Managing the rapidly growing electric vehicle load on distribution networks

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While electric mobility is still in its infancy in South Africa, a global transition to electric vehicles (EVs) is underway. The uptake of EVs is steadily gaining momentum in South Africa, and EV sales are expected to grow exponentially in the coming years. Over the last decade, virtually all municipal electricity utilities have seen a decrease in sales volumes. However, transportation electrification is a major opportunity for load growth. While this load growth can lead to significant revenue growth for municipalities, the growing EV load will need to be managed carefully to ensure adherence to network operating parameters. This paper assesses the impact of EVs on the City of Johannesburg's network by forecasting the impact of EVs on electricity sales and peak demand. The EV load is disaggregated onto the network's substations to evaluate the impact of EV load growth on network congestion. The conclusion proposes initial recommendations to manage the grid impacts of EVs.

Introduction

Electric vehicles (EVs) are central to decarbonising the transport sector and will play a key role in achieving global climate commitments. South Africa lags the global EV uptake trend and EVs remain extremely marginal in terms of vehicle model availability, vehicle demand as well as local manufacturing capability. However, as the price of EVs continue to decline and more models become locally available, an accelerating uptake of EVs is expected, as has occurred in other countries where price parity is reached.

Government's ambition within the EV space is increasing rapidly, as described in the various policies and plans to accelerate the uptake of EVs in South Africa. Key national policies include the Department of Transport's Green Transport Strategy and the Department of Trade, Industry and Competition's Auto Green Paper, which describe the importance of transitioning to electric mobility from both a socio-economic and environmental perspective.

Forecasting the uptake of EVs in Johannesburg

The uptake of EVs was forecasted for the City of Johannesburg metropolitan area for 2030, 2040 and 2050 to identify the impact of EV electricity demand on City Power's distribution grid. A bottom-up mobility model was developed, with baseline years based on the eNaTIS[1] vehicle registration data and assumptions on vehicle occupancy, daily distances travelled, fuel intensity and fuel shares by vehicle type. The uptake of EVs was based on modelling targets behind the City's Climate Action Plan and

[1] Electronic national administration traffic information system

differed by vehicle type according to the likelihood of EV uptake in each vehicle category, as shown in Table 1. The model also took into account mode shift targets within the City's Climate Action Plan, which envisages a higher share of public passenger transport (increasing by more than 20 percentage points).

Table 1: EV uptake by vehicle type in Joburg

Vehicle type	Rationale
Heavy load 	**Slow EV uptake** ○ Rationale: large batteries, high power charging and long travel distances. ○ Assumption: 1% of heavy load vehicles electrify by 2030, 14% by 2050.
Light load 	**Slow EV uptake:** ○ Rationale: uptake driven by short-distance applications with overnight charging (deliveries). ○ Assumption: 1% of light load vehicles electrify by 2030, 14% by 2050.
Buses 	**Medium EV uptake:** ○ Rationale: uptake driven by City BRT targets. ○ Assumption: 2% of buses electrify by 2030, 50% by 2050.
Minibuses 	**Medium EV uptake:** ○ Rationale: driven by total cost of ownership and government incentives. ○ Assumption: 2% of minibuses electrify by 2030, 50% by 2050.
Cars 	**Fast EV uptake:** ○ Rationale: model availability increasing and price parity rapidly approaching. ○ Assumption: 2% of passenger cars electrify by 2030, 60% by 2050.
Motorcycles 	**Rapid EV uptake:** ○ Rationale: shorter travel distances and increasing difficulty for high-revving engines to meet current EURO standards. ○ Assumption: 4% of motorcycles electrify by 2030, 100% by 2050.

The uptake of EVs, according to these assumptions, is provided in Figure 1. A total of 1.3 million EVs is projected by 2050 – making up 44% of the city's vehicle population. By 2030, expected uptake is 40-50 thousand EVs. The largest number of EVs will be private passenger cars, at 75% of overall EVs in 2050, due to the high number of private vehicles combined with high uptake. Despite modest EV uptake rates in light-duty commercial vehicles (small trucks and bakkies), due to the large number of these vehicles, they represent the second-largest EV vehicle market by 2050.

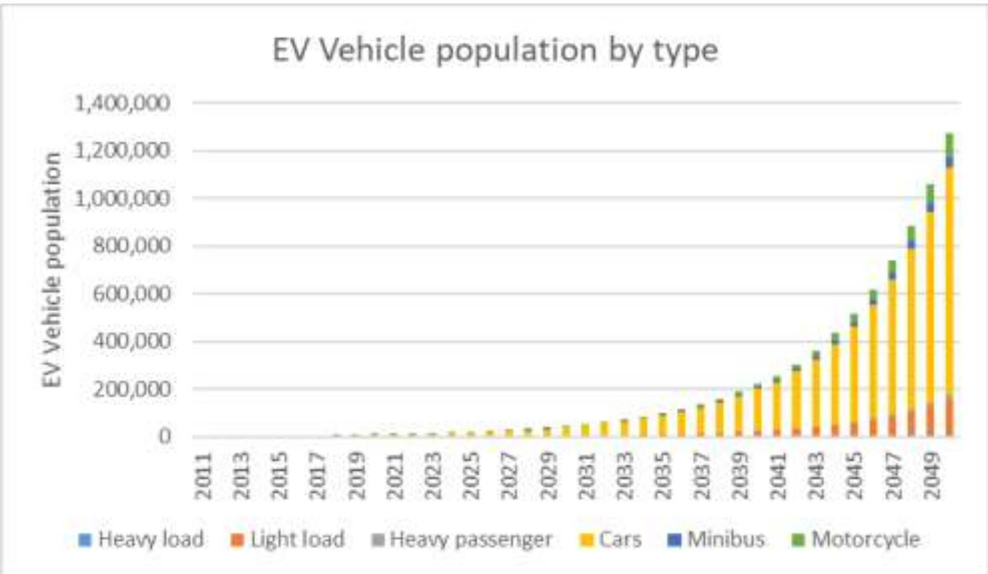

Figure 1: Electric vehicle uptake by vehicle type

The impact of EVs on City Power's grid

Figure 2 quantifies the electricity demand expected from the projected uptake of EVs; about 3.1 million MWh (3.1 TWh) by 2050, across both Eskom and City Power distribution areas. Most of this demand will be from cars (58%) and light-duty trucks (24%). As such, the electrification of transport is one of the only major load growth opportunities in the foreseeable future. If managed correctly, this load growth can translate to significant revenue growth. Yet it must be noted that some of this additional demand may be met by independent power producers or, for car charging by private households, by rooftop PV.

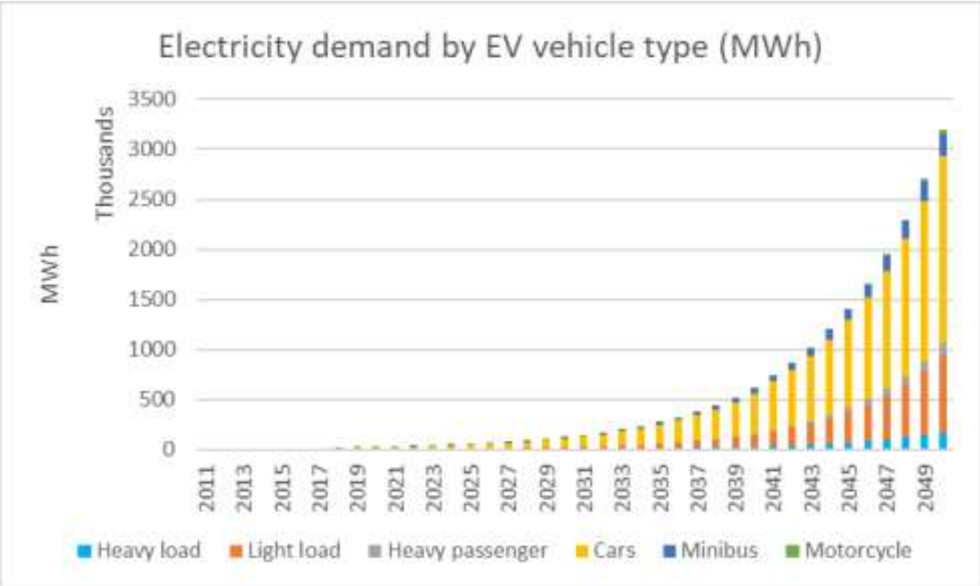

Figure 2: Electricity demand by EV vehicle type

The additional EV electricity demand is compared to demand forecasts (without EVs) in Figure 3. The demand forecast for other sectors was based on emissions modelling related to the City's Climate Action Plan, and follows demand expected in a scenario of ambitious energy efficiency policies and actions across all sectors. By 2050, EVs are expected to increase electricity demand across the city (including Eskom and City Power distribution areas) by 8%.

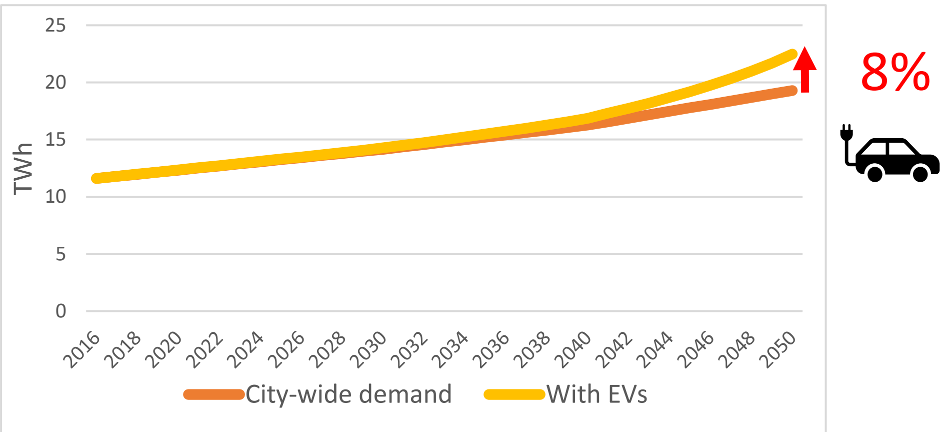

Figure 3: The impact of EVs on city-wide electricity demand

While an 8% increase in electricity demand may seem manageable from an overall system perspective, the localised impact of EVs on the distribution grid is significantly more complex. The adoption of EVs will not be uniform across the City, both in terms of geographic distribution and density. As is the case with rooftop solar PV, EVs are typically found in clusters, linked to suburbs with higher shares of high-income households or to large commercial and industrial facilities, such as malls. Managing these localised impacts will be the greatest challenge for electricity distributors such as City Power.

Roadside EV chargers, or those linked with bus or truck depots, can be installed on higher-voltage networks, while private chargers installed for charging at people's homes will be on low-voltage networks, which usually have less capacity available to deal with the additional load. International experience also indicates that the vast majority (>80%) of EV charging will take place at people's homes[2]. As a result, the focus on the spatial impact of EV charging was on that of charging by private vehicles (cars).

The EV demand forecast for private vehicles was spatialised using ward-level data on household income and car ownership from Statistics South Africa's 2011 Census. It was assumed that EV uptake will be higher in wards where a high share of households are high-income households and where a high share of households already own a car. Figure 4 shows the EV hotspot map and illustrates that EV uptake will be concentrated around the wealthier Northern suburbs of Johannesburg. As such, the substations feeding these areas can expect a significant load growth due to EV uptake.

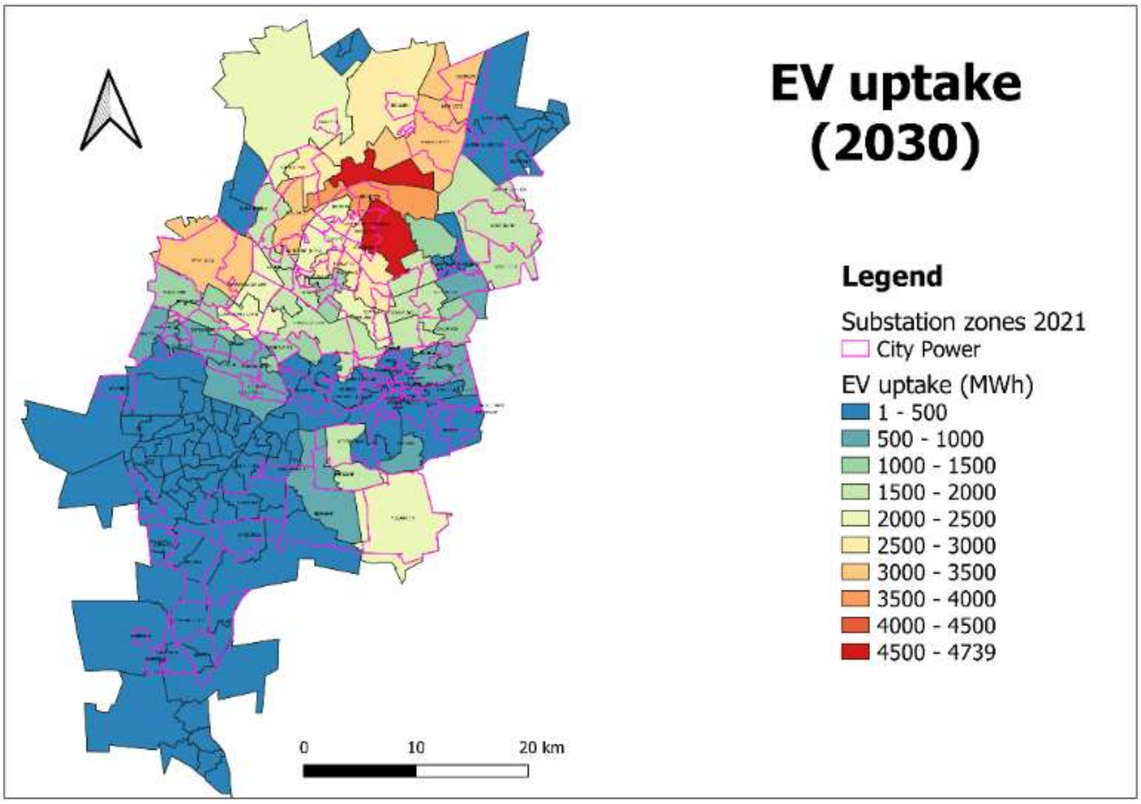

Figure 4: EV hotspot map: annual energy demand from EVs on City Power substations in 2030

Without incentives, EV owners are inclined to start charging their vehicles as soon as they arrive home after work, which will exacerbate network peak demand significantly. In other words, unmanaged "dumb" EV charging is highly likely and will drive costly grid infrastructure upgrades. Figure 5 shows the overall demand impact of various EV charging scenarios on Johannesburg's load profile. Dumb charging increases the City's peak demand. Furthermore, since residential inclining block tariffs are lower than Eskom Megaflex peak prices, the City sells electricity at a loss during peak periods to residential customers. As a result, dumb EV charging will lead to revenue loss for the City, as well as increased costs related to upgrading the substations in order to deal with the additional load.

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[2] US Department of Energy

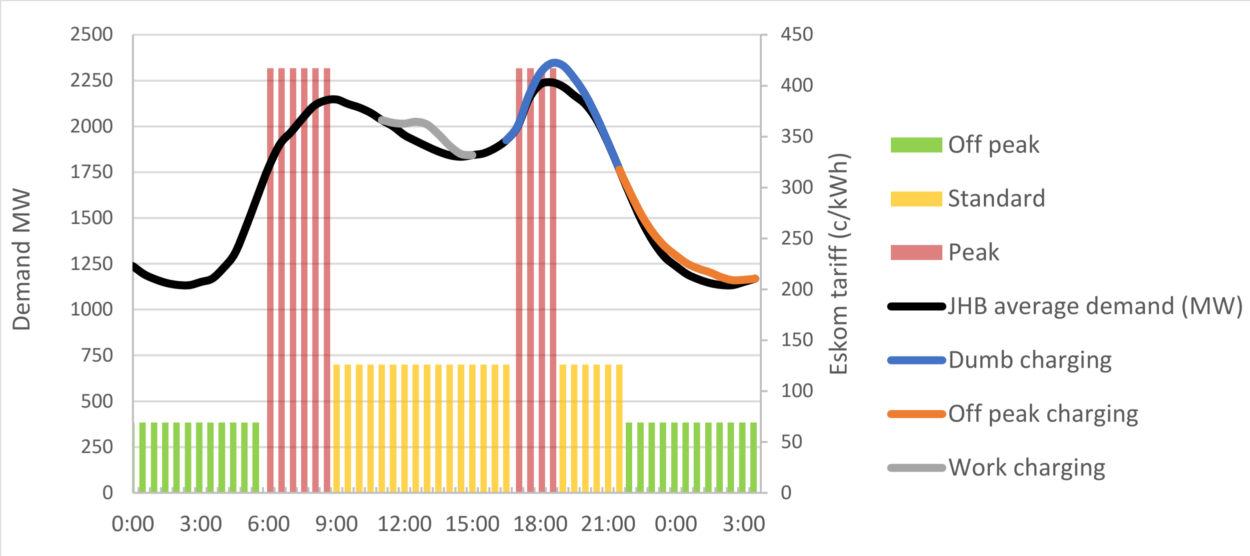

Figure 5: Impact of EV charging scenarios of Joburg's load profile

At-work charging (during the middle of the day) and off-peak charging (during the middle of the night) are preferable alternatives, as these scenarios will delay and/or reduce costly infrastructure upgrades and are revenue positive for the City. Incentivising off-peak and at-work EV charging is therefore the single-most important challenge facing distribution utilities in managing EV uptake.

Managing the grid impacts of EVs

As electricity distributors, municipalities have the authority to develop policies, plans, strategies and programmes in the best interests of the community. In determining an appropriate strategy to manage the grid impacts of EVs, municipalities should consider the effectiveness of previous technology responses as well as the lessons learnt internationally.

The case against mandatory EV registration

When considering the registration of EV chargers to mandate a desirable charging regime, there are important lessons to learn from the challenges of registering embedded generators, such as rooftop PV. Generators legally require registration with the local distribution utility. However, compliance by customers has been low across the country. Both the City of Johannesburg and the City of Cape Town performed aerial surveys, revealing that most residential rooftop PV systems were unregistered[3].

While embedded generation registration has been difficult, EV registration will be even more challenging. Embedded generation systems are usually PV systems, located on rooftops, making them publicly visible. In contrast, private EV chargers will be installed within garages. Furthermore, the electricity consumption pattern of an EV owner may not change dramatically enough to pick up on the billing system, since a typical 3.5 kVA charger has a similar – even slightly smaller – demand to that of a conventional electric geyser. The other standard household charger size of 7.5 kVA may produce more noticeable consumption pattern changes.

International experience indicates that customers will only register EV chargers when they have compelling incentive to do so. In the UK, customers installing an EV charger can receive a government grant linked to emissions reduction, if their charger is registered. Within the South African context, it is untenable to use government grants for infrastructure installed by high-income households.

[3] Direct communication with the respective municipalities.

The case for mandatory time-of-use tariffs

An internationally recognised strategy to manage EV loads is to implement an EV time-of-use (ToU) tariff. The design of these tariffs should incentivise consumers to charge during off-peak hours, by offering lower tariffs during these times (usually between midnight and 6am). This will reduce the EV owner's charging cost, while also reducing the cost of City bulk electricity purchases by avoiding purchases in the expensive peak periods. These tariffs should be developed through engagement with Nersa[4].

Future considerations can include further tariff advancement, such as demand response programmes to manage charging in response to real-time grid conditions. The chargers being installed locally by charge point operators already have the functionality to respond to real-time demand by – for example – ramping down EV charging in response to higher demand by other household appliances.

The case for increased public EV charger rollout

International experience has shown that most charging will take place at home – on residential low-voltage feeders – where grid capacity is most constrained. To reduce home charging, municipalities could facilitate public charging availability in areas where there is grid capacity, such as on higher-voltage networks. As such, public EV chargers can incentivise the uptake of EVs by alleviating range anxiety, while simultaneously reducing the grid impact of EV charging on low-voltage networks.

Conclusion

The uptake of EVs is expected to accelerate rapidly through the 2020s. The uptake will vary across vehicle categories – motorcycles and passenger cars are expected to electrify most rapidly. By 2030, 40 thousand EVs are expected to be on Johannesburg's roads, a rapid growth from the few hundred EVs in 2021. EV uptake will have a range of impacts on municipal electricity utilities. EVs are expected to drive an 8% load growth in Johannesburg by 2050, which is a significant revenue growth opportunity. Conversely, since the majority of the EV load is expected to be concentrated in wealthier suburbs, EVs will have a considerable impact on distribution grids if not managed appropriately.

A range of EV management strategies have been proposed internationally, typically depending on a mandatory EV registration process. However, mandatory registration of embedded generators has been challenging for local municipalities and mandating the registration of EVs is expected to be even more challenging. Appropriate EV management for South Africa include the introduction of mandatory ToU tariffs for all residential customers, and the accelerated rollout of public EV chargers in areas where grid capacity is highest.

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[4] National Energy Regulator of South Africa