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Quantifying the costs of a rapid transition to electric vehicles

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HIGHLIGHTS

- Detailed quantification of the costs of a transition to electric vehicles (EVs).
- Under some circumstances, a rapid transition to EVs may not cost extra.
- Significant benefits from an EV transition may be available at minimal cost.
- The transition to EVs may occur rapidly.
- Energy sector readiness is a matter of urgency.

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ABSTRACT

This paper considers the financial costs of a rapid national transition to electric vehicles (EVs) in comparison to a baseline scenario that is characterised by continuing use of internal combustion engine vehicles (ICEs). The Australian car fleet, which is responsible for 8% of national greenhouse emissions, is used as a case study. To explore the potential range of costs associated with rapid climate mitigation via the transport sector, the transition is assumed to occur very rapidly (by 2025). The analysis focusses on urban areas, where extensive charging infrastructure is assumed to be made available, including rapid charging facilities. Due to uncertainty over input variables, two "boundary" scenarios were constructed. In the High Cost Scenario, a rapid shift to EVs was found to cost approximately 25% more than the continuing use of ICEs, assessed over the period 2015–2035. However, in the Low Cost Scenario, where costs of EVs (especially batteries) fall more rapidly, EV maintenance costs are at the lower end of projections, and liquid fuel costs at the higher end of projections, a rapid transition to EVs is found to cost approximately the same as the use of ICE vehicles. This suggests that a rapid transition towards EV technologies for urban car travel may offer a cost-effective second-best climate change mitigation strategy. More comprehensive transport sector transformation, including changes in transport and land use policy designed to facilitate mode shift, might further reduce the costs of such a transition.

1. Introduction

Global efforts to address climate change received new momentum with the signing of the draft United Nations (UN) "Paris Outcome" in late 2015 [1]. Opportunities to reduce emissions from the transport sector were identified in earlier multi-lateral agreements. The UN Framework Convention on Climate Change, for example, notes "widespread agreement to reduce CO_2 emissions from transport by a minimum of 50% at the latest by 2050" [2].

Given the falling costs and increasing uptake of renewable electricity generation technologies [3], electric vehicles (EVs) offer an option for reducing greenhouse emissions from personal transport. Moreover, EVs are associated with several co-benefits, such as reduced noise and improved air quality [4]. Other studies have noted that uptake of EVs may also benefit the electricity system, by providing flexible spinning reserve [5], vehicle-to-grid technology [6], and active power regulation increasing the potential penetration of renewable generation [7,8].

Understanding these benefits is important for informing policy relating to the uptake of EVs. Indeed, the global market for EVs is growing rapidly: Sales more than doubled from 45,000 in 2011 to 113,000 in 2012, then increased by 70% in 2013, and a further 53% in 2014 [9]. As of the end of 2014, 665,000 EVs were in operation globally [9]. The International Energy Agency notes that the aggregated goal for all countries with known deployment targets is 7.2 million in EV sales and 24 million in EV stock by 2020 [10]. Continuing developments in EV technology, as well as conducive

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policy settings, seem set to support this growth. Given these trends and benefits, some sources argue that a transition towards electric transport now appears inevitable, even if the timing of the transition remains uncertain [11].

In an early but prescient study, Delucchi and Lipman developed a cost model designed to compare the physical and financial performance of EVs relative to ICEs [12]. The results of their analysis suggest that in order for EVs to be cost-effective alternatives for ICEs, the manufacturing price of EV batteries would have to fall to approximately USD 100 per kW h. When adjusted for producer price inflation (PPI) from 2001 to 2016, this is the equivalent of USD 130 per kW h.[1] Delucchi and Lipman also suggest that the competitiveness of EVs would depend on achieving a battery life of 12 years or more, and be associated with a range of between 150 and 200 km.

More recent studies suggest EV technology is converging towards, but has not yet reached, the thresholds identified in Delucchi and Lipman [12]. Weiss et al. conclude "the production costs of lithium-ion batteries may decline by 6–9% per annum, potentially reaching EUR 200-440 per kW h by 2020" [13]. These findings are corroborated in a more recent study by Nykvist and Nilsson, which suggests market-leading manufacturers are now producing EV batteries at a cost of USD 300 per kW h, and that costs are declining by 6–9% per annum [14]. Notwithstanding the rate of technological developments, Weiss et al. conclude "... closing the price gap between battery EVs and conventional ICE vehicles may require several decades if the current price dynamics persist ..." [13]. Urban areas are noted as the possible exception due to "... short driving ranges, accessible recharging infrastructure, and concerns over local air pollution", which in turn could support the uptake of small EVs with limited ranges. Weiss et al. conclude USD 130 per kW h threshold identified by Delucchi and Lipman may be achieved circa 2025–2030 [13].

Whilst the aforementioned studies are largely focused on trends in technological development and financial costs, there is a burgeoning body of literature which focuses on consumer preferences. Hidrue et al. use stated preference data to analyse consumers' willingness to pay for EVs and their attributes [15]. Propensity to buy EVs is found to decrease with age, but increase with education, environmental preferences, future fuel prices, and availability of charging points. In general, people appeared to be motivated more by fuel savings than non-pecuniary factors. Overall, consumers were willing to pay USD 3000 more EVs compared to ICEs. Pearre et al. analyse travel patterns to deduce the range required for EVs, and conclude " ... even modest electric vehicles with today's limited battery range, if marketed correctly to segments with appropriate driving behaviour, comprise a large enough market for substantial vehicle sales" [16]. Sierzchula et al. consider predictors of EV uptake at the country level [17]. Whilst their regressions find that financial incentives, charging infrastructure, and local production are positively correlated with EV market share, the authors do not attempt to control for apparently serious endogeneity issues affecting the last two variables.

Several studies use information on technological developments and consumer preferences to estimate EV market share. Lebeau et al. use stated preference conjoint analysis to estimate the market potential for EVs in Belgium and conclude EVs could achieve a market share of 5 and 15% by 2020 and 2030 respectively [18]. Results are most sensitive to vehicle sales prices, fuel prices, and technological developments relating to range and charging technologies. Shafiei et al. use an agent-based model to estimate EV market share in Iceland, which predicts that EVs could make up 25–70% of the fleet by 2025 [19]. Higgins et al. develop choice models of EV uptake in Victoria Australia, which are calibrated using stated preference data collected from focus groups and surveys [20]. Their model predicts EVs will represent approximately 3% of the total vehicle fleet by 2025. Shepherd and Bonsall reach similar conclusions for EVs in the U.K. using an agent-based model [21]. Al-Alawi and Bradley undertake a detailed review of market share modelling studies for EVs and hybrids in the U.S. and find large variation in predicted market shares [22]. These variations are attributed to differences in modelling approaches, specifically the use of agent-based models, consumer choice models, or technological diffusion models, and assumptions relating to the costs of ICEs, especially fuel, and the level of policy support for EVs.

Based on this literature review, we find a number of studies that make useful contributions to understanding how financial costs, consumer preferences, and technological developments may impact on EV market share. On the other hand, our review identified no studies that estimated the costs and energy implications associated with a transition to 100% EVs. The present study attempts to address this gap in the literature by approaching the problem of EV market share from a different perspective. Rather than considering EV market share under a business-as-usual scenario, we instead assume the transition to 100% EVs is complete by 2025, and then estimate the costs associated with such a transition. This approach helps to highlight the relative cost differential between EVs and ICEs at an aggregate level for the entire vehicle fleet, whilst also highlighting potential implications for energy and related infrastructure.

1.1. This case study

Most previous studies (discussed above) assume consumer preferences and policy settings remain constant, as in a "business-as-usual" scenario. In contrast, the present study considers EV uptake from a different perspective; we ask what are the financial costs and energy implications of a rapid transition to EVs? In posing this question we presume the timelines for a transition to EVs is exogenously determined by, for example, the need for climate change mitigation. We then work backwards from this exogenously determined timeline so as to understand the potential implications of such a transition.

This analysis considers a "stretch" scenario that explores a transition to 100% EVs over a period of ten years (by 2025). Stretch scenarios of this type are not intended to map a preferred or likely path, but instead explore the boundaries of possibility and hence provide insight on possible trajectories available to policy makers. The results of this analysis are thus intended to inform decision makers on the potential costs of reducing greenhouse emissions from the transport sector via policies that promote a rapid EV transition.

Australia provides a useful case study for this analysis. Firstly, Australia relies heavily on road transport. Secondly, Australia has an advanced economy with high levels of vehicle ownership, and could realistically attempt such a rapid transition. Thirdly, being an island nation, road transport in Australia is usefully "self-contained", making analysis of fleet composition relatively straightforward. Finally, Australian government agencies collect relatively consistent and comprehensive data on the composition of the vehicle fleet, facilitating meaningful analysis.

In 2013, almost 17% of Australia's greenhouse emissions were generated from the transport sector, with cars being responsible for 8.02% [23]. This makes car travel the largest single contributor to Australia's transport emissions. Around 75% of the passenger kilometres travelled by car in Australia occur in urban areas [24]. Urban car travel is likely to be well suited to a shift to electric; for example, the average daily driving distance for the Melbourne

[1] Historical data on PPI sourced from: https://research.stlouisfed.org/fred2/series/PPIACO#.