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A Study on Electric Vehicle Footprint in South Africa

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Abstract: There has been a progressive global increase in the usage of electric vehicles in this dispensation. This is mostly due to the need to decarbonise the transport sector and mitigate the concerns of climate change and depleting oil reserves of which South Africa is not an exception. In fact, South Africa is the country with the highest CO_2 emissions in Africa and can reduce its carbon footprint by embracing green mobility. Compared to the internal combustion engine (ICE) market, the electric vehicle (EV) market in South Africa is still in its early stages, with limited local production and usage since its introduction to the country's automotive sector in 2013. Therefore, in this study, the usage of EVs in South Africa, along with adoption rates and challenges were carried out to make a stronger case that would offer a better pathway for increased EV adoption in the country. It has been discovered that the slow adoption rate of EVs is due to factors such as EV procurement, ownership costs, vehicle parts, safety issues, battery technology, tax and import duties, load shedding, and availability of charging stations. This paper also provides insights into government policies, funding, and other efforts that can support EV adoption in the country through the analyses of primary and secondary data. The proposed strategies include the introduction of tax rebates on imported EVs, local production of EVs and their vehicle parts, retrofitting ICE vehicles to EVs, and science-informed strategies to transition from ICE to electric vehicles. Furthermore, more renewable energy grid integration and renewable energy-powered EV charging stations would also provide support for the energy required to power EVs even during load shedding. Preliminary findings from the survey also suggest that the local production of EV components and government-sponsored training programmes on various EV skills are crucial for increasing the adoption rate of EVs in the country.

Keywords: electric vehicles (EVs); battery electric vehicle; greenhouse gas emissions; vehicle to grid; internal combustion engine (ICE) vehicles

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1. Introduction

Awareness of the emissions of greenhouse gasses (GHG) associated with burning fossil fuels for energy needs has resulted in a cautious effort by different government and private organizations to seek green alternative sources such as renewable energy sources [1,2]. The present change in the climatic condition due to GHG emissions has reached a dire state. The results are easily noticed in the increase in global atmospheric temperature due to global warming, bush burning, and melting of icebergs which usually leads to the increase in ocean level. Therefore, urgent policies for preventing and slowing down the worsening impact of climate change are needed especially in a country like South Africa with highest CO_2 emissions in Africa and 12.1% CO_2 emissions from its transport sector [3–6].

As concerns over the environment, energy security, and escalating oil prices grow, there is a solid need to transform the transportation sector and make it more sustainable. Furthermore, with the price of oil rapidly peaking in the past years, many countries across the globe are increasingly acknowledging electric vehicles (EVs) to become the economic and environmentally friendly choice for transportation. Automobile experts have already tipped it as being the intermediate solution to these problems facing the transport sector.

Moreover, with the continual development of EV technologies, it will soon stand as a better competitive means of transport compared to conventional fossil fuel vehicles [7–9].

Analysis of the South African automobile industry indicates a steady annual growth trajectory. Data reveal a notable surge in vehicle sales, with figures increasing by 11.8%, from 446,215 units in 2020 to 499,087 units in 2021. This surge outstrips the global production increase in Internal Combustion Engine (ICE) vehicles, which stood at 3.1% in 2021 [10].. The United Kingdom (UK), which is responsible for over 25 per cent of all South African vehicle exports, has announced plans to prohibit the sale of new gasoline and diesel automobiles by 2030 [11,12]. The statistical data from South Africa's automotive sector shows that sales of vehicles contribute around 6.4% of the total gross domestic product (GDP) with an average of 387,125 exported vehicles amounting to R148 billion to 151 nations. Also, South Africa is positioned 22nd in the global hierarchy of vehicle production, boasting a 0.65% share of the worldwide vehicle production market. The growth strategies of South Africa's automotive sector are oriented towards achieving profound integration into the global automotive sphere by providing for 1% of the global vehicle output, amounting to 1.4 million vehicles annually by 2035. The overarching objective is to escalate production which will significantly enhance the country's standing in the global vehicle production rankings. The leading vehicle brands based on the number of units sold is Toyota with 12,704 units sold as of August 2023. Second on this is Volkswagen Group with 6316 vehicles sold. Suzuki, an emerging vehicle brand occupied the third position, with 4478 units sold during the same period. Of all the factors influencing vehicle purchasing decisions, economic variables such as interest rates, unemployment rates, disposable income, and exchange rates stood out. Additionally, rising fuel prices, inflation, and a possible inclination towards used vehicles further impact the dynamics of the automotive market.

Therefore, South Africa needs to embrace the usage and production of EVs if it will become one of the world's leading exporters of green automobiles as it is with ICE vehicles [13–15]. As time goes on, alternative fuel vehicles, especially electric and hybrid electric vehicles, will become part of government policies worldwide [16]. In addition, the newly published government policy in South Africa has laid out approaches to improve the sales and production of locally made electric vehicles over the next 10 years [17,18]. The gradual importation of 92 electric vehicles into South Africa in 2020 represents a small percentage of 0.02% of the total sales in the domestic automotive market [19]. This latest development shows that the South African automobile industry, though slowly, is gradually gearing towards the sale of EVs.

Many researchers have contributed their knowledge on the usage of EVs in South Africa, such as Tongwane et al. [20], who provided the status of EVs in South Africa and offered more insight into carbon footprint mitigation. However, many of the data shown in the paper are outdated. The work in [13] researched the barriers to EV adoption in the Central province of Gauteng, using different questionnaire data. Also, in [21], the author gave a future policy and technological advancement that could enhance the general adoption of EVs in South Africa. On the technical side, Calitz in [22] performed an optimized fleet of EVs up to the year 2040, and thus, quantified the impact of the future charging EVs with consideration to the cost and portfolio of electricity generated in the country. They posited that the current growth of charging infrastructure will not meet the charging demand come 2040, and thus, additional capacity will be needed. While these findings offer significant insights, it is imperative to acknowledge their limitations in fully elucidating the awareness, adoption, and challenges surrounding electric vehicles (EVs) usage. Nevertheless, they serve as crucial contributions to EV research, not only by the authors involved but also by providing diverse technical inputs aimed at enhancing the EV industry in South Africa. By delving into various aspects such as performance analysis, grid integration, control mechanisms, and real-world interactions, these studies provide a multifaceted understanding of EV deployment and utilization. This deeper comprehension is instrumental in addressing barriers to EV adoption, optimizing infrastructure, refining regulatory frameworks, and fostering sustainable growth within the EV sector. Thus, while recognizing their significance, further research and collaborative efforts are essential to fully harness the potential of EVs and propel advancements in South Africa's automotive landscape.

Henceforth, this paper undertakes an evaluation of the prevailing state of electric vehicle (EV) usage in South Africa, encompassing a comprehensive discussion of the challenges encountered and potential solutions to mitigate them. An extensive examination of secondary data projecting various facets of EV utilization and associated revenues up to the year 2028 was conducted. Additionally, primary data derived from questionnaire responses was meticulously analyzed employing the Statistical Package for the Social Sciences (SPSS). These analyses aim to elucidate the adoption rate of EVs and provide an extensive forecast of their future usage trends within the country.

This paper is organized as follows: concerns about the usage of internal combustion engines are first discussed, and then the usage of EVs in South Africa is discussed. Challenges to EV adoption, EV configurations, and focus areas for EV South Africa are then discussed. Future trends and research gaps are then discussed, followed by the conclusion.

2. Concerns About Greenhouse Gas Mitigation Potentials

South Africa is Africa's largest emitter of greenhouse gasses (GHGs), and 12th globally. The country's total CO_2 emissions in 2019 was 466.92 Mt, which later reduced to 435.93 Mt in 2021 perhaps due to COVID-19 movement and operational restrictions around the country [20,23] (Figure 1). These emissions are predominantly due to a high dependence on coal for energy generation in the country [24,25].

According to the 2019 GHG emissions by industry in Figure 2, the road transport industry produced 56.14 Mt CO_2e in 2015 and 58.54 Mt CO_2e in 2019. Motor vehicles account for the majority of road transport emissions in South Africa [26–28]. The global CO_2 emissions totalled 35 Gt in 2020, a 5% decrease from the previous year owing to the effects of COVID-19. That year, the electricity industry accounted for 37% of CO_2 emissions, making it the single biggest source of CO_2 emissions. The fundamental explanation for this is that coal, the most carbon-intensive fossil fuel, powers the majority of global electric energy production. Despite the reduction due to the COVID-19 lockdown, worldwide coal emissions in 2020 remained at 14 Gt CO_2. After the power-generating industries, the transportation industry is the second-largest source of CO_2, accounting for 20% of emissions in 2020. Passenger automobile emissions accounted for 41% of the total value. Although there are other sources of greenhouse gas emissions, such as deforestation, land clearing, and residential or commercial usage of fossil fuels for heat, transport and power industries account for the highest contribution to GHG emissions [29,30]. Therefore, the adoption of EVs can potentially reduce the over-reliance on fossil fuel vehicles. This further means that the use of renewable energy is to increase in supporting EV charging. However, renewable energy is intermittent and volatile. Solving this problem requires the deployment and use of energy storage devices [31].

The increased carbon footprint from EVs primarily arises from the extraction and processing of minerals used in EV batteries and the production of power cells. However, accurately assessing the specific magnitude of this carbon difference when electric vehicles are sold and pinpointing the moment when they reach a balance between emissions can differ significantly. This situation is dependent on a range of factors, such as the electric vehicle's battery capacity, the gasoline vehicle's fuel efficiency, and the origin of the electricity utilized for charging the electric vehicle. Furthermore, the selection of metals within the electric vehicle's battery and the quantity of aluminum or plastic employed in the vehicle also contribute to evaluating the vehicle's comprehensive ecological footprint [32–34].

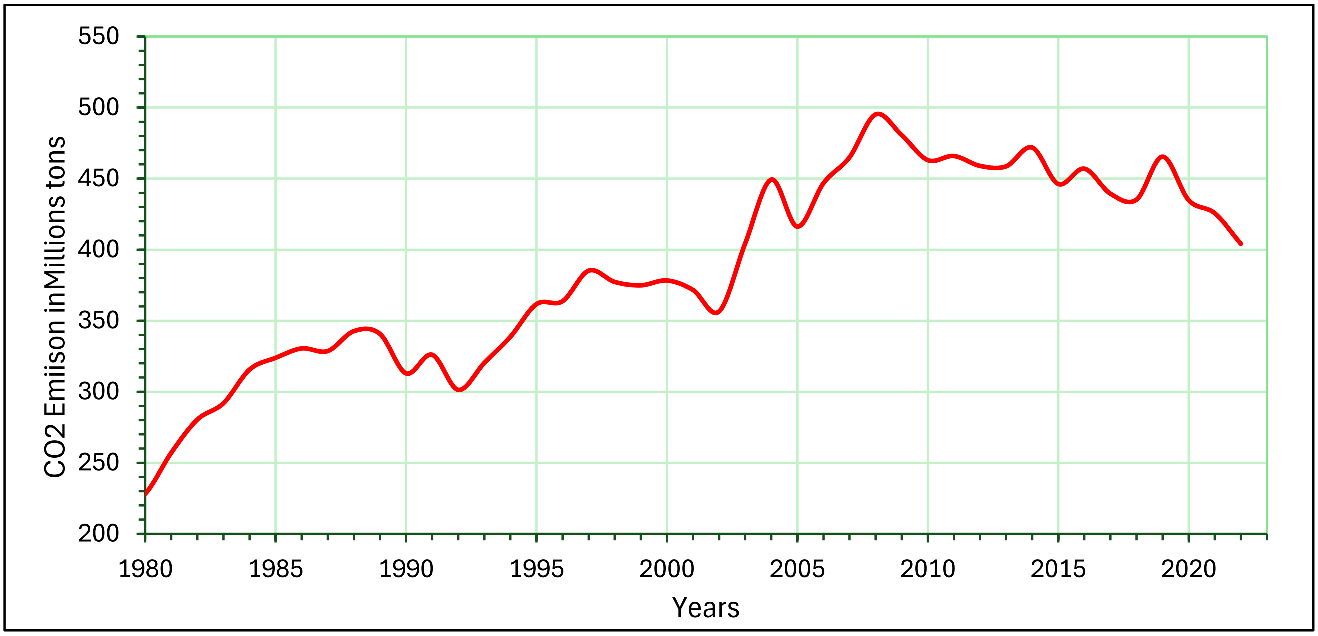


Figure 1. South Africa CO_2 emission [35].

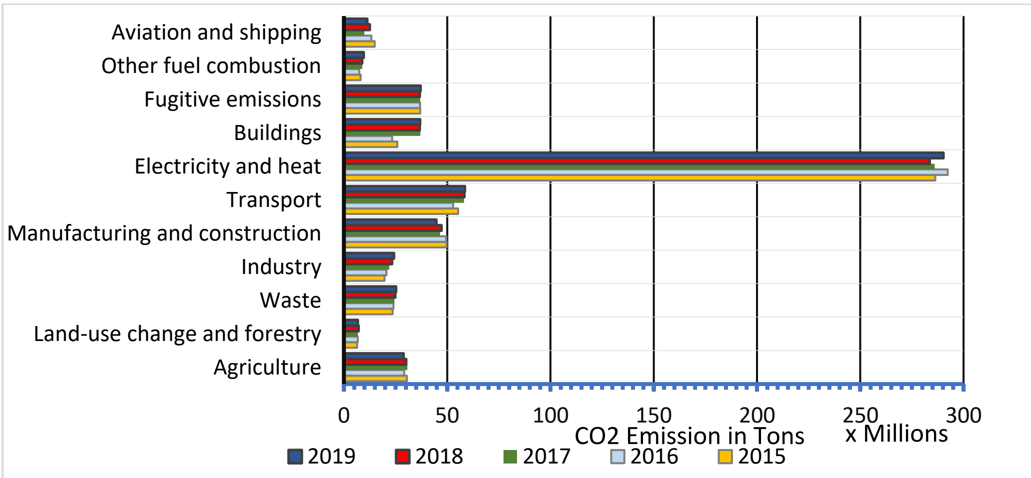


Figure 2. Greenhouse gas emissions by industry [35].

3. Electric Vehicle Usage in South Africa

The first EV in Africa was first recorded in South Africa in the 1970s [36,37]. However, because the country's industrial growth was insufficiently supported, it faded away until 2013, when it was revived [20]. By the end of December 2018, South Africa had over 1000 EVs and 100 charging stations [21,38]. The initial plans in South Africa are primarily for private passenger and light commercial vehicles, despite efforts in wealthy nations to create EVs for all kinds of transportation; however, current plans encompass different configurations of EVs as shown in Figure 3 [39] and described as follows:

- Battery electrical vehicle (BEV): This is alternatively referred to as an All-Electric Vehicle (AEV), and it operates solely using a battery pack and an electric motor. Thus, requires no ICE. Electric trains/tractions, bikes, buses, trucks, etc., are a few BEV examples. The usage of these types of vehicles is slowly increasing in South Africa [40].
- Hybrid electrical vehicle (HEV): To boost fuel efficiency without compromising the performance of an electric vehicle brings the emergence of HEV. This type of vehicle

requires an ICE and one or more electric motors; therefore, it is not counted as a zero-emission EV design. Mechanical energy generated in the ICE is used in charging the battery, which is later used to power the HEV. There is no means of plugging the battery of a hybrid electric vehicle into the grid or power source; instead, the battery is charged through the internal combustion engine and regenerative braking. Opting for a smaller engine in this setup would offer significant benefits. Furthermore, the battery can minimize engine idling during stops and supply power to auxiliary systems.

- Plugin hybrid electric vehicles (PHEVs): The plugin hybrid EV is similar to the HEV, but there is an availability of externally charging the battery by plugging it into an external power source like the grid. In PHEVs, the ICE operates using petrol or any fossil fuels, whereas the electric motor derives power from the batteries. The PHEV batteries can be charged through a power outlet, a charging device, or by utilizing regenerative braking. Generally, the vehicle operates on electric power until the battery's charge depletes significantly, after which it switches to using the internal combustion engine.
- Fuel cell electric vehicle (FCEV): The FCEV employs a fuel cell stack, which is a collection of electrodes that utilize hydrogen and oxygen to generate electricity. The generated electricity is then used to power the electric motor. Unlike other electric vehicles, FCEVs produce their own electricity using hydrogen fuel cells rather than relying solely on a battery. While vehicle makers have the potential to create a FCEV that allows plug-in charging of the battery, the majority of current FCEVs utilize the battery for various purposes. These include recapturing energy from braking, providing extra power during short bursts of acceleration, and enhancing the consistency of power supplied by the fuel cell. Additionally, the battery offers the flexibility to idle or deactivate the fuel cell during situations of low power demand. In addition, FCEVs are subject to progressive performance degradation over extended operational periods, which poses significant challenges to their reliability and cost-effectiveness. This degradation impacts key performance metrics, including efficiency and output power, while simultaneously reducing the service life of the cells and escalating maintenance and replacement costs. Consequently, the precise prediction of fuel cell performance degradation is of critical theoretical and practical importance [41].

Based on these, there were just 23 hybrid electric vehicles (HEVs) models, 2 battery electric vehicles (BEVs) models, and 10 plug-in hybrid models on the market in South Africa as of April 2020 [42–44]. These values have since increased, with 2021 recording over 869 unit sales of different configurations of EVs, and 3092 sales by April 2022. There are now 13 automotive brands selling over 40 different models of EVs in South Africa. Of these brands, the traditional hybrid electric vehicle recorded the largest sales with 2648 units registered at the end of the second quarter of 2022 [45,46]. There are a few fuel cell electric vehicles (FCEVs) in South Africa which may be due to their high cost, scarce hydrogen fuel stations, and high cost of infrastructure needed for hydrogen fuel cell stations. The data in Figure 4 shows the good improvements in the usage of EVs in South Africa and further gives a projected utilization factor until 2028 [46]. From this plot, a considerable improvement was observed since COVID-19.

The EV sales in South Africa showed a significant year-on-year increase of 431.7% in 2020, up from 896 units in 2021, to 4764 units in 2022. However, this number is negligible as a percentage of total vehicle sales (including ICE), at 0.88%. In the first quarter of 2023, South Africa witnessed a significant increase in EV sales, with 1665 units sold, comprising 25 plug-in hybrids (PHEVs), 232 electric vehicles (EVs), and 1408 traditional hybrids (HEVs), marking an 18.8% surge compared to the first quartile (Q1) of 2022. The Q1 of 2023 EV sales figure is remarkably 86% higher than the entire year of 2021 and a staggering 309% higher than 2019 pre-pandemic sales figures [47].

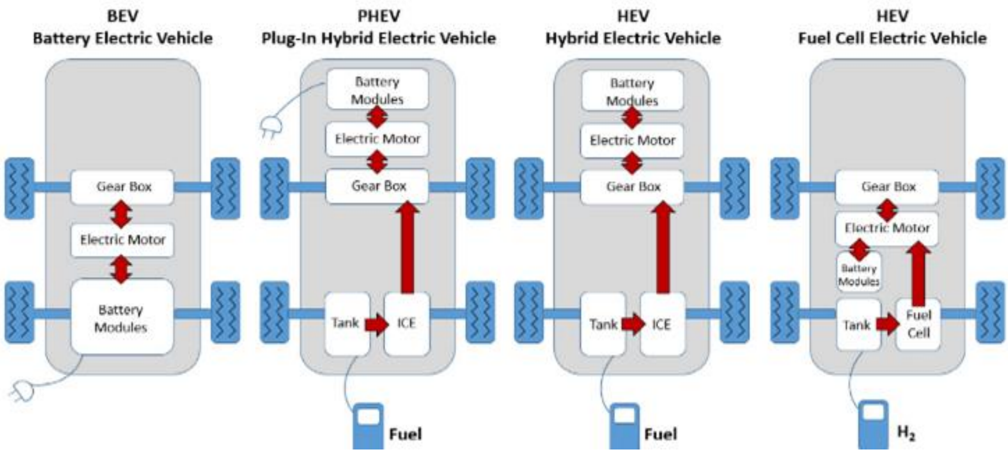


Figure 3. EV configurations [49].

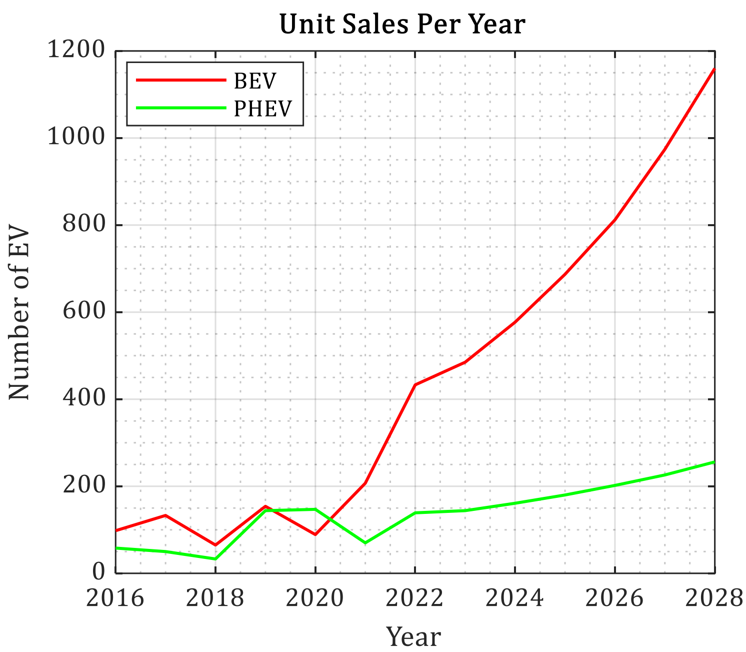


Figure 4. Data on EV usage in South Africa (authors' plot with data obtained from Statista).

Figure 5 illustrates the revenue generated from electric vehicle (EV) sales across Africa, providing a comparative analysis among three prominent countries: Morocco, South Africa, and Egypt, where EV usage is more prevalent. Although South Africa initially led the EV startup scene, it later ceded ground to Morocco. Future projections indicate that while the revenue generated by the EV industry is anticipated to rise to USD 60 million by 2028 for South Africa and approximately USD 98 million for Morocco, these figures remain relatively modest compared to global revenue generation trends, as depicted in Figure 6 [48].

On a global scale, China dominates the revenue generated from EV sales, with an estimated revenue of USD 319 billion in 2024, followed by the United States with USD 82.8 billion. By 2028, the United States is projected to double its revenue generation, while China's forecasted revenue is expected to reach USD 398 billion. European nations such as the UK, Germany, France, and Sweden also feature prominently in the list of top revenue generators through EV sales [48].

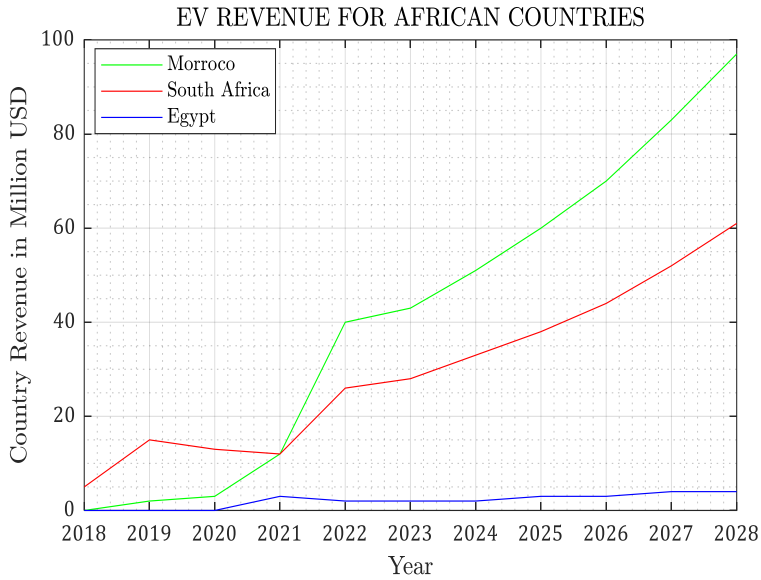


Figure 5. EV Revenue for three African countries (authors' plot with data obtained from Statista).

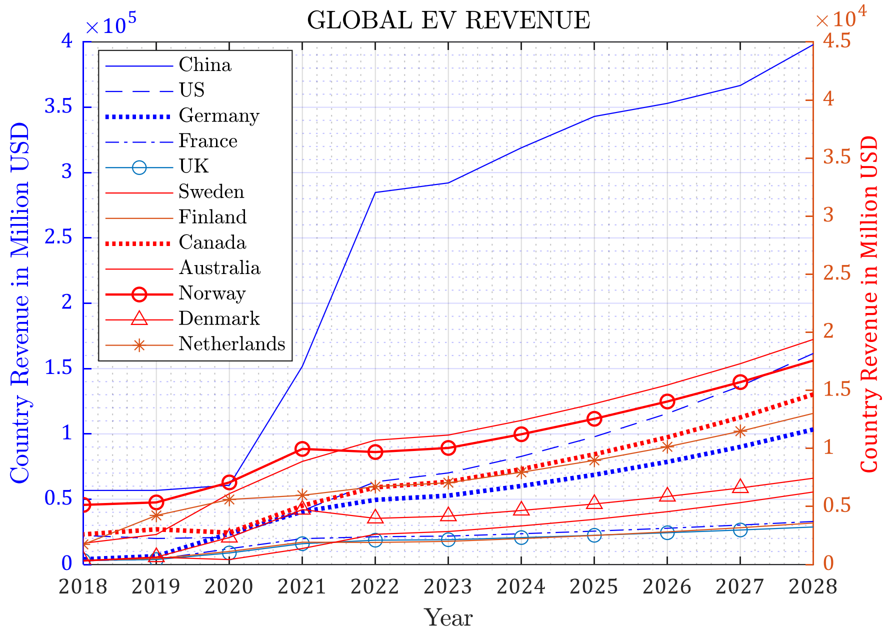


Figure 6. Global EV revenues (authors' plot with data obtained from Statista).

However, this statistic is far behind compared to developed countries like the United States, China, or the United Kingdom (Table 1). Even the actual data on the usage of EVs are lower than the forecast data in South Africa [50,51]. In addition, the statistical data on the usage of EVs already impacted the e-mobility industries in that the projected EV ownership of 3500 units by 2021 was never met. Additionally, the projected number of 14,000 electric vehicles (EVs) expected by 2025, which is three times lower than the potential count achievable through proactive strategies, is improbable given the current rate of growth. However, the European, North American, and Chinese governments failed to meet their goals when they began the electrification of their vehicles. Although the global average growth rate exceeds 30%, substantial endeavours are required for South Africa to possess 145,000 electric vehicles (EVs) by 2025. Since 2015, the objective has been to annually vend a minimum of 3000 EVs. As per the international reference scenario, which considers global trends in EV market adoption, South Africa would only possess 2.4 million EVs by 2040 [52].

Many issues contribute to the country's slow adoption of EV technology, including cost, awareness, a lack of political will, high import duties, and a lack of incentives. In 2022, South Africa, which has the most advanced e-mobility market in Africa, only had around 1000 electric vehicles (EVs) out of a total fleet of 12 million vehicles in the country [46,53].

The South African electric vehicles (EVs) market is projected to experience significant revenue growth, reaching an estimated USD 32.5 million in 2024. This upward trend is anticipated to continue with a compound annual growth rate (CAGR) of 16.93% from 2024 to 2028, culminating in a projected market volume of USD 60.8 million by 2028. Additionally, unit sales in the EV market are expected to reach 1413 vehicles by 2028. The volume-weighted average price of EVs in South Africa is forecasted to be approximately USD 44,000 in 2024. This growing demand for electric vehicles is largely driven by government incentives and increasing environmental awareness among consumers.

Table 1. Global EV and charging stations (selected countries).

Country	Quantity and EV Sales	Charging Stations [54]	Year	REF
United States	≅2.5 million with 1.6 m sold in 2023	100,000 slow and 28,000 fast	2022, 2023	[55–58]
Canada	141,060 with 7.7% of total registered vehicle in 1st quarter of 2022	17,000 slow, 3900 fast	2022	[59]
Italy	244,944 with 1,316,702 units sales in 2022 making 8.6% of total vehicles shares	31,000 slow, 6500 fast	2022	[60]
Germany	1.59 million with 833,500 units sales, up 22% from 2021	64,000 slow, 13,000 fast	2021, 2022	[61–63]
UK	660,000 with 1 million registered making 2.5% of registered vehicles	42,000 slow, 8600 fast	2022	[64,65]
South Africa	4337 With 2137 sales in 2022	285	2021, 2022	[40,66–68]
Australia	83,000 with 3.8% of all new vehicle sales in Australia in 2022	3600	2022	[69–71]
New Zealand	68,543 with 73,660 sales in 2023	340	2022, 2023	[72,73]
China	5.9 million with 58% of global EV sold and 10.2 minion sales in 2022	1.8 million, 1,000,000 slow, 760,000 fasts	2022, 2023	[74,75]
South Korea	131,000 sales in 2022	180,000 slow, 21,000 fast	2022	[61,76]

4. Challenges to EV Adoption in South Africa

Following a release from the Automotive Green Paper by the Department of Trade, Industry, and Competition (DTIC) on the progress of EVs in South Africa in May 2021, the difficulties faced by EV adoption in South Africa is highlighted [77]. These challenges are categorized in two dimensions focusing on demand by the people and supply by different automobile industries [78]. The green paper also states that it will be an unavoidable transformation for the South African automobile sector, as it will be the global automobile industry's future driving technology. The fear of being left behind by global competitors during the shift to EV cannot be overstressed by the South African DTIC sector as this will lead to a loss of revenues close to ZAR 201 billion in export earnings per year if it does not embrace the manufacturing of EVs. However, the local industry still generates a comfortable revenue from the production of internal combustion engine (ICE) vehicles. Therefore, there have been many urgent requests to start producing EVs in the nation, especially now that the UK and European Union are on the verge of phasing out sales of new ICE vehicles [39,79]. The challenges faced by EV adoption in South Africa are summarized in the following subsections according to their order of influence on its adoption.

4.1. Cost

In the first half of 2022, only 205 EVs were registered in South Africa, and according to the National Association of Automobile Manufacturers of South Africa (NAAMSA), this is just 0.08% of the industry total of 253,442 vehicle sales in the same period [10]. The main issue is that EVs are out of budget for the typical South African customer. Industry participants have laid the fault squarely at the government for levying more tariffs on EV importation compared to those vehicles powered by diesel or gasoline engines.

Despite the potential for reduced operational expenses, the primary impediment to the widespread adoption of electric vehicles (EVs) in South Africa remains the significant upfront acquisition cost. With relation to affordability for EVs, the cost is high for low-income earners in South Africa; however, the middle income can afford the purchase of EVs if other problems such as charging infrastructure, insurance, etc., are sorted properly. Figure 7 presents a projection of EV prices over time, providing insights into the future cost of EV ownership. Analysis of this graph reveals a sluggish decline in EV ownership costs compared to those of internal combustion engine vehicles (ICEVs), underscoring the relative lack of affordability of EVs. Currently, the Mini Cooper SE Hatch 3-door stands as the most economical EV option in South Africa, priced at ZAR 723,000, while all other available EV models command a minimum price of ZAR 1 million. TechCentral in [80] compiled a list of all EVs on sale in South Africa according to Table 2, including cost, range, and performance numbers.

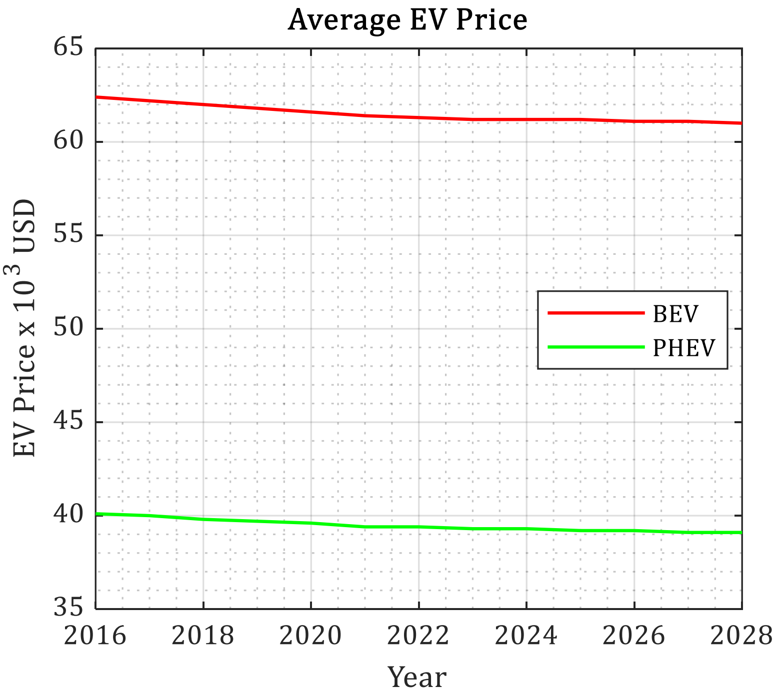


Figure 7. Cost of BEV and PHEV [48].

Despite the challenges, there is a noticeable uptick in demand for electric vehicles (EVs) in South Africa. Leading automakers such as Mercedes-Benz, Volvo, BMW, and Jaguar are progressively introducing EV models into the local market, as depicted in Figure 8. These manufacturers are witnessing a surge in both sales volumes and revenues. Figure 9 delineates the most sought-after types of EVs, namely battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), with corresponding revenue figures for each EV type.

Table 2. EV pricing in South Africa.

Model	Power	Top Speed	Range	Price
Mini Cooper SE Hatch 3-door	135 kW	150 km/h	Up to 215 km (claimed)	R0.723 m
Mini Cooper SE Hatch 3-door Resolution	135 kW	150 km/h	Up to 215 km (claimed)	R0.7263 m
Volvo XC40 P6 Recharge Plus	170 kW	160 km/h	Up to 423 km (claimed)	R1.075 m
Mercedes-Benz EQA 250 Progressive	140 kW	160 km/h	Up to 486 km (claimed)	R1.169 m
Mercedes-Benz EQA 250 AMG Line	140 kW	160 km/h	Up to 486 km (claimed)	R1.222 m
Volvo XC40 P8 Recharge Twin AWD	300 kW	180 km/h	Up to 400 km (claimed)	R1.26 m
BMW iX3 M Sport	210 kW	180 km/h	Up to 460 km (claimed)	R1.29 m
Mercedes-Benz EQB 350 4Matic Progressive	215 kW	160 km/h	Up to 485 km (claimed)	R1.374 m
Mercedes-Benz EQB 350 4Matic AMG Line	215 kW	160 km/h	Up to 485 km (claimed)	R1.427 m
Mercedes-Benz EQB 350 4Matic Edition 1	215 kW	160 km/h	Up to 485 km (claimed)	R1.518 m
BMW i4 M50	400 kW	225 km/h	Up to 620 km (claimed)	R1.6 m

Complied by the authors. Available at [80].

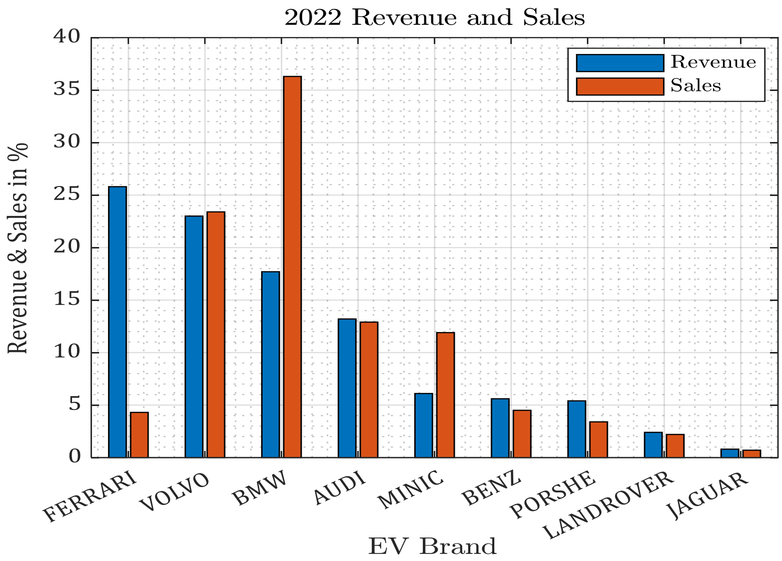


Figure 8. Different EV brand sales and revenue (authors' plot with data obtained from Statista).

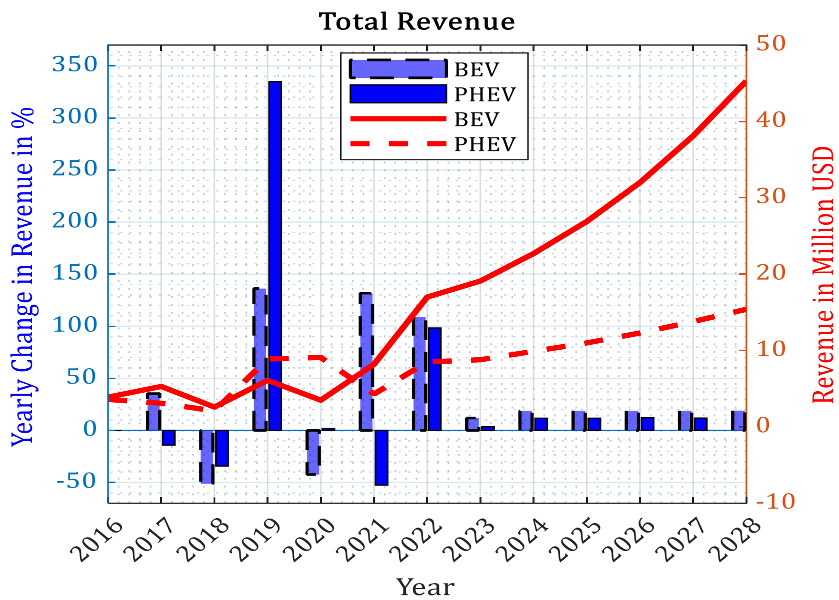


Figure 9. Revenues generated from EV (authors' plot with data obtained from Statista).

Research in [81] suggested that the local production of electric vehicles (EVs) could reduce purchase and ownership costs by minimizing import expenses and tariffs. The comparatively high cost of EVs relative to internal combustion engine vehicles (ICEVs) poses a significant barrier to adoption, necessitating substantial upfront investments from consumers. Another input is to implement policies like reducing oil, gasoline, and diesel imports in favour of locally generated power. This could yield positive impacts on South Africa's foreign exchange reserves, the Rand's value in foreign exchange markets, and domestic economic development.

4.2. Consumer Perception of EVs

Consumers have long perceived electric vehicles (EVs) as prohibitively expensive, a perception that has impeded their widespread adoption in South Africa. Concerns regarding financing through banks and insurance coverage from insurance companies have also contributed to this apprehension. Additionally, challenges related to the availability of parts and service stations for EVs, as well as the scarcity of charging infrastructure, further hinder the growth of the EV market in the country.

A significant factor driving the high cost of purchasing an EV is the substantial production expenses, particularly attributed to battery manufacturing. This challenge is compounded by the impact of value-added tax (VAT), ad valorem excise duty, and import tariffs, which inflate the overall price of EVs. Moreover, limited product availability, anxieties surrounding range limitations, reliability issues with electrical supply, and a general lack of awareness about EV technology also contribute to the slow adoption of EVs in South Africa.

Furthermore, the elevated interest and insurance rates associated with vehicle loans in South Africa, driven by the high upfront costs of EVs, further discourage consumers from investing in EVs. These factors collectively contribute to the current nascent stage of EV adoption in South Africa. The cost of selected ICEVs in South Africa is presented in Table 3.

Table 3. Cost of ICEVs in South Africa [82–84].

ICEV Model	Power	Top Speed	Cost in Rand
Mini Cooper 3 door	100 kW	210 km/h	ZAR 537,500
Mini Cooper S	141 kW	235 km/h	ZAR 606,200
Volvo XC40 B4 Dark	145 kW	180 km/h	ZAR 849,000
Mercedes-Benz CLA220d Progressive	140 kW	244 km/h	ZAR 947,630
Volvo XC60 B6 Plus Dark	220 kW	230 km/h	ZAR 1,213,000

Source: compiled by authors.

A consumer gave a detailed experience of the EV power consumption. In September 2023, the total electricity consumption amounted to 691.1 kWh, incurring a cost of ZAR 2294.83, resulting in an average unit cost of ZAR 3.32. Specifically, the XC40 Recharge Twin consumed 23.3 kWh per 100 km travelled, totalling 369.84 kWh for the entire trip distance. Among this, 313.5 kWh was supplied through AC home charging, while 47.15 kWh and 9.19 kWh was acquired through DC fast public charging and AC fast public charging, respectively. Notably, the latter two options incurred significantly higher costs at ZAR 7.35 and ZAR 5.85 per kWh, respectively. The cumulative expenditure for all charges amounted to ZAR 1441.13, translating to approximately 91 cents per km. This represents a saving of ZAR 916.44 compared to the equivalent distance travelled in a Kia Sonet 1.5 LX, and ZAR 1310.05 less than if the journey were made in the XC40 petrol model. The elaborate breakdown of this analysis is shown in Table 4.

The consumer perceives a substantial cost disparity between purchasing a Kia Sonet at ZAR 349,995 and its electric vehicle (EV) counterpart, the Volvo XC40, priced at ZAR 1,108,000, resulting in a difference in ZAR 758,005. Assuming a monthly savings of ZAR 916 attributable to charging an EV, the consumer calculates that it would require 828 months, equivalent to 69 years, to recoup the initial investment.

Table 4. Comparative analysis of EV and ICEV average cost per km.

Volvo XC40 Recharge Twin—23.3 kWh/100 km	Price per kWh	Total kWh	Total Cost
2.3 kW Home charging (AC)	ZAR 3.32	313.5 kWh	ZAR 1040.82
4.4 kW Public charging (AC)	ZAR 5.85	9.19 kWh	ZAR 53.76
100 kW Public charging (DC)	ZAR 7.35	47.15 kWh	ZAR 346.55
Charging Cost	ZAR 3.90	369.84 kWh	ZAR 1441.13
Average Cost per km		ZAR 0.91	
Volvo XC40 Petrol Hybrid—7.3 L/100 km	**Price per L**	**Total L**	**Total Cost**
95 Unleaded—August 2023 price	ZAR 22.83	54	ZAR 1232.82
95 Unleaded—September 2023 price	ZAR 24.54	61.87	ZAR 1518.36
Refuelling Cost	ZAR 23.74	115.87	ZAR 2751.18
Average Cost per km		R 1.73	
Kia Sonet 1.5 LX Petrol—6.25 L/100 km	**Price per L**	**Total L**	**Total Cost**
95 Unleaded inland—August 2023 price	ZAR 22.83	45	ZAR 1027.35
95 Unleaded inland—September 2023 price	ZAR 24.54	54.21	ZAR 1330.22
Refuelling Cost	ZAR 23.76	99.21	ZAR 2357.57
Average Cost per km		ZAR 1.49	

4.3. Economic Factors

The shift from ICE automobiles to EVs would have far-reaching, diverse macroeconomic consequences for South Africa. The first and most important consequences would be the demand and supply of ICE automobiles and gasoline products. The other point of consideration would be the environmental, household, and infrastructural spillover impacts.

A strategic government policy is required to steer the EV transition in the right path. The advantages and expenses of an unavoidable shift would not be equal if left to the market. How will EVs thrive in the South African economy with the current regulatory framework in the market? A big concern is that a liquid fuels transition strategy is required to minimize employment losses while maintaining liquid fuels and raw materials for petrochemical production. If ICE production has to be stopped or reduced, a strategic intervention is required. Some are an initiative and a mechanism to facilitate adequate preparation for potential refinery shutdowns, which also entails reimagining the logistical framework and, when feasible, repurposing existing refuelling stations for other purposes. Another is that a modern global-scale refinery needs to be considered to align with the future evolving range of anticipated products.

Another economic challenge is the government response due to fears that the drop in gasoline or diesel engine vehicle usage would result in a fall in government revenue, with a significant decrease in fuel levy revenue. Fuel taxes provided ZAR 70.9 billion to government income in 2017/18, accounting for about 6% of total revenue [17,85]. A decrease in sales of internal combustion engine (ICE) vehicles would then lead to a decline in the carbon levy imposed on automobiles, generating ZAR 1.3 billion in revenue during the fiscal year 2017/18 [86]. The influence of South Africa's tax incentives designed for the manufacturing of motor vehicles, which amounted to ZAR 28.4 billion in the fiscal year 2016/17, remains uncertain as it hinges on the extent of domestic production and imported vehicles [87]. All these economic barriers are major reasons for why EVs are not fully embraced or sensitized. A complete transformation of the nation's vehicle fleet will need a significant expenditure by vehicle manufacturers to upgrade production lines. The economic implication of these would result in a two-third reduction in imports and the structure currently in South Africa places electric vehicles (EVs) at a disadvantage in comparison to internal combustion engine (ICE) vehicles.

In addition, petroleum products were South Africa's top import in 2017, valued at USD 11 billion. The country imports 80% of their petroleum products, with oil and gas industries manufacturing the balance through coal and liquid–gas operations [88,89]. These imports are further means of generating revenues for the government. Removing ICE vehicles could jeopardize these revenue sources and further have an adverse impact on the economic situation of the country. Therefore, losing these revenue streams is why many charges and tariffs are labelled on it.

Also, in the shift towards electric vehicles (EVs), ensuring an equitable transition becomes crucial for ensuring sustainable and inclusive long-term economic development. These mandates provide adequate support for workers, small enterprises, and communities, thereby ensuring that the shift to EVs positively impacts all sectors of society.

4.4. Loadshedding

Another big concern will come from dwindling energy availability in the country as supplied by South African utility provider Eskom. This concern is due to the recent power crisis in the country, which has led to the president of the country declaring a state of disaster on electricity and appointing a Minister for Electricity, an office which never existed in the country [90–92]. Some concerned populace and energy experts believe using EVs on a power grid that uses coal power plants is the same as driving an ICE vehicle. However, this is not totally correct. For example, buying a Tesla electric Model 3 with the idea of going green will require a 21,725 km break-even distance to be covered for it to be considered as doing less harm to the environment. In addition, an energy systems analyst, based on research conducted on life cycle analysis, opined that the process of manufacturing EVs may result in higher carbon emissions compared to traditional combustion engine vehicles [93].

The research conducted involved a Tesla Model 3 and a gasoline-fuelled Toyota Corolla. The Tesla Model 3 was equipped with a 54-kWh battery and a cathode composed of nickel, cobalt, and aluminum, while the Toyota Corolla, which weighed 1340 kg had a fuel efficiency of 14 km per litre. The analysis assumed that both vehicles would cover a distance of 2,786,017 km over their lifetimes. However, it should be noted that these factors are not the only variables considered in the evaluation. If the same Tesla Model 3 were to be driven in Norway, where a significant proportion of electricity is generated from renewable hydropower, the break-even point between the two vehicles would be achieved after just 13,518 km. On the other hand, in regions where electricity for EV charging predominantly comes from coal-fired power plants, such as South Africa, China, and Poland, it would require driving approximately 126,655 km to reach carbon parity with the Toyota Corolla [93]. Therefore, EVs are still more environmentally friendly than ICE vehicles depending on the intensity of usage and the energy source for the electricity consumed (as well as second battery and recycling of EVs).

In addition, deploying EVs will raise yearly electricity consumption by up to 29 GWh in the power industry, resulting in a greater energy shortage. This represents 7% of the expected 2050 power demand in the Draft 2018 Integrated Resource Plan in South Africa. With the current lack of adequate planning and system management, investing in EVs will require a large investment in extra energy-generating capacity unless the EVs are self-generating like solar vehicles.

Another concern is the adherence of EV users to charging during off-peak hours to reduce the impact on the demand curve. The inability to enforce this will cause an increasing need to invest in network infrastructure. Additional sales might raise the value of the power industry by up to 11%. Therefore, what proactive efforts are required to offset the possible grid implications of clustering and uniform pricing during peak hours? Considering that the cost of charging an electric vehicle is intended to affect charging behaviour in conjunction with direct regulations and should be evaluated and altered iteratively as demand grows, how will the price be regulated? [21].

The energy effectiveness of EVs when contrasted with fossil fuel-powered vehicles diminishes the potential economic advantages of ICE vehicles. The additional potential grid advantages of electric vehicles encompass encouraging investment in integrated generation, furnishing storage capacity to aid in balancing demand, and facilitating a more extensive incorporation of renewable energy into the network. These benefits have not been fully realized due to the nascent stage of development of intelligent technologies, such as vehicle-to-grid (V2G) connectivity [17].

4.5. Charging Stations

The local public charging network in South Africa presently has 373 charge stations, according to the charging infrastructure mapping website PlugShare shown in Figure 10 [94]. This is the highest charging network on the African continent. The chargers range include 22 kW (AC), 80 kW (DC), and 150 kW (DC) ultra-fast recharging capacity and are currently available to all South African EV drivers, independent of brand or model ownership. The provision of electric vehicle (EV) charging infrastructure in South Africa is primarily facilitated by automotive manufacturers such as BMW, Audi South Africa, Jaguar, and Nissan. Notably, these manufacturers have formed partnerships with GridCars, which is recognized as South Africa's largest public EV charging operator. GridCars boasts an extensive network comprising approximately 350 chargers, demonstrating a significant commitment to enhancing EV charging accessibility and promoting the widespread adoption of electric vehicles across the country.

On 1 June 2023, the prevailing rates for utilizing public chargers in South Africa were ZAR 7.35 per kWh for DC fast chargers and ZAR 5.88 for AC chargers. Volvo South Africa conducted a study on its fully electric Volvo XC40 Recharge Twin over an extended period, covering a total distance of 1587.3 km. Charging the vehicle at home in the City of Tshwane, the pricing structure for prepaid electricity is shown in Table 5.

Table 5. Consumer analysis of EV monthly power consumption.

Average Distance per Day (Over 28 Days)	**56.69 km**
Average energy consumption	23.3 kWh/100 km
Total energy consumption	369.84 kWh
First 100 kWh of the month	ZAR 2.78 per kWh
Next 300 kWh of the month	ZAR 3.25 per kWh
Next 250 kWh of the month	ZAR 3.54 per kWh
Above 650 kWh of the month	ZAR 3.82 per kWh

With respect to the data of some selected countries' fast and slow charging stations, shown in Figure 11, South Africa still has a long way to go if it will compete globally. Also, considering the vast population and land area, this is still small compared to the total number of gasoline fuel stations in the country, not to mention the time taking to charge a single EV from 0% to 100% of its battery capacity. The reason why the usage of the BEV or PHEV is yet to meet a good start in the country. In addition, the South African retail fuel market currently has approximately 4600 fuelling stations in the country compared to the 309 EV charging stations.

There is hope in turning things around as Audi, one of South Africa's EV providers, through Sascha Sauer, head of Audi SA, stated that they are committed to ensuring that consumers of any EV may traverse the nation easily, knowing that the EV charging infrastructure is in place to support their progressive choice of mobility [95].

Future charging stations need to make provision for an active state-of-the-art EV charger not only at crucial destinations, but also readily available in comparison to different ICE gas stations, and provide chargers that will allow vehicle-to-grid (V2G) capabilities to discharge unused energy.

Figure 12 shows the charging points per EV and kW per Light Duty Vehicle in selected countries. The significance of kilowatts (kW) of charging per electric vehicle (EV) stems from its direct relationship with charging speed and efficiency. kW represents the rate at which electric energy is transmitted to the vehicle's battery while charging. Higher kW charging rates allow for faster replenishment of the battery's energy reserves, reducing charging time and increasing convenience for EV owners. Furthermore, the kW of charging per EV is critical for determining the capabilities and compatibility of charging infrastructure with various EV models. EVs have variable charging capacities, and the kW rating of charging stations defines the maximum power available to the vehicle. Ensuring an adequate kW of charging per EV is critical for enhancing charging experiences and meeting the changing needs of electric vehicle owners. Thus, the lower the number of electric vehicles per charging point, the better the charging facilities. The kW of charging per EV affects infrastructure planning and investment decisions, as faster charging speeds may entail changes to electrical systems and infrastructure to meet growing power demands.

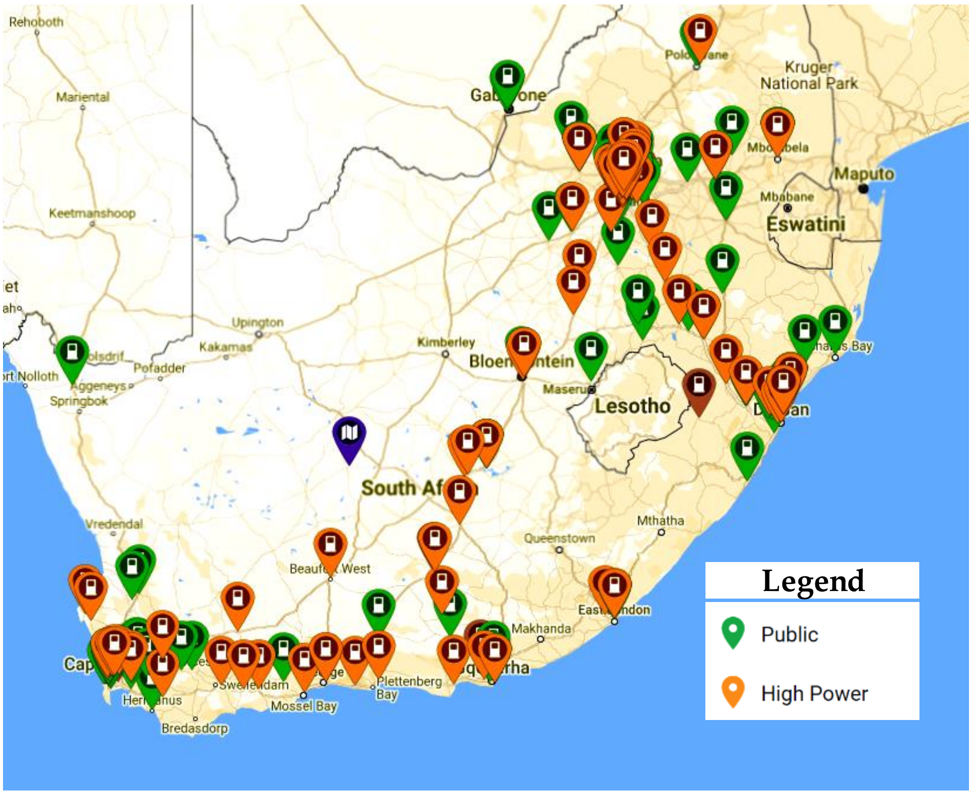
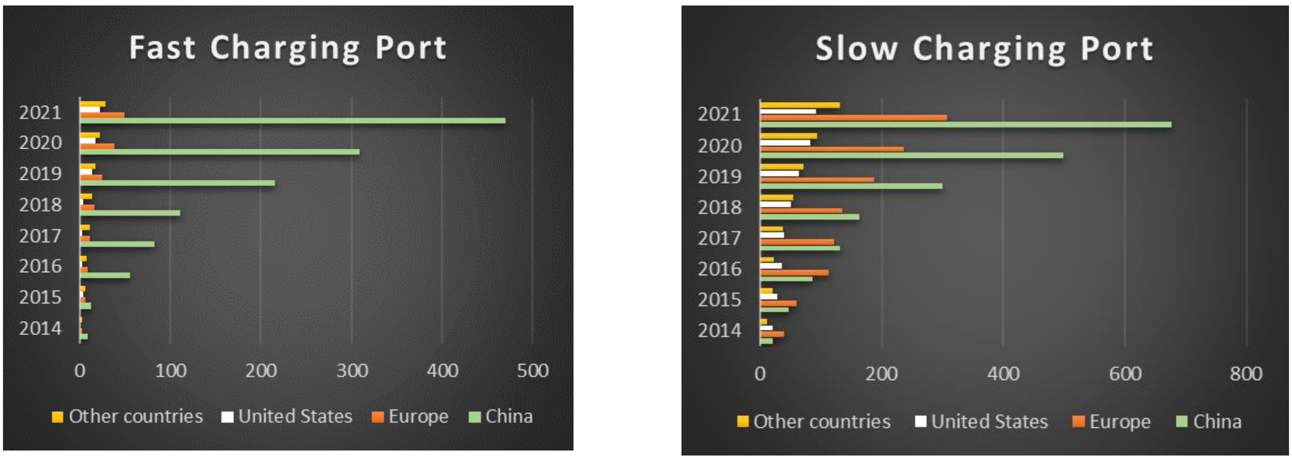


Figure 10. EV charging infrastructure in South Africa [94].



(**a**) (**b**)

Figure 11. AC and DC global publicly available (**a**) fast and (**b**) slow charging stations [96].

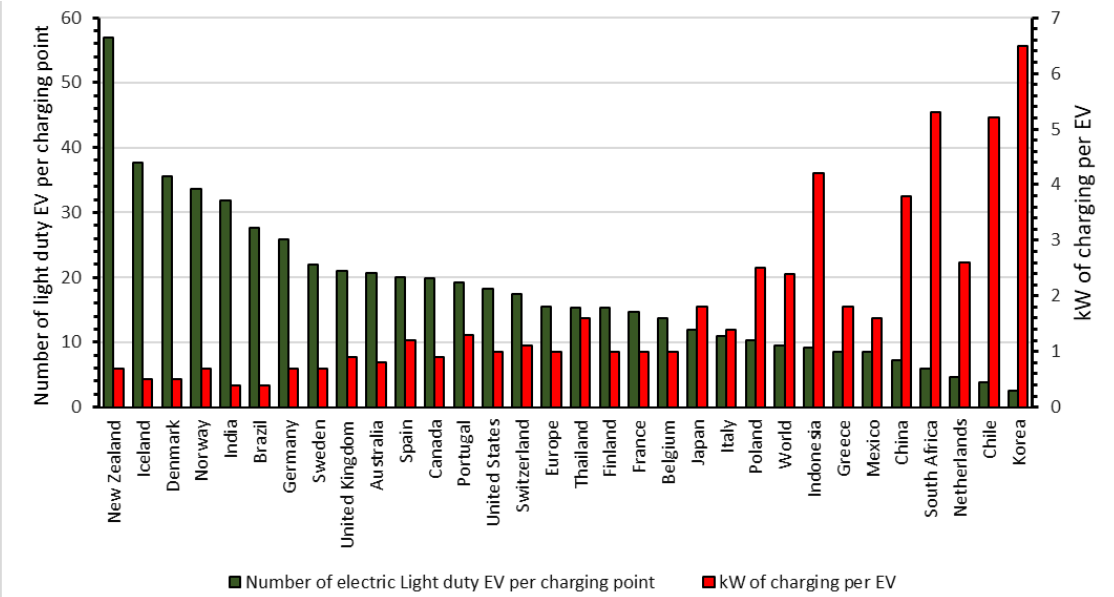


Figure 12. Charging points per EV and kW per light duty vehicle in selected countries [97].

These charging stations are highly reliable. However, the distance at which each is situated makes it difficult to access. A case of one user was captured on how he utilizes these charging stations and further stated that using an EV is better than the ICEV. However, the user failed to fathom the cost of using an EV charger in his calculation.

4.6. Security

According to Tracker, a South African vehicle tracking industry, South African vehicle theft and vehicle hijackings amounted to ZAR 8.5bn in 2014 [98]. While residents do their best to recover these vehicles, about 30% of these vehicles are taken across the borders rendering all recovery efforts futile. Because of the permeable borders and the inadequate collaboration of those responsible for preventing crime, the emergence of cloned vehicles and cross-border criminal groups is turning into a noteworthy issue. The crux of the matter lies in the sharing of data. Compounding the issue, approximately 39,000 vehicles resurfaced within the system last year, causing substantial financial burdens on the insurance industry as they had to settle claims without being informed that these vehicles had been duplicated. Insurance companies are not required to pay out when you cover a cloned vehicle since the erroneous vehicle is represented on the books.

In the last quarter of 2022, a report was published by Business Tech stating how vehicles stolen in South Africa are primarily transported to nearby nations such as Botswana, Mozambique, Eswatini, Namibia, Zambia, Zimbabwe, and Swaziland [99–101]. The vehicles that pose a high risk are the most targeted by vehicle hijackers and the location, termed as a hotspot, is also published in this newsletter [102]. According to the crime data from the South African Police Service (SAPS) shown in Figure 13, 5866 vehicle hijackings were recorded across the country within three months in 2022, a 14% rise from the 5146 vehicle robberies recorded in the same period in 2021. Government development indicator data released in 2021 of different reported criminal activities in Figure 14 shows an upward trend of vehicle hijacking in South Africa. According to Tracker, vehicle theft has risen by 7% on a national scale in terms of quantity, and incidents of hijacking have increased by 4% compared to the previous study period. Luxury vehicles or big SUVs are mostly the targets, while smaller vehicles such as Volkswagen or Sedan vehicles are sold as scraps locally or as a whole. Vehicle surveillance and tracking firms, automobile rental companies, and banks all play essential roles in technology. But in the light of this, more premiums are required for high-risk vehicles.

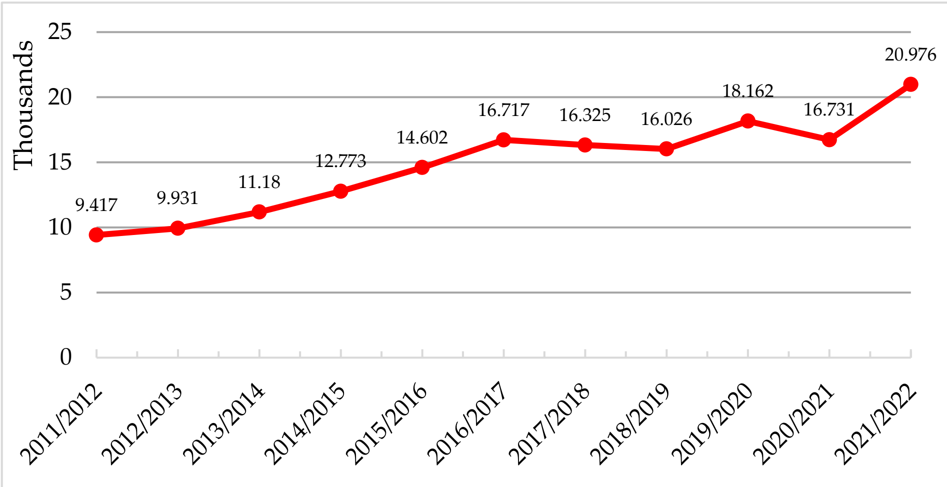


Figure 13. Vehicle hijacking statistics in South Africa [102].

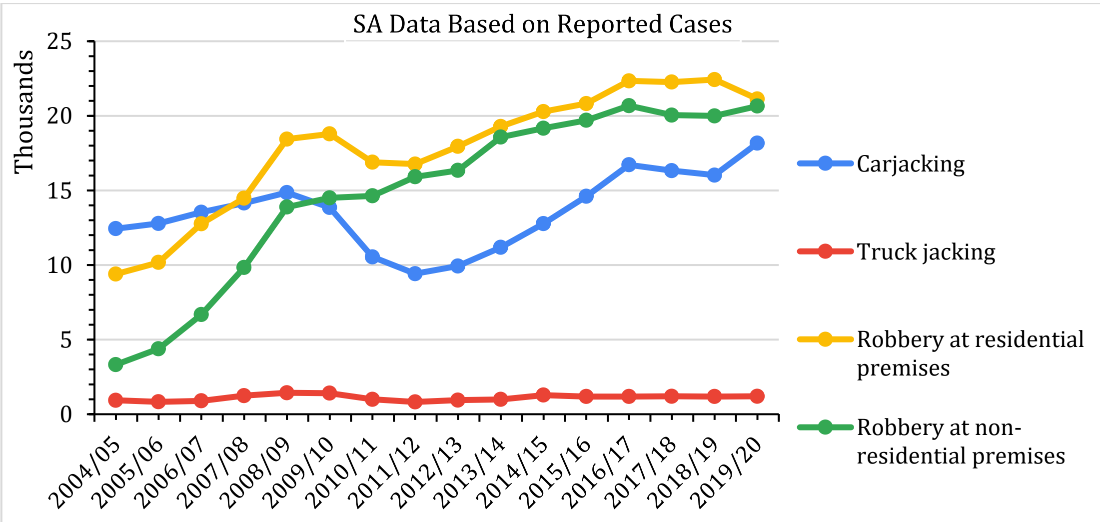


Figure 14. SA Data of reported cases of different robberies and hijackings (authors' plot with data obtained from Government Developments Indicators).

Now, considering the usage of EVs in the country, the insurance companies are in uncharted territories considering the stage of technology, cost of ownership, and different unknown risks. Therefore, it makes it very challenging for SA to fully take on EVs. Additionally, security issues surrounding other types of EVs are significant, despite the low maintenance benefits that they offer. Also, thefts of EV parts such as batteries, converters, and metal parts are going to be a future problem for South Africa as the number of EVs increases. Developed countries hardly experience this type of theft due to high-security infrastructure.

Another EV security threat is inextinguishable fire due to the thermal runaway of the battery. Electric Vehicle (EV) fire incidents represent a significant security concern within the automotive industry. In 2022, the New York City Fire Department in the United States reported over 200 fires, resulting in six fatalities. Notably, a blaze from a scooter in the Bronx required the efforts of 200 firefighters and resulted in injuries to seven individuals. While South Africa has not recorded any instances of EV-related fires, the increasing adoption of EVs is anticipated to expand the presence of diverse EV parts suppliers, just like the scenario observed with Internal Combustion Engine (ICE) vehicles which can increase in the usage of fake or counterfeited parts. Such fake or counterfeit battery units and factors such as overheating, and damaged or faulty electrical circuits can heighten the risk of fire outbreaks in EVs. Reports indicate that extinguishing such fires is particularly challenging due to the nature of lithium-based battery fires. Therefore, EV manufacturers and suppliers are cognizant of the risks associated with lithium-ion batteries catching fire and are actively addressing safety measures to mitigate such incidents [103–105].

5. Further Focus Areas for EVs in South Africa

5.1. Present Research Organizations Sponsoring EVs

Diverse research organizations are rapidly working towards the usage of EVs in South Africa. Also, different research institutes, universities, and automobile industries are all looking for different methods to reduce the country's carbon footprint. One of the leading research institutes in the country, the Council for Scientific and Industrial Research (CSIR), in conjunction with the Automotive Industry Development Centre (AIDC), has proposed a collaborative partnership to conduct road mapping sector studies focusing on electric vehicles, particularly the conversion of local buses to be more environmentally friendly buses [106]. The primary areas of research will encompass the establishment of charging facilities at the CSIR, localization of charging stations, as well as exploring cross-sector opportunities in battery manufacturing. This initiative has been formalized and aimed at enhancing the global competitiveness of the local automotive industry for green mobility in the nation. The collaboration between the CSIR and the AIDC marks a significant milestone in the advancement of South African automotive manufacturing. By supporting the growth of small, medium, and micro enterprises (SMMEs) and driving innovations, the partnership seeks to foster a thriving industry ecosystem and contribute to overall economic growth. This collaborative venture will explore state-of-the-art concepts like plant simulation, modelling, optimization, as well as equipment localization and various industry support initiatives. The core objectives of the CSIR and the AIDC in this endeavour are to facilitate comprehensive training and capacity building, empowering the workforce with the necessary skills for embracing the Fourth Industrial Revolution (4IR) [107]. Table 6 highlights different research carried out in South Africa on EVs and their summaries.

Table 6. Review of papers published on EVs in South Africa.

REF	Area of Study	Summary of Study	Result
[15,36,108]	Affordability of battery electric vehicles and market penetration	Employs a system dynamic model to forecast the cost of BEVs in South Africa. It also incorporates various parameters, including the gross domestic product (GDP), BEV growth drivers, and the national electricity consumption for charging, among others. The researchers aim to predict the regional affordability of BEVs in South Africa.	The findings indicate that the targeted low growth value of 233,700 battery electric vehicles (BEVs) by 2040 is unachievable. Additionally, the cumulative CO_2 emissions from 2019 to 2040 will yield negligible reductions, and thus be insufficient for significant emission mitigation.
[109,110]	Distribution network analysis for EV	The study utilizes a simplified Monte Carlo simulation to estimate the hosting capacity of EVs on South African low voltage networks. Thus, probabilistically assess the network's ability to accommodate a specific number of EVs charging concurrently without experiencing adverse power quality problems.	The results show a worst-case scenario of 5 to 8 hosting capacity and 9 to 13 for best hosting capacity. Moreover, variations in the hosting capacity index are influenced by the geographic placement of the charging station.
[111–114]	Battery manufacturing and technology	Zero Emission Battery Research Activity (ZEBRA) strategy for the effective removal of harmful substances from the manufacturing of Battery.	The primary objective of ZEBRA batteries is to deliver extended lifespan and exceptional reliability while minimizing cell corrosion. Technical hurdles to overcome include enhancing the battery's specific power towards the end of discharge and achieving cost-effectiveness.

Table 6. *Cont.*

REF	Area of Study	Summary of Study	Result
[115–120]	Smart Grid and renewable energy for charging of EVs	Deploying of different renewable energy sources for the charging of EVs. Also utilizes smart grids and microgrids to effectively reduce the carbon footprints from non-renewable energy generation.	The findings show that smart charging systems for EVs are key to EV market penetration. Distributive generation utilizing renewable energy is also a key to reducing the power fluctuation from the grid.
[13,17,21,45,121–126]	Ethics, risk, and policies for the EV adoption or transitioning to EVs	These research works focused on the ethics and policies related to EVs. They highlight all the challenges facing EV adoptions.	A solution was proposed appropriately for African governments and different entities to offer a smooth transition to EVs.
[42,127–129]	Emission through the usage of ICE in South Africa	The usage of ICE vehicles in South Africa contribute to greenhouse gas emissions. These emissions primarily consist of carbon dioxide (CO_2) and other pollutants like nitrogen oxide (NO), particulate matter (PM), and hydrocarbons.	These studies highlight different opinions on the ICE emissions and the carbon tax law.
[130–132]	Progress and sustainable methods for EVs and E-mobility	Analysis of different sustainable indicators for developing countries using EVs was evaluated with different roadmaps to reduce the overreliance on the electric grid.	Results show that Egypt and Morocco lead in the EV transitioning in Africa, and further shows that the potential reduction of CO_2 emissions by 54% is possible if Africa transitioned to e-mobility
[133,134]	Towards the manufacturing of EVs, which metals are rare and vulnerable to supply risk?	Indeed, the manufacturing of electric vehicles (EVs) relies on the use of certain rare metals, and research has shed light on the geopolitical and environmental risks associated with the mining and processing of these metals. These concerns are paramount due to the potential impact on resource availability, geopolitical tensions, and environmental consequences.	The findings in this research show that several African countries boast of abundant reserves of critical materials for the manufacturing or EVs, including cobalt, nickel, lithium, copper, aluminum, manganese, and others. It also outlines significant roles of global supply chains of EV raw materials. Analyzing these dynamics is crucial to assessing and monitoring future market transformations
[22,135–137]	EV charging infrastructure and optimization	These articles introduced a novel approach for evaluating the appropriate carport power selection for electric vehicles (EVs) by employing the Metalog probability distribution family. The proposed method aims to enhance the efficiency and accuracy of determining the optimal carport power capacity for charging EVs.	The results show successful modelling of an efficient, sustainable, and economical electric vehicle charging stations that benefit both the grid and the environment using POET (performance, operation, equipment, and technology) energy efficiency improvement and management framework
[138,139]	Introducing EVs and initial research	Some of the first research works on EVs highlight South Africa as one of the countries with the lowest cost of electricity globally and thus of the opinion that this will be of high benefits to usher in the era of EVs.	The results show a significant reduction in total emissions when a comparative study where all ICE vehicles were replaced with an EV. The conclusion shows that, though impossible to fully implement this transition, a gradual change is needed to save SA automobile industries.
[140]	Education and research for debt relief	This research advocated for 'debt-for-science' swaps in Africa, a concept where creditors would forgive a portion of a country's debt in return for increased investment in research and development as an incentive for bolstering scientific endeavours in the region.	The author's conclusion highlights the alarming fact that approximately 600 million individuals in Africa face a lack of access to electricity, a fundamental necessity. Furthermore, this figure exhibits a concerning trend of stagnation rather than decline. Without the implementation of innovative mechanisms such as debt-for-science swaps and other creative solutions, numerous African nations remain susceptible to a vicious cycle of debt and austerity.

Table 6. *Cont.*

REF	Area of Study	Summary of Study	Result
[141]	Green Transport Demonstration Project	This study demonstrates the role of clean energy and eco-friendly transportation technologies in advocating for environmentally conscious transport solutions and partially mitigating CO_2 emissions. The objective is to initiate the production of the Joule electric vehicle within South Africa.	The research outlines the establishment of the Green Transport Centre in South Africa for exhibition during the FIFA 2010 World Cup. Different EV projects were displayed, and the best of the projects was the development of ZEBRA batteries by the Council of Scientific and Industrial Research (CSIR).
[142,143]	Converter link for EVs	A comprehensive comparative analysis was presented, contrasting the performance of two-level and three-level inverters in the context of electric vehicle traction applications. Additionally, an innovative switching sequence was introduced, tailored for space-vector pulse width modulation (SV-PWM)-based three-level neutral point clamped inverters employed in electric vehicle converters.	Experimental tests, when compared with results obtained from a proportional–integral (PI) controller, demonstrate noteworthy enhancements in the performance of the permanent magnet synchronous motor (PMSM). These improvements encompass reduced variation in the DC-link capacitor voltage and expanded operational capabilities across a wide range of speeds and torques. Moreover, there was a notable decrease in the total harmonic distortion, indicating enhanced electrical efficiency.
[144]	Battery discharge rates	This article introduces diverse battery assessments across varying discharge voltages and capacity scenarios. Various machine learning techniques including neural networks, modified support vector machine (M-SVM), and linear regression are employed to forecast the state of health.	The results show that their proposed Modified Support Vector Machine (M-SVM) exhibits strong performance with reduced errors across the entirety of the four-battery discharge datasets.
[145]	Novel electronic differential control for EVs	Convectional wheel drive using an induction motor was flawed in that it requires a proportional, integral, and differential control that requires constant tunning at every operating point. A novel electronic differential control was then proposed in this research.	The wavelet control technique proposed in this study offers enhanced stability and facilitates seamless control of the two rear driving wheels in electric vehicles (EVs).
[146]	Prediction of EVs	This article centres around the representation of an electric vehicle (EV) using modelling techniques and the creation of an algorithm. The algorithm's purpose is to recommend the best driving speeds based on the battery's power capacity, aiming to achieve the quickest possible arrival at the destination and alleviate the driver's concerns about the EV's driving range. Python serves as the platform for both the modelling process and algorithm development. Elements like road incline, distance, and velocity will be utilized as input parameters for the simulated EV.	The study indicates that road angle significantly influences the energy demands of electric vehicles (EVs). For instance, at a 5% incline, a speed of 80 km/h necessitates 25 kW, whereas a 15% incline requires 58 kW. Additionally, higher speeds amplify power requirements; for example, at a 10% incline, 20 km/h demands 10 kW, while 80 km/h demands 40 kW. Moreover, EV power requirements exhibit a linear correlation with tyre pressure and air temperature and increase proportionally with the square of the vehicle's speed.
[14]	Feasibility study for the incorporation of E-taxi	This research paper examined the environmental impact of introducing 100 electric vehicle taxis in Johannesburg (JNB), South Africa. The study initially delved into the present electricity generation scenario and vehicle standards in South Africa, along with its associated carbon emissions. Subsequently, it was demonstrated that the current electricity generation mix does not support sustainable electric vehicle adoption.	The results in this paper suggested the integration of renewable energy systems at charging stations, comprising a renewable energy fraction (REF) of 40% and 58%. This integration is aimed at aligning the carbon emissions from electric vehicles with the emission standards of Euro III and Euro V for petrol ICE vehicles. The appropriate size of the renewable energy systems was determined through Electric System Cascade Analysis.

Table 6. *Cont.*

REF	Area of Study	Summary of Study	Result
[147]	Influence of fuel cell on hybrid EVs utilizing fuel cell battery	Comparative driving tests were executed in two modes of propulsion: solely battery-powered and a hybrid mode combining both battery and fuel cell technologies.	The integration of the fuel cell yielded a remarkable improvement in driving range, showcasing an augmentation ranging from 63% to 110%. This enhancement was contingent on the stored H_2 fuel quantity, which fluctuated between 55% and 100% of the maximum capacity. Operating in the hybrid mode not only yielded more consistent driving performance but also yielded greater overall energy utilization by the vehicle.
[148]	Solar electric vehicle energy optimization	This study integrates optimization algorithms and anticipated values of predicted weather variables to develop an optimal speed pattern for a solar-powered electric vehicle, aimed at minimizing energy consumption and maximizing distance. These algorithms and probability mass functions are implemented and assessed over a considerable distance of 2396 km, encompassing varied weather conditions and challenging terrains.	The study underscores the necessity of forecasting energy requirements for solar electric vehicles traversing routes in South Africa and emphasizes the significance of optimizing speed. The Sun Chaser III solar vehicle's outstanding performance, securing first place among local teams and fourth place internationally in the Sasol Solar Challenge 2018, can be attributed to the precision and resilience of this research's physical implementation.

5.2. Government Interventions Relating to EV Skills Gaps and Transfer and Policy Recommendation

For South Africa, carbon footprint reduction is not limited to environmental considerations; it directly influences public health, societal sustainability, economy, and the global competitiveness of our goods and services. The Just Energy Transition (JET) presents a prime opportunity for stimulating economic growth, diversification, and employment generation. To achieve a just and comprehensive transformation towards a low-carbon, climate-resilient economy, a JET investment plan has been devised [149–152]. This strategic plan is aimed at directing resources to support the affected workforce, communities, and industries during the transition to renewable energy sources while concurrently investing in emerging sectors like green hydrogen and electric vehicles. This approach is increasingly vital as international export markets increasingly demand environmentally sustainable products [153].

Two years ago, the Department of Trade, Industry, and Competition (DTIC) of South Africa issued a Green Paper centred on the progress of new energy vehicles (NEVs). The main aim of this Green Paper was to create the fundamental structure for creating policies and directing a comprehensive plan to make South Africa a central point for producing new energy vehicles and their components. More recently, NAAMSA, the Automotive Business Council in South Africa, put forth a publication titled "New Energy Vehicle Roadmap Thought Leadership Discussion, The Route To the White Paper", focusing on the roadmap for NEVs [40]. The NAAMSA document underscores that the South African National Greenhouse Gas Inventory indicates a swift rise in greenhouse gas emissions from the transportation sector, which makes up roughly 10.8% of the total national emissions. The largest proportion of these emissions is linked to road-based activities, mainly originating from the burning of gasoline and diesel. Accelerating the uptake of electric vehicles would not only help to mitigate these emissions but also cut down on the outflow of foreign currency by reducing the necessity to import fossil fuels.

Despite South Africa's predominantly coal-powered grid, the nation is expected to witness a greener energy mix over the next few decades as it progressively replaces a significant portion of its ageing coal-based power plants with new lower carbon generation capacities.

Because South Africa has a considerable industry for producing internal combustion engine (ICE) vehicles and their components, the government is placing additional emphasis on the importance of a well-rounded strategy to support a significant shift to new energy vehicles (NEVs) within the country. This shift demands meticulous planning to promote a gradual change in the local market's preference towards NEVs, create a charging infrastructure based on renewable energy, and guide the transformation of South African vehicle manufacturing from ICE vehicles to a mix of HEVs, PHEVs, and BEVs.

Further importance is also needed in reducing carbon dioxide (CO_2) emissions throughout the complete automotive lifecycle as soon as practically viable is a goal. Even though electric vehicles (EVs) produce no emissions from their exhaust pipes, the manufacturing, distribution, recycling, and eventual disposal phases still involve CO_2 emissions. EV charging via a coal-powered generating plant is also another factor to bring into this discussion. Achieving carbon neutrality for the life cycle assessment of EVs necessitates CO_2 emissions reductions throughout their entire life cycle and value chain.

To shift the South African automotive sector toward a market dominated by new energy vehicles (NEVs) while aligning with the goals of the South African Automotive Masterplan (SAAM) 2021–2035, numerous actions and assistance measures are suggested. These proposals should be considered by the South African government for their consideration [149–152]:

- Commitment to reducing CO_2 emissions across the automotive value chain.
- Protection, strengthening, and retention of the manufacturing base in South Africa, considering the potential risk of losing over 50% of production volume between July 2025 and 2035 due to Euro7 emission regulations in Europe and the phasing out of ICE drivetrains in European countries.
- Introduction of NEV purchasing subsidies to encourage the adoption of HEVs, PHEVs, and BEVs.
- Alignment on NEV import tariffs with the EU and the UK through the Southern Africa Development Community and Southern Africa Customs Union and Mozambique Partnership Agreement, and the establishment of more flexible Rules of Origin for exports to these regions.
- Provision of a 50% CKD (completely knocked down) rebate on the import of specified NEV components for a limited period.

There is also a need for subsidies to support the South African automotive industry's NEV transition up to 2035 to stimulate increased NEV consumption. These subsidies are going to be subjected to a periodical review and adjusted based on changes in NEV cost competitiveness relative to ICE vehicles over time. The overall cost of the subsidy programme is estimated to be ZAR 7.6 billion until 2025, ZAR 31.9 billion until 2030, and ZAR 94.5 billion until 2035. a Summary of these subsidies includes the following:

- ZAR 20,000 per HEV until 31 December 2030;
- ZAR 40,000 per PHEV until 31 December 2035;
- ZAR 80,000 per BEV until 31 December 2035.

With increased funding allocated to South Africa's Just Energy Transition, it is believed that this will be an opportunity to make substantial investments in enhancing the electricity grid and expanding renewable energy generation in the country and thus play a crucial role in effectively addressing the issue of load shedding in the country. This funding for the Just Energy Transition will further facilitate significant advancements in the electricity grid's resilience and the establishment of new renewable energy generation capabilities. Overcoming the challenges of load shedding, South Africa can further expect improvements in economic growth and enhanced competitiveness in the export market, ultimately leading to job creation that will foster the growth of emerging industries, such as electric vehicles and green hydrogen, which will contribute to the nation's industrial development and provide employment opportunities in the economy of the future [154–156].

This also entails a focus on public EV transportation, collaborative ownership models, and all-encompassing urban planning. The adoption of EVs will bring about significant alterations in the government's financial structure due to reduced revenue from fuel-related sources and decreased expenditure resulting from improvements in the balance of payments, transportation costs, and enhanced public health. A key challenge involves addressing the disparities arising from the varied recipients of both the costs and benefits of this transition. Allocating a budget to guarantee an impartial and just transition is imperative. An opportunity exists to establish a proactive policy framework that would effectively shape and steer an equitable transition, benefiting all South Africans in a harmonious manner. It is essential to capitalize on this opportunity without delay.

Drawing from global lessons, the implementation of electric vehicles (EVs) requires policy interventions guided by a defined vision and a collection of objectives. Before a successful transition to electric vehicles in public transportation in South Africa could happen, there will be a need for the policymakers to answer at least the following major strategic questions:

- How will charging VAT and/or excise duty (as in the case of passenger electric vehicles) be carried out properly?
- How can electric minibus taxis (e-MBTs) through the Taxi Recapitalisation Programme be deployed and promoted?
- Will enhanced access to favourable interest rates for financing electric buses and electric minibus taxis (e-MBTs) be implemented?
- Will there be an improvement in public procurement practises, specifically focusing on metropolitan buses and Bus Rapid Transit systems?
- What type of incentives will the government offer to manufacturers, importers, exporters, owners, drivers, and passengers of EVs?
- How will e-hailing be profitably aided by EVs?

5.3. International Funding Challenges

South Africa aims to invest billions of dollars to promote the development of the electric vehicle (EV) industry, leading to complexities in finalizing a USD 8.5 billion climate aid package before the upcoming United Nations climate summit [157]. The funding plan, initially introduced at the Conference of the Parties (COP) summit in Glasgow, was designed to assist South Africa in transitioning away from coal and serve as a model for other developing nations adopting cleaner energy sources. However, current negotiations have stalled due to disagreements regarding the allocation of funds. Funders which are the US, UK, Germany, France, and the EU, intend for the majority of the funds to be invested in replacing South Africa's coal-fired power plants with renewable energy infrastructure. On the other hand, South Africa seeks a significant portion of the funding to support the growth of its electric vehicle manufacturing sector [158]. As part of an updated draft investment plan presented to funding partners, South Africa has included a five-year, ZAR 70 billion (USD 3.9 billion) subsidy programme for electric vehicles. In total, the plan proposes ZAR 128 billion of spending on electric vehicles, with some of the funds directed towards industrial development and innovation initiatives. South Africa, as the 13th-largest emitter of greenhouse gasses globally heavily relies on coal for over 80% of its electricity generation. The success of South Africa's transitioning away from coal serves as a crucial pilot test for other developing nations that heavily depend on coal-powered grid [159].

NAAMSA is currently allowing the deployment of charging stations for light commercial and motor vehicles to the end of June 2023. The project, valued at "hundreds of millions of rands", aims to establish a new-energy vehicle (NEV) charging infrastructure across the country without government assistance. NAAMSA, representing various locally based original equipment manufacturers (OEMs) and vehicle importers and distributors, is coordinating the financing of this initiative. The Automotive Industry Transformation Fund is also contributing to the funding. Due to the scale of the project, multiple contractors will be involved in installing NEV infrastructure along significant sections of the national road network, including the N1 road from Musina to Cape Town, the N2 road from Cape Town to Richards Bay, the N3 road from the Port of Durban to Gauteng, and the N4 road through Mpumalanga [40,66,67].

5.4. Battery Challenge in EVs

Battery lifespan and recycling are among the biggest issues for EV development [160,161]. However, battery recycling can be a sustainable method of countering this critical issue as batteries are essential components susceptible to issues like capacity reduction and failure, caused by factors like ageing, extensive use, and adverse weather conditions. Another potential future solution is battery swapping, an innovative promising technology in the EV industry. This approach brings various advantages, such as shorter charging times, extended driving ranges, and cost-effectiveness, especially for fleets and commercial EV applications. However, the adoption of battery swapping faces certain challenges that need to be addressed, including high infrastructure costs, safety, and ensuring compatibility and interoperability with diverse EV models [162–164].

To mitigate the high manufacturing cost of EV batteries, automotive engineers have proposed the development of solid-state batteries with enhanced distance range and rapid charging capabilities. Toyota has achieved a breakthrough in this area by streamlining the production of materials required for solid-state batteries. This advancement is being lauded as a significant leap forward, facilitating reduced charge times and extended driving ranges [165–167].

The primary objective for both liquid and solid-state batteries is a drastic transformation of their current characteristics, which include being too large, heavy, and expensive. The ultimate aim is to halve these factors and achieve significant improvements in battery technology [168–170].

The current limitations of lithium-ion batteries, particularly in terms of space, are largely attributed to the presence of liquid electrolytes. While energy density has improved over the years, lithium-ion batteries still fall short of meeting the auto industry's ambitious goals and requirements. Moreover, their liquid electrolyte component renders them more susceptible to hazards and volatility, posing safety concerns, especially in the event of accidents or battery punctures. Solid-state batteries, on the other hand, offer superior safety by eliminating liquid electrolytes and thereby reducing the risk of fires compared to lithium-ion batteries. The chances of EV fires is a significant concern, though, only 25 incidents per 100,000 vehicles were reported, making fuel-powered vehicles the second most susceptible and hybrids the most prone to fires [171–173]. The adoption of solid-state batteries can further enhance safety standards in electric vehicles [174–177].

6. Analysis Based on Questionnaire's Data

The production rate of electric vehicles (EVs) in South Africa remains significantly low, with the majority of EVs being imported. The importation process incurs additional costs due to import duties and taxes. To assess the impact of local EV production and the extent of governmental intervention required in skills development for EV manufacturing, a series of questions were posed to a group of professionals and students. This survey included 51 respondents, all holding qualifications ranging from master's degrees to PhDs. The respondents' net income and familiarity with EVs were also considered to gauge the significance of their responses. The questionnaire setup used for this study are presented in Table A1 of Appendix A.

Table 7 provides statistical data on the respondents and the questions asked. One of the key questions, Question 6, inquired whether local production of EV components would promote economic growth and sustainability in South Africa. Another important question explored whether the government should invest more in skill development for the EV manufacturing sector. Respondents rated their agreement on a scale from 0 to 4, where 0 indicated strongly agree and 4 indicated strongly disagree. Table 7 also shows the qualification range of the respondents. Most of the respondents are middle-income earners with a mean value of 2.22.

Table 7. Descriptive statistics.

	N Statistic	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
						Statistic	Std. Error	Statistic	Std. Error
Highest Qualification	51	1	8	6.27	2.127	−1.362	0.333	0.835	0.656
Net Income	51	0	6	2.22	1.566	0.147	0.333	−0.687	0.656
Familiarity with EVs	51	0	3	1.22	1.101	0.207	0.333	−1.371	0.656
Do you wish to own an EV?	51	0	2	0.39	0.777	1.575	0.333	0.615	0.656
Do you know the cost of electric vehicles?	51	0	2	1.14	0.722	−0.213	0.333	−1.014	0.656
Q6	51	0	4	0.75	0.956	1.258	0.333	1.370	0.656
Q7	51	0	3	0.45	0.856	1.752	0.333	1.896	0.656
Valid N (listwise)	51								

Source: authors' compilation.

For Question 6, the mean value shows that the respondents are of the opinion that local production will increase economic growth in the country while that of question 7 also shows that the impact of governments is highly needed for skill development. The skewness and kurtosis of these two questions show that a skewness of 1.258 and 1.752 with a standard error of 0.333 for questions 6 and 7, respectively, suggests a positively skewed distribution, where the right tail is longer or fatter than the left tail which also indicates a positively skewed distribution. According to the rule of thumb, if the skewness is greater than 1, the data are highly skewed. In this case, both skewness values exceed 1, suggesting that the data distributions are highly positively skewed. A kurtosis of 1.370 and 1.896 with a standard error of 0.656 for both respective questions indicate a leptokurtic distribution, which is more peaked and has heavier tails compared to a normal distribution. The summary of these values shows the significance of both skewness and kurtosis values that these deviations from normality are not due to random chance and are meaningful characteristics of the data.

6.1. Question 6 Significance Test

For Question 6, the t-value of 5.567 indicates the ratio of the difference between the sample mean and the population mean relative to the standard error of the mean as shown in Table 8. A higher t-value signifies a greater divergence between the sample mean and the population mean, suggesting that the observed effect is highly unlikely to be due to random chance. The p-value of <0.001 indicates that there is less than a 0.1% probability that the observed result is due to random variation, implying a highly significant outcome and strong evidence against the null hypothesis. The t-test result, with a t-value of 5.567, and a p-value of <0.001, confirms a statistically significant difference between the sample mean and the population mean (or between two sample means if applicable).

The mean difference of 0.74, with a 95% confidence interval ranging from 0.48 to 1.01, indicates that the observed difference is not only statistically significant but also practically meaningful. Given the extremely low p-value, the null hypothesis, which typically states that there is no difference, can be rejected with high confidence. These results provide robust evidence that the observed mean difference is not due to random chance, and the true mean difference is likely to lie within the specified confidence interval. This suggests a meaningful deviation from the hypothesized population mean, with the sample mean being significantly different.

Table 8. *t*-test for Questions 6 and 7.

	t	df	Sig. (2-Tailed)	Mean Difference	95 % Confidence Interval of the Difference	
					Lower	Upper
Q6	5.567	50	<0.001	0.745	0.48	1.01
Q7	3.763	50	<0.001	0.451	0.21	0.69

Source: authors' compilation with Test Value = 0.

6.2. Question 7 Significance Test

For Question 7, the t-value of 3.763 indicates that the sample mean is 3.763 standard deviations away from the hypothesized population mean, suggesting a substantial difference as shown in Table 8. The *p*-value of <0.001 indicates that there is less than a 0.1% probability that the observed difference is due to random variation, which denotes a highly statistically significant result. The t-test result, with a t-value of 3.763 and a *p*-value of <0.001, confirms a statistically significant difference between the sample mean and the population mean (or between two sample means if applicable).

The mean difference of 0.451, with a 95% confidence interval ranging from 0.21 to 0.69, suggests that the observed difference is both statistically significant and practically meaningful. Given the extremely low *p*-value, the null hypothesis, which typically states that there is no difference, can be rejected with high confidence. These results provide robust evidence that the observed mean difference is not due to random chance, and the true mean difference is likely to lie within the specified confidence interval. This indicates a meaningful deviation from the hypothesized population mean, with the sample mean being significantly different.

6.3. Clustered Analysis of Questions 6 and 7

The clustered analysis of Questions 6 and 7, based on two respondent factors—familiarity with electric vehicles (EVs) and qualifications—is depicted in Figures 15 and 16. These figures illustrate the strong beliefs of individuals who are well-versed in EVs and possess relevant qualifications.

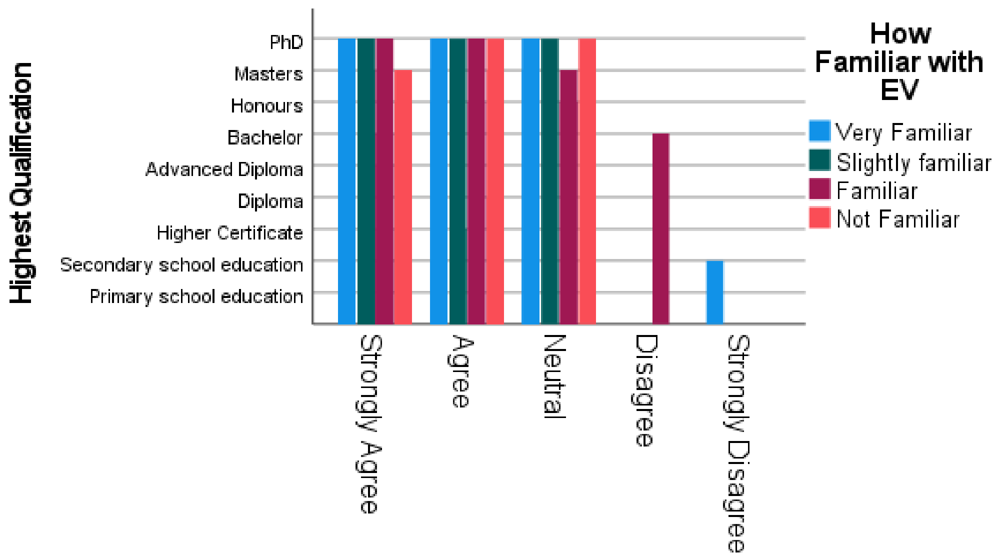


Figure 15. Clustered bar diagram of highest qualification by Q6 by familiarity with EVs.

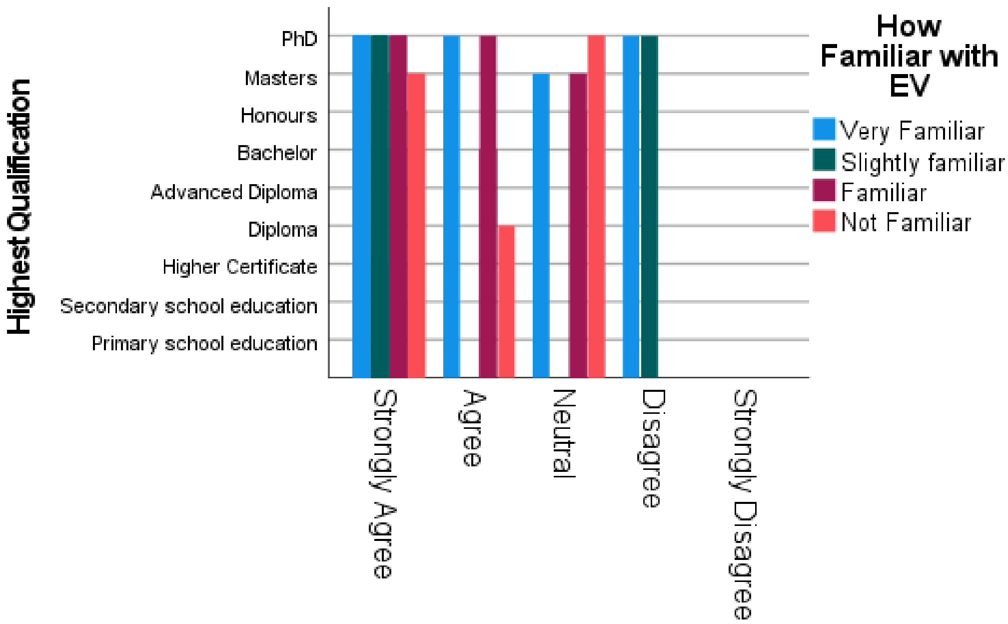


Figure 16. Clustered bar diagram of highest qualification by Q7 by familiarity with EVs.

Figure 15 showcases the correlation between respondents' familiarity with EVs and their support for local production of EV components, indicating a potential boost in EV adoption rates within the country. Similarly, Figure 16 reflects respondents' agreement with the notion that government investment in skill development for the EV manufacturing sector is crucial.

In essence, the successful adoption of EVs hinges on various factors, with governmental involvement in parts, components, and skill development playing a pivotal role in fostering a robust EV manufacturing industry. The alignment of responses to Questions 6 and 7 underscores the significance of government intervention in enhancing the adoption rate of EVs in South Africa, offering valuable insights into strategies for achieving a more widespread EV adoption in the region. This analysis offers valuable insights into strategies for achieving more widespread EV adoption in the region, emphasizing the importance of targeted government policies and investments in building the necessary infrastructure and skills base.

Q6: The local production of EV components will promote economic growth and sustainability.

Q7: The government should invest more in skill development for the EV manufacturing sector.

7. Future Trends and Research Gaps

To have a high penetration of EVs, the government, through proper legislation, needs to lower the total cost of ownership by reducing the import duty tariff. The government also needs to create a favourable electricity tariff structure and give a purchase subsidy for any vehicle owner willing to purchase EVs or companies willing to operate a fleet of EVs. By doing this, the over-reliance on ICE vehicles will be reduced. The South African government has implemented several policies to support the adoption of electric vehicles (EVs) in the country [156].

One of the main hindrances to the usage of EVs is the lack of adequate public charging infrastructure. This problem can be tackled by allowing private investors in the EV market, giving incentives for carports with EV charging stations, installing charging stations in key locations such as shopping centres and highway rest areas, and developing a national charging network.

Giving preferential access to reduce the amount of traffic on general lanes, free parking, dedicated lane access, reduced licence cost, etc., can be added motivations for owning EVs.

Also, skills development, awareness, communication campaigns and proper enlightenment will go a long way toward making people embrace EV usage.

Investing in regional economic development programmes by converting ICE's existing production and supply infrastructure into a manufacturing plant for EVs.

Different universities and research institutes are currently working towards the local manufacturing of EV components; however, there is a slow pace in this field in the country. State-of-the-art research and developments will also go a long way to improve EV performance and efficiency. Future research topics on EVs in SA and globally can focus on the improvements of the motor, batteries, converter design, fast charging ports for EVs, smart charging, contactless charging of EVs, and EV load impacts on the grid. These three areas encompass the performance, range, charging and discharging rate of batteries, cost/time charging rate, optimization for V2G, self-driving or autonomous vehicles, etc. More research should focus on the new technology for EV batteries.

The problem with Eskom's power-generating capacity shortage can be managed by integrating renewable energy sources into the grid, giving allowances for V2G and G2V, creating optimal charging behaviour and improving optimization of the charger controllers and vehicle charging stations. A smart charge control centre linked with a smartphone for charge updates will help reduce overcharging and thus reduce electricity consumption. A reduction in electricity tariffs will bring about a changed behaviour to EV ownership.

The successful automotive sector that can compete in the global EV market is also a key to growth in the EV sector. An increase in research and development on battery storage systems and different converter architectures will help increase EV range and reduce losses and discharge rates. The government also needs to enable an environment that will aid the creation of the fourth and fifth industrial revolutions in manufacturing different battery storage systems (BSS) and compliant converter architectures. This can be achieved by proper skills development programmes.

Employment vulnerability assessment combined with resilience plans, active labour market policies (skills development), regional economic development programmes, and modernisation programmes for public transport with a pass-through of benefits to commuters are a few of the policies African governments need to embrace. Others include the following:

- The inclusive rollout of EVs;
- The allocation of budget to address imbalances in EV ownership;
- Support to new consumption models that do not rely on EV ownership;
- A reconsideration of government financing models;
- A balanced and just energy transition.

Future research endeavours should adopt a holistic approach by considering the entire value chain of EVs encompassing raw materials, processing, and discrete component manufacturing. These components include the electric motor, transmission, batteries, electronics, capacitors, braking system, structural elements, wheels, and tyres, along with the vehicle base as penetration into these key areas is still very low as shown in Figure 17. By doing so, a comprehensive financial model can be developed to assess cost elements and pinpoint variable changes that offer the most substantial cost reduction benefits.

Apart from advancing battery technology, an exploration into other areas like carbon fibre and lightweight materials holds potential to increase EV range, lower costs, and reduce environmental emissions. Additionally, conducting a comprehensive "well-to-wheel" emissions study can ensure that electric vehicles truly function as a green technology option. As the adoption of battery electric vehicles (BEVs) rises, the study of time-of-use charging behaviour in the residential sector becomes more imperative. The understanding of the daily BEV demand on electricity load will significantly support grid integration studies.

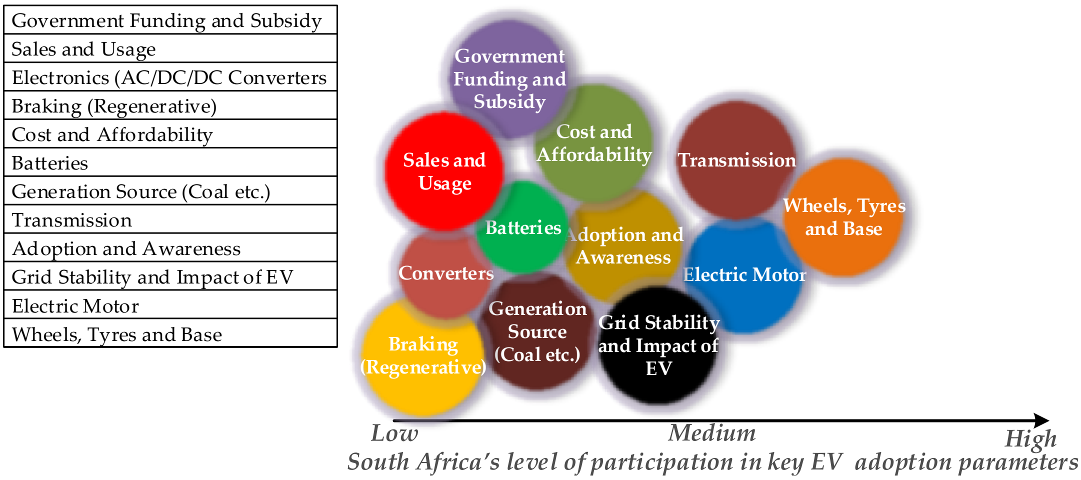


Figure 17. Highlighting what is being done, and at what level is being done from low, medium, and high.

8. Conclusions

When compared to internal combustion engines, EVs have a significant potential for decreasing greenhouse gas emissions and air pollution. South Africa's shift to EVs might considerably help the country's efforts to mitigate climate change and improve urban air quality. Therefore, this paper gives a comprehensive detail of the percentage usage and current adoption rate of electric vehicles in South Africa. The statistical data shows that South Africa is still in its early adoption of EVs compared to other countries outside Africa. However, there is a promising future as many automakers have begun introducing electric vehicles into the South African market. Although EVs boast of reduced direct emissions, it is vital to evaluate the complete lifecycle of these vehicles from battery production to the procurement of raw materials. These can influence the environment, particularly when it comes to mining and processing elements such as lithium, cobalt, and nickel.

Different companies and organizations are working to promote the use of EVs in South Africa. Government data from the Department of Energy show a recently launched programme to install EV charging stations in various locations, including shopping centres, office buildings, and government buildings. Therefore, the charging infrastructures must be carefully planned, or else, the increasing demand for electricity from EV users might overburden the current power grid. The incorporation of renewable energy sources into the grid might help overcome these issues and optimize the benefits of EVs.

Furthermore, ongoing initiatives aim to enhance awareness of the benefits of electric vehicles (EVs) and educate consumers about the various EV options available. These efforts include the implementation of incentives such as tax rebates and the expansion of charging infrastructure to facilitate the rapid transition of diverse mobility sectors to EVs.

Data collected through questionnaires, stratified by participants' income levels, indicate a greater willingness among higher-income individuals to transition to EV usage. Additionally, respondents express the belief that an increased local production of EVs will substantially reduce the overall ownership costs of EVs.

Despite these initiatives, the report shows some challenges limiting the widespread adoption of electric vehicles in South Africa, such as the high cost of ownership, lack of awareness of its benefits, insecurity and theft, and the limited availability of charging infrastructure. To expedite the adoption of EVs in South Africa, the governments need to review their policies and provide incentives such as tax breaks, subsidies, and the construction of charging infrastructure. Not only would this cut pollution, but it would also encourage the local electric vehicle sector and generate new economic prospects. Public education and awareness are also critical in raising awareness about the environmental benefits of EVs.

In summary, the adoption of EVs in South Africa offers a potential avenue to reduce GHG emissions and provide a more sustainable means of transport, especially if charged via a renewable energy medium. However, to realize the full potential of EVs in attaining a more environmentally friendly transportation system for the country, a comprehensive approach that examines the whole lifetime of EVs, tackles infrastructural challenges and adopts supporting policies is required. Adequate research on different aspects of EV design, modelling, and analysis, especially on the analysis of the impact of V2G on the grid is also crucial.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Questionnaires Setup.

	Questionnaires	Range of Responses and Code Used on SPSS	
Q2	Highest qualification obtained	Primary school education (0) Secondary school education (1) Higher Certificate (2) Diploma (3) Advanced Diploma (4)	Bachelor (5) Honours (6) Masters (7) PhD (8)
Q3	What is your net monthly income?	ZAR 100 to R4999 (0) ZAR 5000 to R9999 (1) ZAR 10,000 to R19,999 (2) ZAR 20,000 to R39,999 (3)	ZAR 40,000 to R 59,999 (4) ZAR 60,000 to R 99,999 (5) ZAR 100,000 and above (6)
Q4	How familiar are you with electric vehicles (EVs)?	Very familiar (0) Slightly familiar (1) Familiar (2) Not familiar (3)	
Q5	Would you like to own an electric vehicle?	Yes (0) No (1) Maybe (2)	
Q6	The local production of EV components will promote economic growth and sustainability	Strongly agree (0) Agree (1) Neutral (2) Disagree (3) Strongly disagree (4)	
Q7	The government should invest more in skill development for the EV manufacturing sector		

Source: authors' compilation.

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