	−2.7%	−3.6%
Generalised cost per km ($/km)	$0.683	$0.75	$0.799	$0.845	9.8%	17.0%	23.7%
Op cost (petrol/electricity/ DBC) per km ($/km)	$0.133	$0.147	$0.160	$0.173	10.5%	20.3%	30.1%
CO_2 daily emissions (tonnes)	32,389	30,660	30,115	29,633	−5.3%	−7.0%	−8.5%
Government revenue:							
Total daily fuel excise (A$)	$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%

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 when scalable 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, both for congestion and crash risk.

An initial step to 'contain' some of these negative externalities is to introduce a distance based charge. This is not a new idea, 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 CO_2 emissions, associated with under-priced road use. Recent policy initiatives in Australia include a DBC on BEVs, which could be seen as an initial step towards governments utilising road pricing within broader transport policy.

To provide some serious insight into the implications of the proposals

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 BEV	No	$11,121,584	$11,167,696
2	Base 2 BEV adoption	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

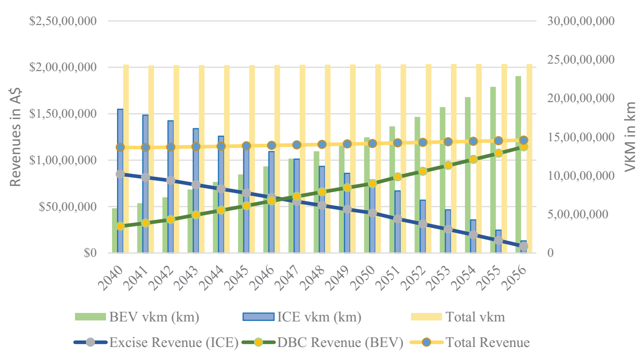

Fig. 4. Daily VKM & Revenue for Scenario 2g - DBC 5c/km on BEV Only.

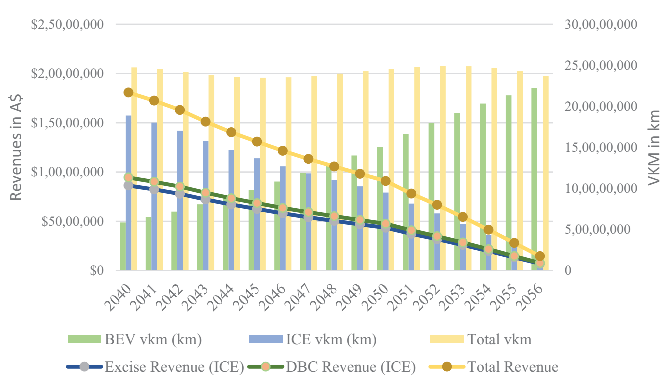

Fig. 5. Daily VKM & Revenue for Scenario 2d - DBC 5c/km on ICE Only.

to tax BEVs, we have explored the revenue implications of the switch away from ICEs to BEVs. 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). 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 is that a 5c/km DBC on BEVs will reinstate government revenue to the level associated with fuel excise in a future period after 2040 when we have a significant switch to

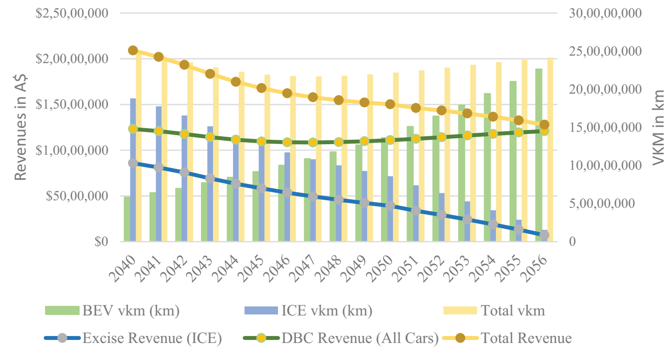

Fig. 6. Daily VKM & Revenue for Scenario 2a - DBC 5c/km on All Cars (ICE + BEV).

electric cars. The charge 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. The 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 a fuel cell battery). 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. A final consideration is that the approach has emphasised the revenue dimension. It is possible that a similar research strategy could explore other aspects of BEV adoption such as impacts on air pollution and to delve deeper into consequences for public transport in terms of service provision and infrastructure.

A finer scale scenario development involving other costs such as the battery replacement will also be a useful extension, although the cost of batteries is changing at a fast rate. There continues to be great uncertainty about battery costs including the capacity of batteries and hence the recharging time and distance between charging. Some of the inputs, such as lithium, may become more costly in the future, but equally important, motorists might tend to use battery cost reductions to purchase larger batteries, not to save money. Newer electric vehicles tend to have much higher capacity batteries than in the past, with reductions in unit costs not necessarily resulting in reductions in the total cost per vehicle. The battery of BEVs is about a quarter of the BEV cost, and price parity with ICE cars are likely to be achieved as early as 2025.[12] For example, if a battery price is $80/kWh by 2025, for a standard 100 kWh EV battery pack, the BEV price may be around $30,000, resulting in a lower price than a comparable ICE. However, it is uncertain that consumers will purchase the BEVs at the comparable models of their existing ICEs if the price of BEV becomes lower due to lower battery cost; BEVs with larger battery packs may be in higher demand. Considering the large gap between the fuel and energy consumption over the same travelled distance for ICEs and BEVs, one could argue that consumers would have a significant consumer surplus for BEVs due to lower operating costs, resulting in purchasing BEVs with larger battery packs.

Taking a wider view suggests that BEV adoption will not be a painless panacea to transport issues but will require careful management and organisation. The analysis of scenarios like those presented here will be a valuable foundation for that activity. This evidence can be used as input to calculate and compare the full costs and subsidies currently used to promote electric vehicles, including purchase subsidies, subsidies to create recharging infrastructure, plus their exemption from fuel tax road user charges where this is promoted in contrast to a DBC.

[12] From https://about.bnef.com/blog/electric-cars-reach-price-parity-2025/

Disclosure statement

This is to acknowledge that there is no financial interest or benefit that has arisen from the direct application of the research.

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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 purchase 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	$9830	$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 BEV	No	243	243	244	244	244	244	244	244	244	244	244	244	244	244	244	244	244
2	Base 2 BEV adoption	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

(continued on next page)

Table B1 (*continued*)

Scenario No	Scenarios	EV Projection	Total daily car kilometres (in million kilometres)																
			2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056
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

Appendix C. 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 Zhang 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 CO_2 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.

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 sustainable.[13]

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[13] Australia is a small part of the international new vehicle sales market, roughly 1 m of 65 m. 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.

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