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Jacobus Nel
University of Pretoria
Roula Inglesi-Lotz
University of Pretoria
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Department of Economics
University of Pretoria
0002, Pretoria
South Africa
Tel: +27 12 420 2413

Electric vehicles market and policy conditions: Identifying South African policy "potholes"

Jacobus Nel[*], Roula Inglesi-Lotz[**]

Abstract

This study investigates the policy environment, specifically the policy "*potholes"* (shortcomings), in South Africa and provides policy recommendations to accelerate electric vehicle (EV) adoption in the country. The EV markets in South Africa and Europe in a novel way, to add to the depth of the analysis and associated recommendations. To accomplish this, EV sales are forecasted by fitting an S-curve to the available sales data and assuming a 40% market share in 2050. Secondly, the number of years the South African EV market is lagging behind Europe's is estimated, both dynamically and statically. We make policy recommendations in the wake of a detailed analysis of the literature on the effects of policy intervention on EV adoption, the evaluation of the current policy environment, and the comparison. A supply-side policy might be best suited for the country's political environment.

JEL: P25, R41, D78, G18

Keywords: electric vehicles in developing countries, market comparison, policy analysis, forecasting technology adoption

[*] Corresponding author. Department of Economics, University of Pretoria, Private Bag X20, Hatfield 0028, South Africa. Email address: neljaco380@gmail.com.

[**] Department of Economics, University of Pretoria, Private Bag X20, Hatfield 0028, South Africa. Email address: roula.inglesi-lotz@up.ac.za.

1. Introduction

In the late 1800s, Electric Vehicles (EVs) successfully competed with steam and gasoline-powered vehicles (in the North-eastern United States of America); however, in the early 1900s, the internal combustion engine (ICE) was considered superior, and subsequent large-scale adoption ensued (Santini, 2011), with other vehicle technologies seemingly becoming redundant. Cowan and Hultén (1996) investigated technology lock-in in the automotive sector. They concluded that it would be difficult for EVs to overcome technical issues (mainly relating to battery technology) and reliance on other industries (relating to the high price of parts and serviceability). Chege (2021) touches on some of these concerns, explicitly showing the decline in the price of inputs for batteries.

Despite this scepticism, the IEA (2019) reports that EV sales increased by 63% year on year in 2018, with China accounting for 45% of EVs acquired in 2018. They also found that the number of charging points increased by nearly the same percentage in the same year, of which 90% were private installations. Burch and Gilchrist (2020) report that 22 countries have passed legislation to ban ICEVs on various dates. Japan has an aggressive incentive program to promote EV sales, while 46 cities have made similar pledges. Some cities have already banned ICEVs in certain areas, usually city centres.

On the supply side, Liener and Chan (2019) report that 29 automakers are planning to invest at least $300 billion in EVs, while Burch and Gilchrist (2020) report that ten automobile manufacturers (groups) have already made pledges to promote EV sales. Some are setting a goal of 50% of sales to be fully electric by 2025. Others have pledged significant investments in EV development and manufacturing. Volkswagen, for instance, pledged 20 billion euros for its EV program (Burch and Gilchrist, 2020).

The shift to electromobility is of particular concern to South Africa, given that approximately 12% of the country's exports are automobiles Chege (2020), and the ban on ICEVs is seemingly imminent, as reported in Burch and Gilchrist (2020). A big motivator behind the shift to EVs is the need for a cleaner transportation sector. Lamb et al. (2021) review the trends of global emissions on a sectoral level for the period 1990 to 2018 and report that the energy sector accounted for 34%, industry 24%, agriculture, forestry and other land use (AFOLU) 21%, transport 14%, and building operations 6%. The transport sector accounted for 12.88% of South Africa's emissions in 2020, while 0.88 p.p. was attributed to electricity generation-derived emissions; the rest was to oil use (Climate Transparency, 2020). This indicates that South Africa has the potential to reduce emissions from the transport sector through the use of EVs, despite their energy mix, as Albatayneh et al. (2020) show that EVs from coal and diesel have similar energy efficiencies as ICEVs. From an emissions standpoint, there would not be any negative impacts on moving to EVs (apart from the relocation of emissions). However, EVs would also get cleaner as the energy sector transitions to low-carbon sources. World Bank Group (2022) investigated the potential of EVs to decarbonise the country's transport sector in their Country Climate and Development Report for South Africa.

Against this backdrop, we analyse the policy environment in South Africa to determine what policy-related issues should be addressed to speed up the adoption of EVs. We also compare the South African EV market to that in Europe (EU) to determine how far South Africa is lagging the EU, as this will give policymakers a timeline until we observe similar macroeconomic changes, albeit emission reductions (assuming a greater share of renewable energy sources) or increased demand for electricity. Therefore, looking at the policies implemented in Europe and their effectiveness (and possible unforeseen consequences) can benefit South African policymakers by having Europe's 20:20 hindsight.

The rest of the paper is structured as follows: Section 2 gives an overview of the literature, while Section 3 provides an overview of the South African policy environment relating to EVs. Section 4 deals with the data and methodology, and we discuss the results in Section 5 before concluding in Section 6 with a discussion of the results and policy recommendations.

2. Literature review

The link between policy intervention and its effect on EV adoption has received much attention in the literature. These studies have been conducted in the US (see, Soltani-Sobh et al., 2017; Jenn et al., 2018; Narissimhan and Johnson, 2018; Wee et al., 2018; Zambrano-Gutiérrez et al., 2018; Zhou and Li, 2018; and Clinton and Steinberg, 2019), Europe (see, Yan, 2018; and Münzel et al., 2019), and Asian countries (see, Kim and Heo, 2019; Li et al., 2019; Qui et al., 2019; and Guo et al., 2020). There are also multi-country studies (apart from the Europe studies), for instance, Kim et al. (2017) and Palmer et al. (2018).

For the US, most of these studies find that incentives contribute to accelerating the adoption of EVs, with rebates proving to be more effective at increasing the number of EVs than income tax credits, aligning with consumers' preference for current consumption over future consumption (they have a high time discounting factor). Gallagher and Muehlegger (2011) find a similar result studying HEV incentives. By incorporating the effect of fuel savings on purchase decisions, they estimate an implicit discount rate of 14.6% on future fuel savings. Jenn et al. (2018) find that increasing the tax credit or rebate by $1000 increases EV sales by 2.6%, while access to high-occupancy vehicle (HOV) lanes increases sales by 4.7%. This later result shows drivers' aversion to traffic, as HOV lanes are usually less congested than normal lanes on the highway, which is similar to the effects of Chang et al. (2016) for HEVs; however, they find a negative relationship between federal incentives and HEV sales. Jenn et al. (2018) also find that increasing consumer knowledge about EVs, and the related incentives, is critical to the effectiveness of incentive programmes. Narissimhan and Johnson (2018) find that early investments in charging infrastructure (especially along highways) are essential in the transition to EVs.

Wee et al. (2018) find that an increase of incentives of $1000 increases EV registrations between 5% and 11% when they analyse state-level data in the US.

Li et al. (2017) investigate the indirect network effect between EV adoption and charging station installations in US metro areas from 2011 to 2013. They find evidence of network effects for both EV adoption, as well as charging station installations. They find that federal income tax credits accounted for 40% of EV sales, with feedback loops explaining 40% of this increase. They conclude that subsidising charging station installations with an equally sized policy would have been twice as effective.

Using a theoretical framework, Zhou and Li (2018) find that there are critical mass constraints in some US metropolitan statistical areas (MSAs), indicating that a rebate of at least $15 000 (double that of the federal government) was needed for these MSAs to cross into the high adoption region. Policies targeting the MSAs with a critical mass constraint, with the same fiscal incidence as the federal rebate, can help push them into their respective steady states, meaning the budget is more efficiently used. These results possibly also explain the finding of Jenn et al. (2013) that the Energy Policy Act of 2005 increased HEV sales from 3% to 20%, and the incentive needs to be sufficiently large.

Kim et al. (2017) found that driving range and relative price are important determinants in EV adoption in analysing 31 countries, while Soltani-Sobh et al. (2017) investigated EV adoption in US states from 2003 to 2011. They find that electricity prices are negatively related to EV adoption, which of their regressors influences EV adoption the most (from a sensitivity analysis).

Palmer et al. (2018) take a different perspective; they relate the total cost of ownership to the market share in the UK, US, and Japan from 1997 to 2015. They find that the total cost of ownership for HEVs and EVs has decreased since their introduction until the end of the study period. Interestingly, subsidies have allowed EVs to reach cost parity in the UK and US, but not for PHEVs, mainly due to the lack of financial backing. These price reductions are likely, at least in part, due to the decrease in batteries, as shown by Chege (2021).

Yan (2018) and Münzel et al. (2019) find that incentives do increase EV sales, with Yan (2018) finding that a 10% increase in incentives results in a 3% increase in EV sales, while Münzel et al. (2019) finds that a €1000 increase in incentives, leads to a 5% to 7% increase EV sales. More importantly, Yan (2018) points out that despite recent advances in cleaning up the energy supply mix and lower battery costs, incentives are still a fiscally expensive way to reduce CO_2 emissions (and other externalities) by electrifying the transport sector.

Kim and Heo (2019) find that financial incentives are insufficient for the Korean market to motivate consumers to shift to EVs from ICEVs. Still, that technological improvement (longer batter ranges) is the most important factor for that market. Li et al. (2019) investigate the effect of various policies in Chinese cities. They find that removing purchasing and driving restrictions has a much more substantial impact than financial incentives (Zhang et al. (2016) find that the latter has no effect). These results make sense in light of the overcrowding issues of Chinese city roads. However, these policies are likely not sustainable; once every vehicle is electric, they will have the same congestion problem. Qiu et al. (2019) find that purchase subsidies are ineffective in China but that charging discounts and infrastructure construction subsidies (to build more charging stations) are positively related to EV sales. However, in light of the results of Li et al. (2019), these results might not be due to the actual subsidies and could only be picking up the effect of the relaxed restrictions for EV owners. Guo et al. (2020) consider the relationship between air pollution and EV sales, finding a positive relationship. However, these are likely not causal, given Li et al. (2019), and that air quality could be another reason for the purchase restrictions on ICEVs in Chinese cities.

Apart from the studies above, there are also some studies on HEV incentives that have some interesting results (for a systemic literature review listing most of the quantitative economic studies on HEVs and EVs, see Austmann (2021)). For instance, Chandra et al. (2010) find that rebates are attributed to 26% of the sales of HEVs in Canada but that these incentives are costly at reducing emissions at $195 per tonne of CO2.

Most studies above agree that the most important factors influencing EV sales are price (including financial incentives), driving range, and non-financial incentives (ability to use HOV lanes, purchase a private vehicle, etc.). Another important aspect of electric vehicle adoption is the availability of charging infrastructure (as modelled by Li et al. (2017) and shown to be a contributing factor in purchasing decisions by Gnann et al. (2018a)), as well as the more technical aspects, which include the potential for EVs (and PHEVs) to be used in smart grid applications and their potential to shift peak electricity loads (Gnann et al., 2018b). Gnann et al. (2018a) investigate the role of fast charging infrastructure on EV demand and find that the future ratio of fast chargers to the number of vehicles can be similar to conventional fuelling stations, with around 1000 vehicles per fast charger (at least 150kW chargers). Funke et al. (2019) provide a literature review of existing studies modelling the demand for charging infrastructure and how it differs between countries. They also find that public charging infrastructure is only a substitute for home charging in densely populated areas. This highlights the importance of not just country-specific policies for the rollout of charging infrastructure but also regional (or even municipal) specific policies.

Ensslen et al. (2020) analyse the results of a field study in Germany to evaluate the potential of organisations to drive the shift to EVs and report a net benefit (even without external incentives to shift to EVs from ICEVs) in that shift. Gnann et al. (2018c) compare 40 EV market penetration models and find that the price premium over ICEVs is most often modelled for the US. At the same time, it is the cost of energy and charging infrastructure for Germany. Models also consider the role HEVs, and

PHEVs play in the shift to e-mobility. They recommend that these models also consider policy incentives to model the real world better. Future research in this area should focus on country-specific dynamics and behaviours of consumers when modelling future demand for EVs.

There are only a few studies that consider the effect or potential effect of financial incentives in developing (or emerging) countries, or even if they are appropriate, aside from the studies in China and Korea, which have a GDP per capita far greater than South Africa (a fellow emerging economy), and the demand for EVs is likely driven by other factors (such as overcoming strict private vehicle sales in China). Given that nearly all the studies we evaluate above find that financial incentives contribute positively to EV sales, it is reasonable to assume that this would also benefit countries like South Africa. We will discuss this in the policy recommendations later. More importantly, however, there is no study comparing the EV markets in an emerging country, like South Africa, to that of a developed country and no study determining the lag time of the infant market. This is one of the contributions we make in the literature on EV markets, while the other contribution is evaluating the policy environment (see the background section) and making policy recommendations that would likely be more suitable to a developing/emerging country's political and fiscal environment.

Some studies conducted for South Africa include that of Pillay et al. (2019), which investigated the affordability of EVs in South Africa, and those by Moeletsi (2021a,b). Pillay et al. (2019) investigate the affordability of EVs in South Africa using a system dynamics model. They find that when they model the spending behaviours of consumers across the various provinces, the expected number of EVs decrease by about 5, which also decreases the range of expected vehicle stock (high growth scenario minus low growth scenario). From a policymaker's perspective, their results reduce the uncertainty tremendously, so planning for the additional electricity consumption would be less cumbersome. However, this also means that the emission reduction would be much less. Pillay et al. (2019) also find that consumers prefer charging their vehicles in the evenings at home, which greatly impacts evening peak electricity demand. Moeletsi (2021a,b) used survey data on residents in the Gauteng province to determine the appetite for EVs in the province. They find that price is one of the main factors listed as a concern by respondents and discuss some policy implications.

3. Background

Considering the potential benefits to an economy adopting technologies, it is important to investigate the current policy environment and how legislators change it. For this, we analyse the South African policy environment, as it will likely be the gateway for electrification of the road transport sector for the rest of Southern Africa.

The South African government has identified the need for policy intervention to transform the current ICE manufacturing plants to new energy vehicles (NEVs), which EVs fall under, with the ultimate goal of creating a policy environment that will enable South Africa to become a leader in the manufacturing of NEVs (DTIC, 2021b). This draft green paper sets the foundation for the country's shift to EVs, and the Montmasson-Clair et al. (2020) report for the Department of Trade, Industry, and Competition (DTIC) by TIPS (Trade and Industrial Policy Strategies) gives more insight into the potential avenues to increase EV adoption in South Africa. These mainly hinge on addressing the price disparity between EVs and ICEVs (which can range from 18%, using the latest pricing for the Audi Q8[1] and e-tron[2], and 73% for comparable vehicles from the same manufacturers). One of the primary sources they highlight is the tariffs added to imported vehicles, also highlighted by Chege (2021), where the tariffs on importing a Tesla Model X would nearly double the price of the vehicle. The three options Montmasson-Clair et al. (2020) evaluated are: temporary decreases in VAT and/or excise duties, preferential treatment for EVs manufactured in the EU, and lower interest rates for financing EVs. They also consider possible policy interventions for public transport and a more detailed plan for increasing local production of EVs and EV components.

Before getting into the details of these policy interventions, it is important first to detail the current policy environment, specifically how current legislation forms a market barrier (as outlined by Chege (2021)). They note that the low- to middle-income groups in South Africa (that can afford vehicles) typically purchase vehicles between R150 000 and R350 000 ($10 000 and $23 333 at R15/USD), which is far below the cheapest new electric vehicle on the market starting at R694 600 (or $46 306 at R15/USD for the Mini Cooper SE[3] as of July 2022), nearly double the upper limit. Chege (2021) also highlights the problem with the limited options for EVs, even once an individual can afford them. This will likely become less of a problem as more manufacturers import their EVs. However, manufacturers are also likely to look to the sales of EVs currently on the market before deciding to launch their EVs in a new market.

Another major issue discussed above is the high import duties on EVs, which are currently at 25%, whereas busses and heavy commercial vehicles are taxed at 20%, and ICEVs at 18% Chege (2021). EVs are also currently classified as luxury goods, which could result in additional ad valorem duties. Currently, EVs and HEVs average 17% levied (Chege, 2021), while manufacturers of ICEVs produced in South Africa may qualify for a rebate (DTIC, 2021a) under the Automotive Production and Development Programme (APDP). This can further increase the price disparity between ICEVs and EVs from the same manufacturer. The previous iteration of the APDP was also used to motivate against reducing the excise duties on EVs in 2018, while vehicles from the EU with an engine size below 1000cc are zero-rated (Montmasson-Clair et al., 2020, Table 3, p. 31). There are discussions to increase the latter and reduce the ad valorem duty on EVs, while BMW applied for EVs to be zero-rated for

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[1] https://www.audi.co.za/dam/nemo/za/prices/q8//July-2022/Audi-Q8_July-2022.pdf [Accessed: 26 July 2022]

[2] https://www.audi.co.za/content/dam/nemo/za/prices/e-tron/July-2022/Audi-e-tron-July-2022.pdf [Accessed: 26 July 2022]

[3] https://www.mini.co.za/content/dam/MINI/marketZA/mini_co_za/New-LCI-Pricelist/727706_MINI_Cooper_SE_June_2022.pdf.asset.1655810000067.pdf [Accessed: 27 July 2022]

three years and then increased to 10% to promote the adoption of EVs (Chege, 2021). Chege (2021) also highlights the risk posed by the lack of clear policy regulations for the future, which is what the automotive green paper (DTIC, 2021b) seeks to address. The last barrier Chege (2021) highlights are the lack of sufficient skills in the entire value chain; however, this can easily be rectified by manufacturers providing training to workers in relevant sectors, say, emergency services and how to disconnect the battery before cutting into the structure of the vehicle.

The South African government has, however, already started with discussions aimed at addressing these issues, with the Green Transportation Strategy for South Africa: 2018-2050 (GTS) (DoT, 2018) and South African Automotive Masterplan (SAAMP) (DTIC, 2018), which highlights the role EVs can play in mitigating the transportation sector's carbon footprint (also highlighted in World Bank Group, 2022) and how the EV market in South Africa can be developed. The SAAMP deals with more general automotive manufacturing goals, of which the updated APDP forms a part. At the same time, the GTS delves into EVs and their potential in the South African market.

Montmasson-Clair et al. (2020) provide more details for the potential avenues the South African government can take to increase EV adoption, and Montmasson-Clair (2022) consider the inclusive rollout of EVs. As mentioned above, Montmasson-Clair et al. (2020) consider three aspects: passenger EV rollout, EVs in public transport, and increased local manufacturing for the EV value chain. We have already discussed the three main financial interventions Montmasson-Clair et al. (2020) propose for increasing EV adoption for passenger use. They also highlight the importance of implementing measures that would be socially acceptable in order not to create a negative connection with EVs (say, providing lower interest rates to EV buyers would initially be a regressive policy). Other policies consider waiving toll and vehicle registration fees, and non-financial policies consider restricting ICEVs to certain areas, dedicated EV lanes and parking and bundling solar solutions with EVs. However, only conduct a cost-benefit analysis for the three central policies to reduce the initial capital cost of EVs. The recommendations for the electrification of public transport also aim to address these and electrify municipal buses (Montmasson-Clair et al., 2020). Lastly, to increase the local production of EVs in South Africa, Montmasson-Clair et al. (2020) recommend policies similar to the updated APDP to include EVs and reduce the import duties on batteries and promote local research and development (and eventual production) of EV batteries.

Montmasson-Clair (2022) recommends a dual-sided approach to promote inclusive EV adoption. Firstly, offering cash incentives (reducing the purchase price of HEVs, PHEVs, and EVs), particularly for entry-level EVs. Grants between R20 000 and R80 000 ($1 333 and $5 333 at R15/USD), depending on the vehicle type, are required to bridge the gap between NEVs and ICEVs in the lowest two quintiles. Montmasson-Clair (2022) shows that consumers in these lower two quintiles are price elastic, while quintile 3 is unitary elastic and above that price inelastic. The second recommendation of Montmasson-

Clair (2022) is to electrify public transport, where they recommend that the government-assisted taxi recapitalisation program be extended to EV minibus taxis, as well as the amount for scrapping the old vehicle be increased to R162 000 ($10 800 at R15/USD) or double the maximum for purchasing an ICEV minibus taxi, in addition to low-cost financing. Non-minibus taxi public transport should also be supported through innovative business – and financing models (Montmasson-Clair, 2022).

The policy environment in South Africa still has a long way to go before EVs feel welcomed. Apart from the high initial capital costs, other structural issues also need to be resolved. Firstly, rolling blackouts, as Montmasson-Clair (2022) mentions that EVs are likely to be charged at home instead of public chargers, and with the electrical grid under pressure due to various factors, the uncertainty regarding electricity supply is expected to be a psychological barrier to EV adoption. Secondly, the poor road infrastructure could negate any savings on running costs EVs have over ICEVs (in particular, excessive wear on vehicle tyres and suspension) due to the heavier EVs and poor road quality in some regions of the country.

4. Data and Methodology

This section will cover the data, data sources, and transformations, as well as the methodology that was followed.

4.1 Data

We have two data types, EV registration and population. EV registration data (as a measure of sales) for Europe is obtained from the European Alternative Fuels Observatory for 29 European countries[4]from 2008 to 2021. The EV registration data for South Africa can be found in Chege (2021). The population data is obtained from the World Development Indicators. Table 1 details the sources and the data transformations, where applicable.

Table 1: Descriptive statistics and data sources

Description	Source
EU electric vehicle sales	European Alternative Fuels Observatory. Available at: https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road
South African electric vehicle sales	Chege (2021)
Population	World Development Indicators. Available at: https://databank.worldbank.org/source/world-development-indicators#
Per capita EV sales	Author creation. Electric vehicles Sales/Population x 1000000

[4] Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovenia, Spain, Sweden, and United Kingdom.

4.2 Methodology

Given the policy stumbling blocks discussed in section 3, it is important to compare the South African EV market with that of a more mature market, in this case, Europe. This will give stakeholders a rough timeline to amend and introduce new policies to accelerate EV adoption in South Africa. We consider two measures for EV adoption: EV sales and per capita EV sales (both are defined above). This allows us to look at the market in absolute terms and consider the effect of population size.

To this end, we compare the South African EV market with that in Europe by looking at how far we are lagging behind the European market (in years) and at the yearly five-point summary values. This will provide five estimates for the years we lag behind the European EV market to reach their minimum, Q1, Median, Q3, and Maximum. The time South Africa lags behind Europe would then be the number of years it takes to reach the sales of Europe for the five different scenarios. This presents an issue that we do not have a long enough time period to make the comparison.

To overcome this issue, we first take 2021 as the reference year for the European market, simply as these are the latest values available, and forecast the demand for South Africa using a logistic S-curve (detailed in equation 1). S-curves have been shown to closely follow data in adopting new technologies and have been used to model this adoption in the literature (Denning and Lewis, 2020). For a detailed discussion on modelling diffusion of technology or information, see Geroski (2000).

$$S(t) = S_0 + (S_T - S_0) \times \left(\frac{1}{1+e^{-k(t-x_0)}}\right)^a, \tag{1}$$

Where $S(t)$ gives the market share of EVs relative to ICEVs at time 0, S_0 (or $S(t=0)$) gives the initial share (at time $t=0$), S_T (or $S(t=T)$) gives the end share (at time $t=T$), and as a result, t gives the time intervals ($t = 0 \dots T$). a and k are shape parameters, both determining how soon the fast growth starts or the initial kink (comparable to the hockey stick phenomena in growth theory) and restricted to positive values. x_0 is the inflexion point or the point where the rate of growth changes from positive to negative (i.e., second derivative equal to 0). We parameterise a and k to fit the actual data for South Africa from 2013 to 2019 by setting the initial share of zero in 2012 ($S_0 = 0$) and 40% in 2050 ($S_T = 0.4$, World Bank Group, 2022), the inflexion point is set to 24 years after $t = 0$, i.e., 2036. The two shape parameters then take the values of 1.79 and 0.3 for a and k, respectively.

Figure 1a shows the forecasted shares of EVs to ICEVs, and Figure 1b shows the forecast and actual shares for the period 2012 to 2019 to show the fit of the forecasts to the data. To obtain values for EVs, we fit a linear model to the stock of ICEVs (see Figure 2) and multiply this with the EV shares to obtain a forecast of EV stock, with the first difference then representing EV sales.

Figure 1a: South Africa EV/ICEV share forecast

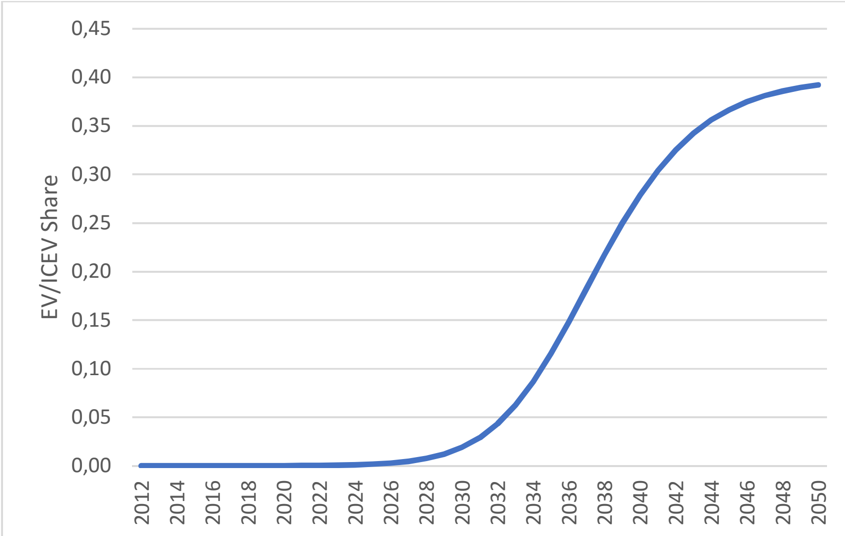


Figure 1b: South Africa EV/ICEV share forecast

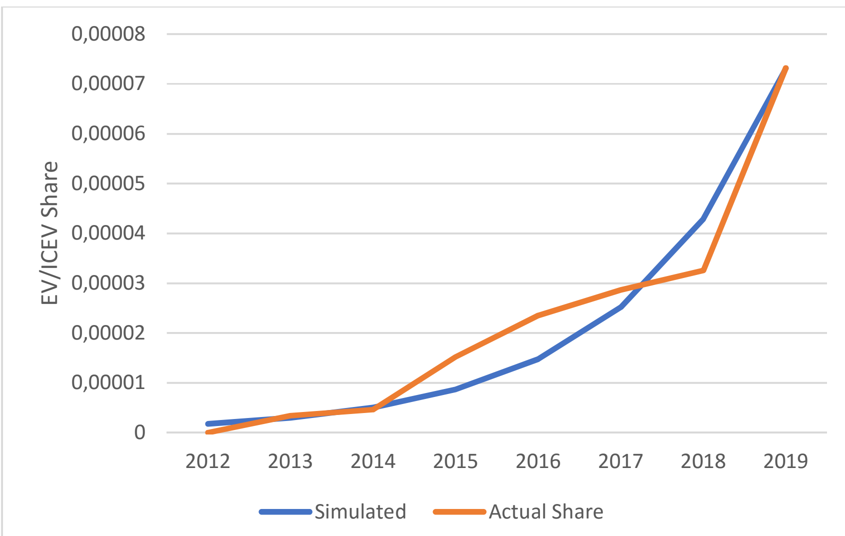
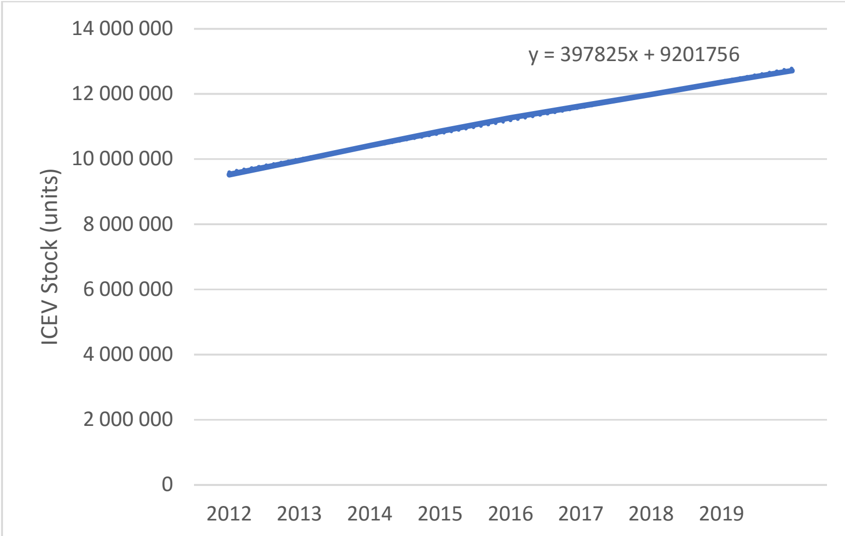


Figure 2: ICEV Stock with a linear trend fitted



5. Results

Table 2 shows the EV registrations in South Africa and the five-point summary values (minimum, 25th percentile, mean, 75th percentile, and maximum) values per year of European EV registrations. Despite EV sales only starting in 2013, South African sales were between the 25th percentile and median European sales until 2016, apart from 2014. After that, a significant and steady decline in EV sales is visible in the data before spiking again in 2019. There could be multiple reasons for this, either due to a lack of variety or vehicle-specific characteristics. Alternatively, it could be due to the macroeconomic environment. Answering this question is beyond the scope of this paper, and we leave this to future studies to investigate. It is important to consider what effect the size of the population has on adoption. As a result, Table 3 shows the EV sales per 1 000 000 people for both South Africa and Europe. This paints a different picture, where South Africa's adoption was between the minimum and the 25th percentile of European countries for the entire period.

In Tables 2 and 3, the values fluctuate and do not exhibit a constant upward trend; this shows that more European countries are starting to adopt EVs and did not all start simultaneously. For 2008, all five values are the same, as only Norway had EV sales this year.

Table 2: EV sales comparison between South Africa and Europe

Year	South Africa	Europe				
		Min	Q1	Mean	Q3	Max
2008		243	243	243	243	243
2009		1	2	21.5	31	145
2010		2	6.5	26	79.5	144
2011		9	10.5	30	351.5	1828
2012		1	19	92	585	5663

2013	34	3	50.5	473.5	1737.5	8583
2014	14	14	75	191.5	1341.5	17999
2015	117	1	102.5	401	2748	25551
2016	100	11	49	231	2211	23878
2017	68	7	71	484	2659	32836
2018	58	1	145	768	5155	46111
2019	154	8	579	1718	8886	61696
2020		36	678	3673	17561	191379
2021		52	1688	4624	33379	351332

Table 3: EV registrations Comparison between South Africa and Europe per capita

Year	South Africa	Europe				
		Min	Q1	Mean	Q3	Max
2008		50.96	50.96	50.96	50.96	50.96
2009		0.02	0.18	1.81	3.00	30.03
2010		0.07	0.97	2.24	5.57	13.39
2011		0.90	3.38	7.95	34.14	75.19
2012		0.09	6.09	28.05	52.67	848.05
2013	0.63	0.27	11.44	41.93	88.26	1550.31
2014	0.26	2.42	8.09	39.22	162.62	3503.64
2015	2.11	0.14	27.04	55.94	186.16	4924.44
2016	1.78	1.54	9.70	37.24	180.67	4561.64
2017	1.19	1.53	12.32	74.07	258.90	6222.51
2018	1.00	0.76	20.64	85.32	436.02	8680.67
2019	2.63	1.77	38.56	277.25	740.76	3557.02
2020		8.22	131.68	546.30	1789.31	14264.22
2021		8.00	207.70	801.14	3726.88	21007.08

Figure 3 shows the EV demand forecasts in South Africa, using equation 1, and the 2021 five-point summary values for Europe from Tables 2 and 3 respectively. These figures show when South Africa's annual EV sales are expected to be that of Europe for 2021 for the various levels. Interestingly, South Africa already matched Europe's minimum annual sales in 2016, while it is expected that they will match Europe's 25th percentile in 2022 and median sales in 2024. However, it will take South Africa until 2028 and 2033 to match the 75th percentile and maximum sales of 2021, respectively. EV sales in South Africa are expected to peak in 2038, as it starts to decline, as is the nature with an S-curve. Again, accounting for the size of the population, South Africa will match the minimum, 25th percentile, median, and 75th percentile of Europe in 2021 in 2019, 2026, 2028, and 2032, respectively. Note, that South Africa never actually matches Europe's maximum per capita sales in the 40% market share in 2050 scenario from World Bank Group (2022), as sales peak in 2038, as described above. To obtain these estimates population was forecast using the same technique as for ICEV sales (see Figure A1 in the

Appendix). The per capita results paint a more realistic picture of what to expect for the South African EV market.

Figure 3a: Years lagging: South Africa EV sales forecast and 2021 five-point values for Europe

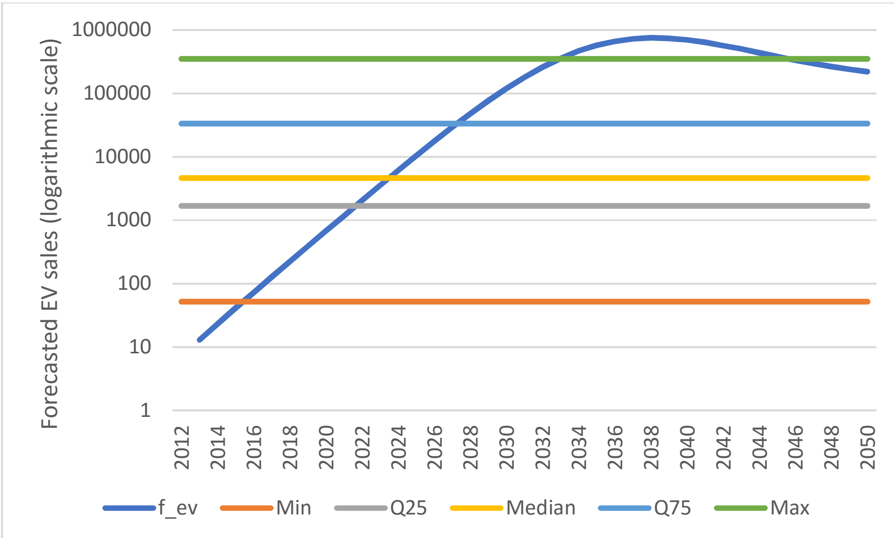
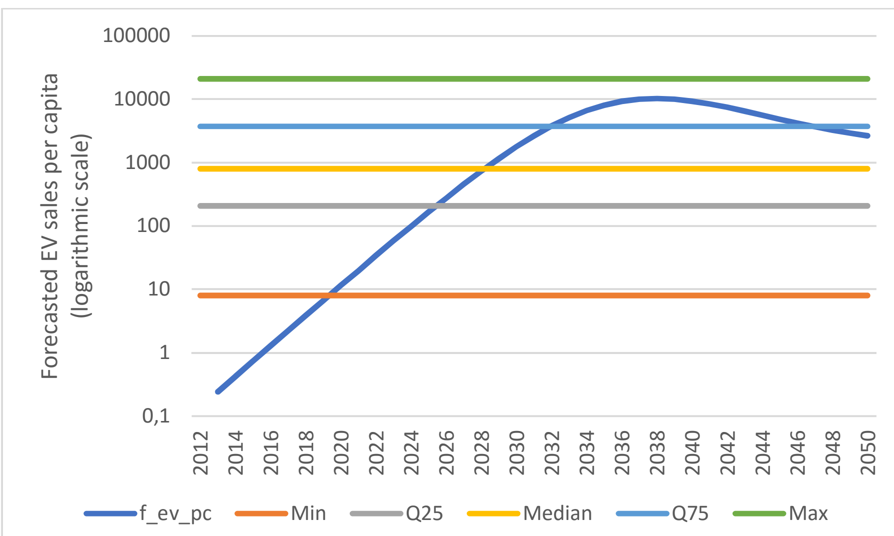


Figure 3b: Years lagging: South Africa EV sales per capita forecast and 2021 five-point values for Europe



Simply considering the European sales in 2021 tells only part of the story; as such, we also consider this comparison dynamically. To do this, we use the sales of Europe from 2008 to 2021 to examine how this gap changes over time. The results are shown in Figure 4a for EV sales and Figure 4b for EV sales per 1 000 000 people. A positive (negative) value indicates that South Africa is lagging (leading) Europe with that many years. We see that years South Africa is lagging behind changes year on year, but that in general, the trend is upward, indicating that they are falling further behind Europe. What is more interesting is the fact that the number of years South Africa is lagging behind Europe's 75th percentile and maximum starts to increase exponentially, which is more indicative of the pace at which some European countries are adopting EVs. Note, in Figure 4b, the maximum plateaus at 30, this is due to South Africa never matching the Europe's maximum per capita sales, as indicated in Figure 3b.

Figure 4a: South African market years lagging change over time for Europe five-point values

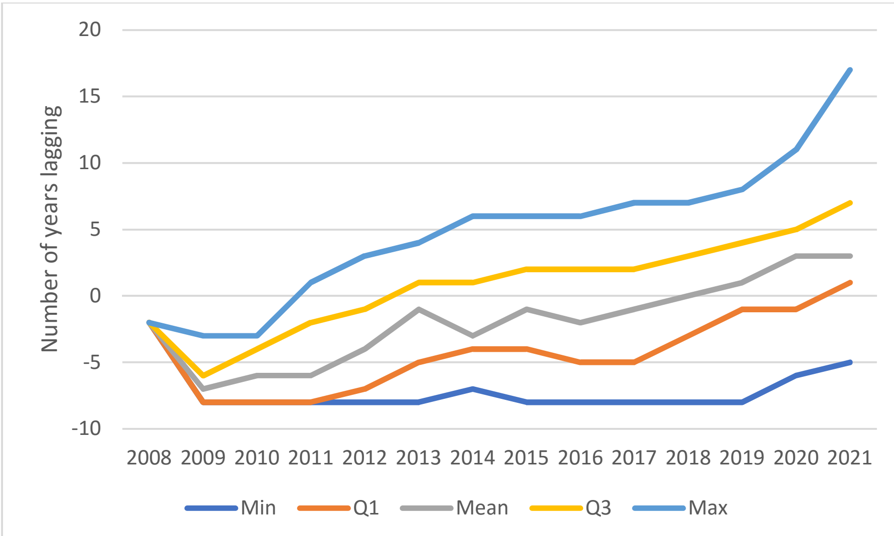
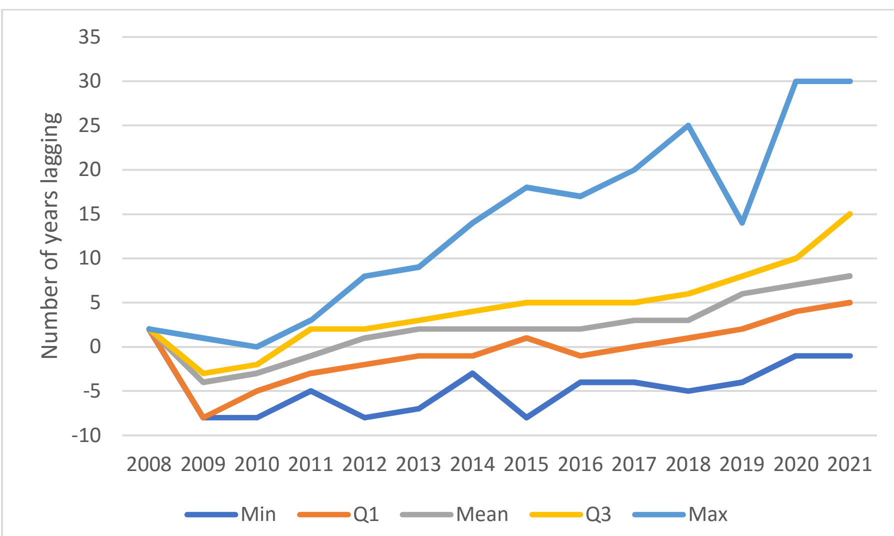


Figure 4b: South African market (in per capita terms) years lagging change over time for Europe five-point values



7. Discussion and policy recommendations

Ou et al. (2019) compare EV incentives and their effectiveness in China and the US. They find that there is a change from demand-pull incentives to supply-push incentives, which are more fiscally efficient at increasing EV adoption. This is a concerning fact, especially in the face of results showing how significant the impact of financial incentives on EV adoption was. This is even more concerning given that over 40% of respondents in Moeletsi (2021b) said they would "very likely" purchase an EV if there were some form of financial incentives (albeit a purchase subsidy or reduced (or exception) from vehicle registration fees and toll fees). Vehicle registration and/or toll exemption policies, from a practical aspect at least, might be feasible in the short-run; however, they will likely lead to quicker infrastructure degradation due to the large weight difference between EVs and ICEVs, 140kg in the case of the cheapest available EV in South Africa.[5] This might sound marginal. However, this EV only has a claimed range of 215km. The weight penalty for larger EVs with longer ranges can be much more extensive. This effect will also be amplified if many "marginally heavier" vehicles drive over an imperfection on the road. Purchase subsidies are much less likely to gain political traction, given the high inequality in the country. They would be seen as regressive, as much-needed tax revenue would be directed towards the upper-middle and high-income groups since they are likely the first adopters of EVs due to the price difference between comparable EVs and ICEVs. Subsidising only the households in the lower portion of the income distribution might do more harm, as this might cause individuals to transition away from public transportation.

It is in this instance where the results of Ou et al. (2019) should instead be taken under consideration. Instead, implement policies that would reduce costs on the supply side of the equation; this is likely the best route for South Africa to take (and they are already making inroads with the policies that are in draft form at the time of writing, see: DoT (2018), and DTIC (2018, 2021a,b)). These policies could encourage foreign direct investment in the automotive manufacturing sector, where the country already has manufacturers with plants in various regions, which can be adapted to produce EVs in conjunction with ICEVs. At the same time, the latter is being phased out. World Bank Group (2022) also modelled biofuels to transition public transport to EV buses and taxis. This could be extended to all vehicles in the initial transition path, meaning that at least a portion of the tailpipe emissions would be from biomass instead of fossil fuels. Some policies to consider would be to incentives companies to produce EVs in South Africa, say, temporary tax reductions, reduced import tariffs on batteries and EVs in general, and incentives for the production, installation, and maintenance of charging infrastructure (as Narissimhan and Johnson (2018) showed its importance while the market is in its infancy).

This study's novel contribution (in this literature) is in approximating the lag between the South African and the EU EV markets. Using the 75th percentile and maximum EV sales of the EU in 2021, South Africa is lagging by between 5 and 10 years, with this gap increasing over time. This can sound disheartening; however, it should be considered a blessing. With EV technology still progressing at a tremendous pace, South Africa can focus on creating a policy environment that is conducive to EV

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[5] The weight of the electric Mini is 1365kg, while the ICEV Mini Cooper S weighs 1225kg (see: https://www.mini.co.za/en_ZA/home/range/mini-3-door-hatch/mini-3-door-hatch-models-and-options.html [Accessed: 29/11/2022]).

sales, but more importantly, EV production. The latter will ensure that the automotive sector still contributes to the country's exports (12% of current exports).

The transition to EVs cannot be had without mentioning the need to transition to cleaner energy (but electricity specifically) sources, as Tongwane and Moeletsi (2021) notes in their study of the mitigating carbon potential of EVs in South Africa. They also mention the need for South Africa to ensure that current electricity demand can be met, not negatively influencing the transition to EVS. As such, the country should focus on the just transition to renewable energy sources, as the mitigating carbon potential (unsurprisingly) depends entirely on the grid being clean (or near clean).

Future studies can look at estimating the potential incidence of EVs on the grid by forecasting the demand for EVs and the effect of different policy incentives (demand side and supply side) on the economy could be. Another area for future research to explore would be the effect of EV adoption on public transportation use, especially in countries with large purchase subsidies, and the associated impact on well-to-wheel emissions.

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Appendix A