Rethinking Economic Policy for South Africa in the Age of Covid-19:

Innovative policy responses for the post-lockdown Phase

Vehicle-to-Grid (V2G) energy-transport system

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A V2G energy-transport proposal for phase 3 of President Ramaphosa’s recovery plan

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Executive Summary

This NIHSS policy proposal addresses all three of President Ramaphosa's Covid-19 crisis targets for longer-term economic recovery process; namely, 1. an economic strategy to drive economic recovery; 2. continuous measures to stimulate demand and supply; and 3. a significant investment in new infrastructure. The policy aim – minibus vehicle electrification and battery storage known internationally as the Vehicle-to-Grid system (V2G) – targets a sector with clear growth, employment, and income-generation potentials. V2G not only promotes optimal charging times for eTransport – including battery-powered minibuses – but also provides for their off-take of electricity at periods of system-wide or local peak demand. When optimally implemented, it would make transport more affordable, cleaner, more streamlined, extensive, and safer; generating tens of thousands of permanent, direct and indirect transport and renewable-energy related jobs; improving air quality and reducing congestion and traffic-related accidents and deaths; and providing a source of decentralised energy storage for offtake of surplus renewable energy generation, which in turn would stimulate investment in small-scale RE generation, stabilise the grid through the provision of decentralised, vehicle-based storage, and thereby lowering average retail electricity prices.

Adequate implementation requires that network augmentation costs are addressed along with flexible charging infrastructure. After the V2G policy concept and its potential benefits are elaborated in section 1, section 2 details the economic case for V2G policy, using SATIMGE modelling, which iteratively integrates energy utilization (and associated CO2 emissions) in with dynamic assessments of demand, price and technology mix, for the period of 2020 to 2040. This also allows for comparison of different scenarios: in addition to the reference V2G case including charging infrastructure, and capex for network connection, these also include scenarios with either no transport demand profile, or no charging infrastructure, or neither additional factor.

From the exclusive perspective of maximizing generation capacity (and thus, over time, maximizing the proportion of RE generation capacity), the modelling finds that the most preferable scenario would be V2G without controlled charging stipulations, followed by neither V2G nor controlled charging stipulations for private vehicles, then no provision of additional charging infrastructure, then minibus V2G, with business-as-usual being the least preferable. However, this perspective excludes consideration of several additional variables, as elaborated upon in the conclusion, including: saved imported fuel, refining, and peaking-power costs; saved health, congestion, and traffic death costs; employment multipliers from vehicle conversion and RE construction; and stimulated rural development from extended MBT route provision.

Introduction

The third phase of President Cyril Ramaphosa's response to the Covid-19 crisis targets the longer-term economic recovery process to include:

1. An economic strategy to drive economic recovery;
2. Continuous measures to stimulate demand and supply; and
3. A significant investment in new infrastructure

This policy paper – combining public transport and energy generation and storage policy – addresses all three of these areas, with relevance to fiscal, health, labour, social, and environmental policy. Below, it first outlines the aim and mechanism of the policy. The second section provides a detailed model of its financial feasibility. The concluding section discusses potential implementation strategies.

I. Aim/ mechanism

The policy aim targets a sector with clear growth, employment, and income-generation potentials: minibus vehicle electrification and battery storage known internationally as the Vehicle-to-Grid system (V2G). A national scheme could in theory achieve several positive outcomes simultaneously, including making transport more affordable, cleaner, more streamlined, extensive, and safer; generating tens of thousands of permanent, direct and indirect transport and renewable-energy related jobs; improving air quality and reducing congestion and traffic-related accidents and deaths; and providing a source of decentralised energy storage for offtake of surplus renewable energy generation, which in turn would stimulate investment in small-scale RE generation, stabilise the grid through the provision of decentralised, vehicle-based storage, and thereby lowering average retail electricity prices.

Background:

The inclusion of large-scale renewable energy (RE) onto central electricity transmission grids (as has occurred in South Africa over the past decade) necessitates accommodating these sources' variable generation profile. This means purchasing wind and solar when it is generated, with ensuing 'peaks' and 'troughs' in both supply and demand. Because this generation is more modular and scalable than, for example, large-scale fossil fuel generation (still the norm in South Africa), it can be added and taken off the grid more rapidly than coal-fired power plants, and is thus better placed to avoid the load-shedding and blackouts plaguing the South African energy sector. At the same time, however, increased RE generation can also lead to periods when more electricity is generated than needed, thus necessitating forms of storage.

It is increasingly recognized that the rapid electrification of transport – entailing plug-in electric vehicles (PEVs), plug-in hybrid vehicles (PHEVs) and battery electric vehicles (BEVs) – is necessary to achieve deep greenhouse gas (GHG) reduction targets.[1] Such vehicles are also increasingly cost-competitive with their internal combustion engine (ICE) counterparts in South Africa. Even at current prices, EV charging costs are lower than petrol per km travelled, meaning that interest free loans could cover most if not all of excess vehicle costs over a decade.[2] This transition to electrified transport will, however, invariably impact electricity grids due to increased electricity demand and the temporal shifting of demand peaks—offering both benefits and risks to electricity systems. Whereas 'smart' or 'controlled' vehicle charging (V1G) is widely recognized as a means of reducing peak demand on the grid, this alone does not provide additional storage.[3]

Presently, more than 300,000 minibuses operate in South Africa, providing more than 15 million daily commuter trips (more than the total number of train, bus, rapid bus transport, and Uber trips combined) accounting for the dominant mode of transport besides walking for nearly 70 percent of all SA households, with usage increasing 25 percent over the past five years (see Table 14.1 below).[4] Almost all routes are well within the typical electric minibus range of 300 km per charge. New internal combustion (ICE) minivans cost R450,000, and battery-powered models are typically at least twice as expensive (R1 million). Virtually none of the minibus fleet is electric at present, yet if the entire fleet were electrified, it would create a storage capacity of more than 7 GWh (300,000 x 60 KWh battery operating at 50 percent capacity and connected to a 7kW charger). By comparison, South Africa currently has a pumped storage capacity of almost 3 GW.[5] Thus for three hours of late-afternoon peak demand, for example, this fleet could provide backup electricity at least equivalent to the entire national pumped storage infrastructure.

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[1] Jäger-Waldau et al. 2020; Williams et al. 2012.

[2] In 2020, a 69-litre tank with 93 unleaded petrol inland (including tariff costs, discounts, et al.) cost R964 (Woosey 2020). Assuming 20km a litre yields a range of 1380 km per fill up. The average e-minibus requires 40 kWh to fully recharge; at the current rate of R2 per kWh, it would cost R80 to fully recharge ("fill up") for a range of 300 km. Thus, 4.5 recharges = 1 full petrol tank, but cost only R360; petrol therefore costs more than 2.5 times the cost of electric recharges per km. Since the average SA minibus travels over 70,000 km/year, the driver would save more than R30,000/ year, with an additional R20,000/ year in saved repair costs.

[3] Kempton 2001; Kempton and Tomić 2005.

[4] StatsSA 2018: Table 14.1; Wasserman 2019.

[5] Barta 2018.

Furthermore, as the viability for public transport becomes established, the policy could be extended to private electric vehicles – as well as privately owned homes and businesses with home energy storage systems – on purely market-based terms: owners could choose to sell electricity stored on their batteries back to the grid during peak periods, and buy at more favourable prices during trough periods, thereby evening out demand and promoting grid stabilisation. More than 10 million such privately owned vehicles currently on the roads could add at least an additional 10 GWh of battery storage capacity to the grid once full conversion to EV is achieved.[6] South Africa's ICE-dominated road transport sector is responsible for 43 million kg/year of carbon emissions[7] or 60 MtCO2eq.[8] The South African transport sector, which accounts for 14 percent of total emissions, is set to potentially become the largest greenhouse gas emitter by 2050 if the current trend of increasing motorisation and defection from public transport persists. Thus full conversion would reduce total emissions by 7 percent, and enable 50 percent of avoided emissions by 2050.

Table 14.1: Mode of transport used by household members to travel to school and work, 2018

Mode of transport	Usual transport to school		Usual transport to work	
	N	%	N	%
Walking	10 185	64,6	3 588	20,4
Bicycle/motorcycle	133	0,8	167	1,0
Minibus taxi/sedan taxi/bakkie taxi	1 079	6,8	4225	24,0
Bus	571	3,6	800	4,5
Train	55	0,4	370	2,1
Minibus/bus provided by institution/government and not paid for	462	2,9	na	na
Vehicle hired by a group of parents	1 828	11,6	na	na
Own car or other private vehicle	1 421	9,0	5932	33,7
Lift club	na	na	379	2,2
None, studies/works from home	na	na	2098	11,9
Other	34	0,2	50	0,3
Subtotal	**15 770**	**100,0**	**100,0**	**100,0**
Unspecified	**284**		**220**	
Total	**16 054**		**17 831**	

In addition, more than 15 million privately owned homes and businesses could add more than 1 TWh (1000 GWh) of further capacity, with the added advantage that older batteries no longer suited for optimal driving use – but still retaining up to 80 percent of their charge capacity – can still serve as modes of home-based storage, thereby further stabilizing the grid.

[6] StatsSA 2018: Table 14.1; AA 2018.
[7] Tongwane, Piketh, Stevens, & Ramotubei, 2015.
[8] Ahjum, Merven, Stone, and Caetano 2018.

Although South Africa has far more wind and solar potential than it can conceivably consume, the full extent of its potential storage capacity is nearly as great.

At the same time, since Minister of Energy Jeff Radebe gave NERSA leave to licence 500MW worth of SSEG projects without requiring his personal authorisation in 2019 (and increased the per-project ceiling from 1MW to 10MW), small-scale embedded generation (SSEG) is poised to grow at an even faster rate.[9] This will increase incentives for the provision of net-metering (enabling excess generation to be sold back to the grid) at the municipal and provincial levels, generating at least 1.5 GW of rooftop and small-commercial photovoltaic (PV) generation per year for the foreseeable future.[10] A tariff structure for surplus generation (e.g. R0.10 / KWh over the first MWh/year) could be devised that is sufficient to cover municipal costs while still providing adequate incentive for SSEG promotion. For present purposes, we presume that V2G implementation could occur more quickly, and at lower cost, on a decentralised (metro-by-metro or province-by-province) basis, than via national legislation and top-down implementation.

II. Financial feasibility

Below, we test the following hypothesis – *V2G can provide superior, lower cost, more flexible, scalable and reliable storage than current options available to SA by 2030* – using the SATIMGE model.

SATIMGE, a hard-linked energy-economic modelling platform, is used to assess the potential for battery-electric minibus taxis (eMBTs) to provide grid services. In this analysis the model is configured to dynamically assess the extent of electricity provision at the district level, and the consequent effect on capacity deployment in the electricity sector.

Unlike other energy-economic models which include either a simplified version of an economic model into an energy model or vice versa, SATIMGE combines a bottom-up integrated full sector energy systems model, SATIM, with eSAGE, a detailed dynamic recursive computable general equilibrium model for South Africa.[11] By combining these detailed models of different aspects of the country, SATIMGE is able to consistently capture all the technical detail needed for full-sector energy systems analysis and assess the impact across various agents in the economy, accounting for behavioural responses to relative price changes.

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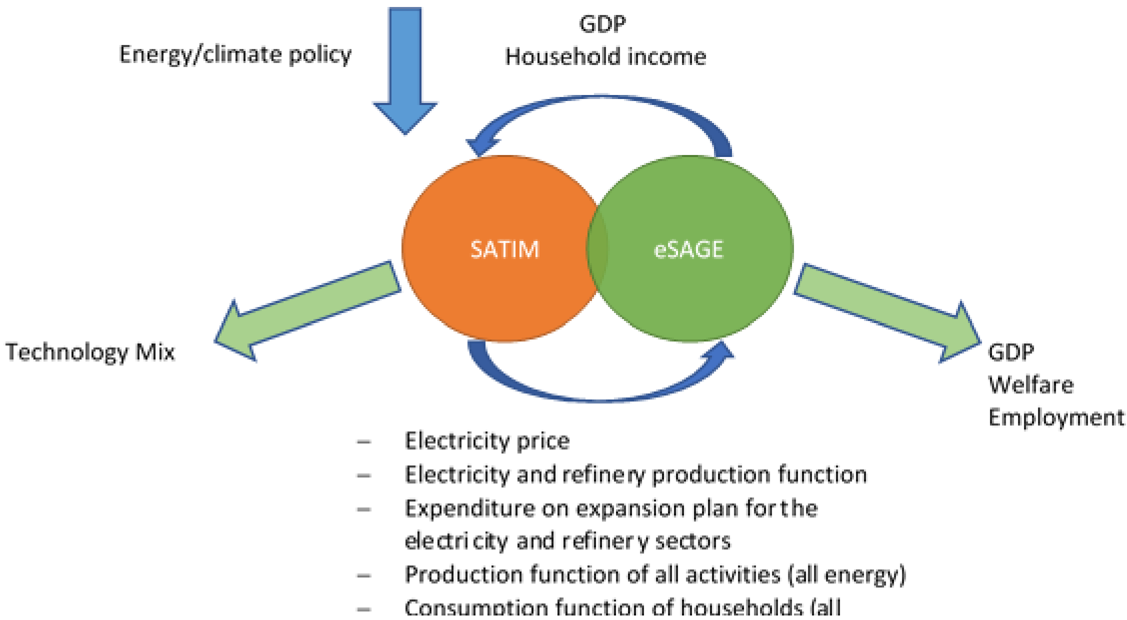
[9] Caboz 2019.
[10] Breytenbach 2017.
[11] Arndt et al. 2016.

SATIMGE links the SATIM and eSAGE models in an iterative process (see Figure 1) that mimics South Africa’s energy planning process in which energy investment and pricing decisions (in the case of electricity) are taken outside of the market. New energy and electricity investment is determined by the Department of Energy (DoE), while electricity prices are set by the National Energy Regulator of South Africa (Nersa). Specifically, given initial sector and household income growth projections, SATIM is used to compute the least-cost energy technology mix for the country including the resulting investment plan and electricity price. This information, along with information on fuel efficiency and fuel switching by agents, is passed on to eSAGE which is run to incorporate the new energy supply and demand composition. To facilitate the exogenous electricity price, the sales tax on electricity is made endogenous. This provides the eSAGE model with sufficient room for electricity demand to respond to changing electricity prices over the horizon. All other energy prices are endogenous in the eSAGE model. Updated sector and household income growth projections are then passed back to SATIM which optimises based on this new information.

This iterative process continues until the model converges such that energy utilization (and associated CO2 emissions) in both models are aligned and internally consistent in terms of demand, price and technology mix. In the first iteration, electricity and refinery sector investment is not imposed on the eSAGE model to circumvent the problem of electricity demand not responding to price changes. The SATIM and eSAGE models are calibrated based the 2012 energy balance and social accounting matrix respectively.[12]

Figure 1: Iterative approach used in SATIMGE (Updated from Arndt et al. 2016)

[12] van Seventer et al. 2016.



The existing stock of technologies (e.g. power plants, refineries, vehicle fleet), and committed build to 2022, are included in the SATIM model with existing power plants retired as specified by government.[13] Technology costs are aligned to that used in national government planning, except for renewable energy costs which are outdated.[14] Conservative costs by Ireland and Burton (2018) are used for solar PV and wind. Demand profiles for all end-uses are assumed to be fixed over time. Fuel switching for thermal and transportation energy services is allowed. The overall demand profile seen by the grid will vary over time because of differing growth rates by different sectors, fuel switching to and away from electricity, and the growth in distributed generation and storage installations. System adequacy is insured by imposing an overall reserve margin of 15 percent of firm capacity over peak demand. Thermal plants (including CSP with storage), hydro, pump storage and batteries are given a full capacity credit. PV is given no capacity credit while wind is given a 15 percent capacity credit. PV and wind profiles are aggregated to the 8 time slices used in this model from the profiles used in Wright et al. (2017) and Reber et al. (2018). Coal and nuclear based technologies are given limited flexibility in that they are not permitted to vary their output during the day. Stone et al. (2018) describes the method for the vehicle parc model calibration – in particular, the disaggregation of the freight fleet – while Ahjum et al. (2018) describes the incorporation of potential future vehicle technologies.

[13] DMRE IRP 2018.
[14] DOE IRP 2016.

As described by Stone et al. (2018), the vehicle parc model is a bottom-up technology-rich description of calibrated-to-fuel sales reported by DMRE and SAPIA, whilst vehicle population data is calibrated to the eNatis database. The parc model is a stock model and includes a representation of vehicle population survival and mileage decay per annum over the modelling horizon.

Key model revisions since Ahjum et al. (2018) are summarised below:

- Revised energy balance from 2006 to 2017 for the calibration base year.
- Differentiated petroleum products, i.e. transport versus non-transport in economy model
- Time slice electricity demand included for electric vehicles
- Assumptions for vehicle efficiency progress adjusted from Ricardo-AEA (2012) to conform with the Integrated Energy Plan (DoE, 2016)
- Refinery production and investment are linked between the energy and economy models

Battery Electric Vehicles and V2G

Battery electric vehicles, henceforth referred to as electric vehicles (EVs), have to date enjoyed increasing shares of new passenger vehicle sales. By 2025-2030, purchase price parity with conventional internal combustion engine (ICE) vehicles is forecasted, with demand for EVs anticipated to accelerate as a result without subsidy support. This is mainly due to the lower total cost of comparative vehicle fuel costs and ownership, as well as progressive improvement in driving range. The motor vehicle industry forms a key part of industrial policy in South Africa with a total contribution to national GDP estimated at between 1-7 percent of total GDP.[15] National accounts data from StatsSA indicates that direct motor vehicle production (including parts and accessories) accounts for 0.8 percent of total value added.[16] Policy-based incentives to promote the adoption of zero emissions vehicles have centred predominantly on global action to reduce greenhouse gas emissions and improve local air quality. This has resulted in, presently, electric vehicles (EVs) emerging as increasingly the technology of choice by market share. The combined change in global and potential local demand for EVs presents an opportunity for the South African automotive sector to diversify production to include EV manufacture. With an increasing emphasis on public transport in South Africa, the minibus taxi fleet presents an ideal opportunity for such a transition given its dominance in public transit ridership and the local industrial value chain.

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[15] Jordaan et al., 2018; StatsSA, 2014.
[16] StatsSA, 2014.

As noted, in addition to the environmental benefits and resource efficiency offered by EVs, the battery pack facilitates additional services as an energy storage medium. While the prime utility is the provision of motive traction in a vehicle, the battery is essentially a mobile energy services platform, able to assist with network services and stability via what is commonly referred to as vehicle-to-grid (V2G) services. In this analysis, we examine the impact of electric minibuses upon V2G capability, which requires further structural revisions of the SATGME transport model. For each vehicle type (e.g. passenger car or minibus taxi), the model is able to select from a portfolio of vehicle technologies to supplement the existing fleet in response to demand for motorised travel and the retirement of existing vehicles. For the EV option, in the case of minibuses, the battery pack is modelled as a distinct technology able to dispense energy either to the chassis for traction, or the network in response to electricity demand as depicted in Figure 2.

Figure 2: Model representation of an electric minibus able to also provide residential electricity; depicted with charging process that utilises either commercial or residential electricity

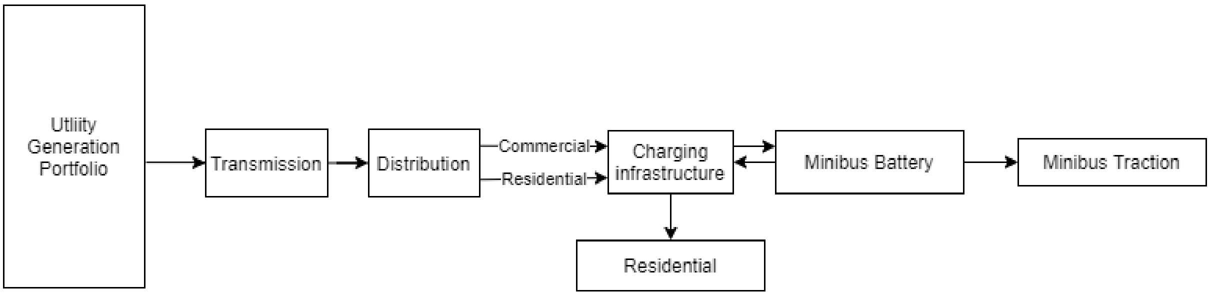


Figure 2 also shows the assumed network configuration for this study: i.e. vehicles are charged via the distribution network servicing commercial and residential premises, and can provide electricity to neighbouring residential premises. The rationale for the adopted configuration stems from the additional electricity demand in the evening and night-time periods from households occurring during low utilisation rates for taxis. As Kempton (2001) notes, at any given moment, most vehicles are not being driven, and thus would be available for electricity provision. Furthermore, additional financial incentives (e.g. favourable charging rates and vehicle financing loan terms) could be made conditional upon 'peak-shaving' electricity provision.

Time of use or time-slices (TS) for electricity supply and demand are in the current model implemented as relatively large periods. The model is a full sector-linked energy-economic model and the TS period selection is a trade-off in computational efficiency. For the preliminary assessment, the annual energy utilisation is divided into 8 intervals split between two seasons: Winter and Pre-winter, as detailed in Table 1.

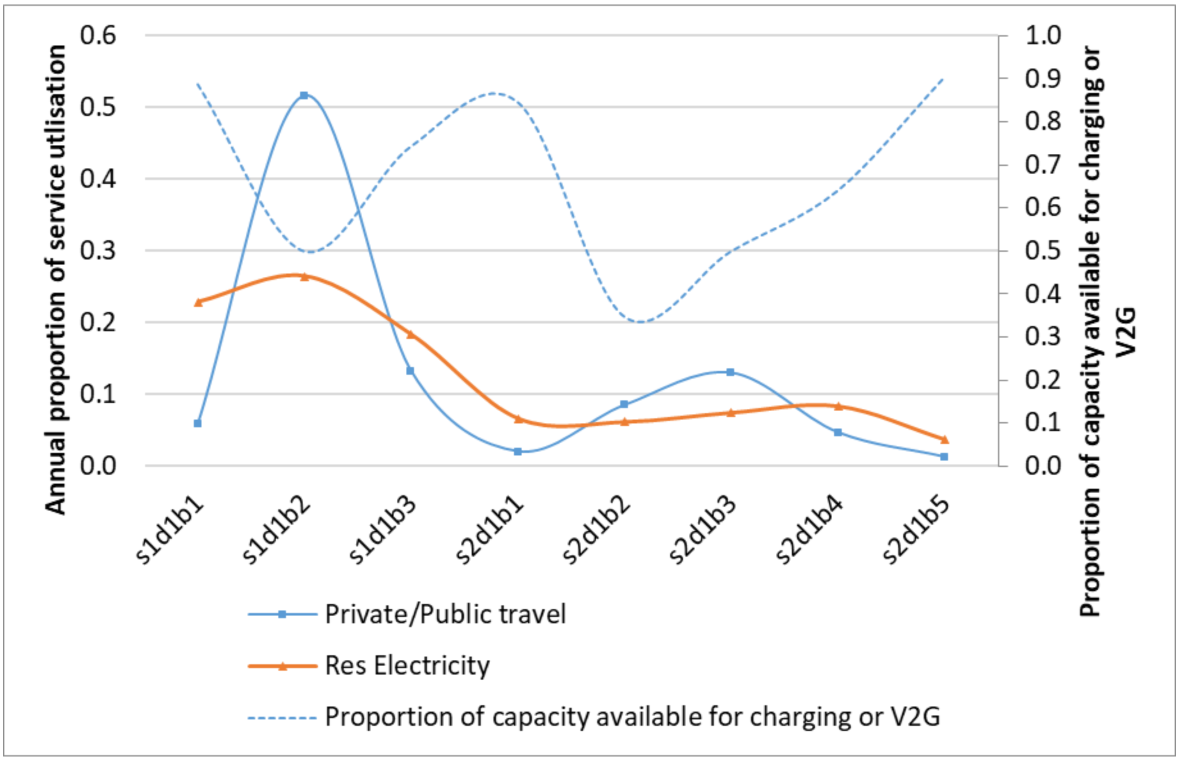
Table 1: Yearly energy utilisation periods or timeslices (TS) in SATIMGE.

Season#	Year Period	Day Period*	Model TS	Time of day	Duration (hrs)
pre-winter	1	1	s1d1b1	2200-0659	9
pre-winter	1	2	s1d1b2	0700-1759	11
pre-winter	1	3	s1d1b3	1800-2159	4
winter	2	1	s2d1b1	2300-0659	8
winter	2	2	s2d1b2	0700-1059	4
winter	2	3	s2d1b3	1100-1759	7
winter	2	4	s2d1b4	1800-2059	3
winter	2	5	s2d1b5	2100-2259	2

*# Winter season assumed to comprise ~30% of the year or 3.5 months. * A single characteristic day is assumed in the reduced TS format.*

Travel times for passenger transport are derived from the Behrens (2004) study for the City of Cape Town, while residential energy utilisation is obtained from Eskom. Reformulated to conform to the model TS format, the time of service demand for both travel and residential electricity demand is shown in Figure 3. Daily travel demand for public and private motorised travel are presumed similar, including across seasons as well. Also depicted is the presumed storage capacity that is available for either charging or network-discharging (V2G). The latter profile is determined from the travel demand profile with the assumption that during peak travel periods – namely S1D1B2 and S2D1B3 – 50% of vehicles are, owing to the time duration, at any time network connected.

Figure 3: Yearly fraction of travel and energy service demand adopted for the study.



Charging infrastructure investment, reproduced in Table 2, is taken from Ahjum et al. (2018). These costs are considered conservative. EV charging costs and efficiencies assume Level 2 charging for commercial premises and is adapted from US data.[17]

Table 2: Key model assumptions for electric minibus infrastructure

Parameter	Unit	Description
Distribution Infrastructure Cost	8000 USD (2013) per charging station	Commercial Level 2 EV charging (5 vehicles per charger) *
Charging efficiency	0.95	
Roundtrip battery efficiency	0.90	
Battery Capacity	60 kWh	Battery capacity of minibus taxi
Capacity availability (energy)	50%	Minimum battery capacity kept at 50% of full charge

*assumed

Method statement

In order to assess the viability of minibus V2G within the holistic SATIMGE framework, milestone years for 2030 and 2040 are reported for a scenario of V2G against a reference

17 Smith and Castellano, 2015; Snyder, 2012; Forward et al., 2013.

scenario of no V2G as listed in Table 3. A key assumption in accordance with Ahjum et al. 2020 is that purchase parity for all EV vehicle types occurs in 2030. As discussed earlier, a present-day minibus EV is approximately twice the cost of a conventional diesel/petrol vehicle. To gauge the competitiveness of minibus-V2G in comparison to alternatives such as utility scale storage, and further RE deployment, the least-cost optimisation SATMGE model is run until 2050 with 2030 and 2040 used as benchmark years to provide insight about a hypothetical mass transition to minibus EVs and the additional benefit to the electricity sector if deployed with V2G utility.

Sensitivities to network costs and charging constraints are tested with additional scenarios listed in Table 3. The key distinguishing attributes for the scenarios are summarised as follows:

Table 3: Scenario summary

Scenario#	Key attributes
Minibus-V2G (reference)	V2G (Residential) with capex for network connection
Minibus-V2G+noTS	V2G (Residential) with capex for network connection with no transport demand profile
No-V2G	No additional capex for network connection
No-V2G+GridCost	With capex for network connection
No-V2G+noTS	No transport demand profile

#Alternate vehicle technologies presumed to be at purchase parity by 2030
Minibus-V2G(Reference): Minibuses with V2G as depicted in Figure 2 with representative costs for additional network infrastructure as detailed in Table 2.
Minibus-V2G+noTS: Similar to the reference scenario but with no time-slice profile included for transport demand. This has the effect of simulating opportunistic charging of EVs as the model apportions demand equally across time periods. This category is used to test the model preference for EVs when allowed the flexibility to shift charging.
No-V2G+GridCost: Additional network investment costs similar to that for the V2G scenario is included to test the system model's preference for EVs given similar V2G infrastructure costs. This allows to gauge the model preference for non-V2G EVs with similar V2G network investment costs.
No-V2G: No V2G with no additional network investment requirement.
No-V2G+noTS: No time-slice profile is included for transport demand.

Results

Table 4 displays total minibus capacity while Table 5 contrasts the minibus technology portfolio profile for the two cases. The total vehicle population remains relatively stable across the period of interest declining by approximately 20 percent in 2040, due to the default assumption of a continued defection from public to private transport.

Table 4:Minibus population (1000s)

	Year		
	2020	2030	2040
Minibus-V2G (Reference)	317,79	323,60	269,30
Minibus-V2G+noTS	317,79	322,68	266,84
No-V2G	317,79	322,96	268,14
No-V2G+GridCost	317,79	323,47	268,80
No-V2G+noTS	317,79	322,65	266,79

From Table 5, the reference V2G scenario, results in an electric minibus (eMBT) fleet comprising ~10 percent of the total minibus population in 2030. This represents approximately 50 percent less eMBTs when compared to the no-V2G or eMBT-V2G+noTS scenarios, suggesting that the additional network infrastructure presents a disincentive to accelerating the deployment of eMBTs. Similarly the TS profile inhibits further EV adoption due to the constraint on charging during specific time periods. This however is a limitation of the model since the model time periods span several hours with limited flexibility as would be achieved with an hourly or ideally sub-hourly assessment.

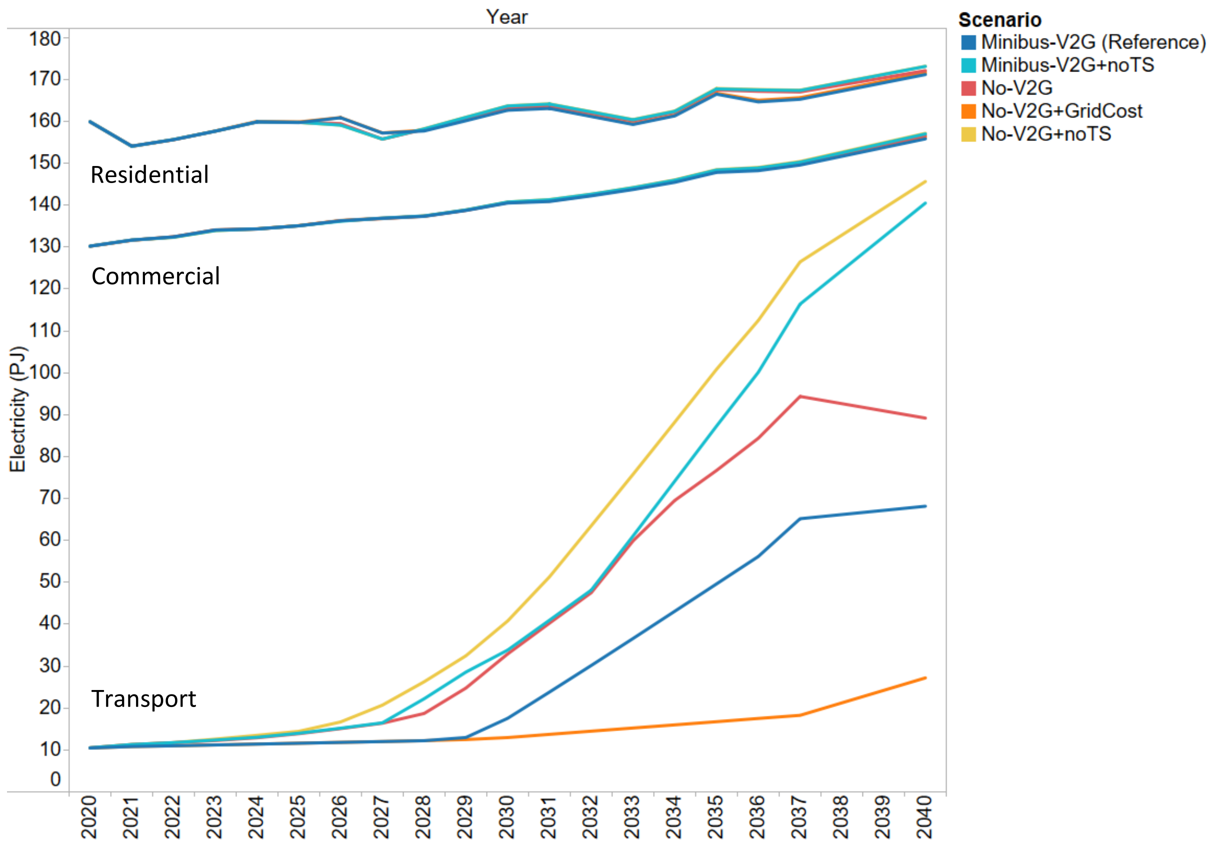
The no-V2G with opportunistic charging has the highest penetration of eMBTs by 2030 as expected due to lower total investment costs with flexible charging. However there is cost convergence for all scenarios, except the No-V2G+GridCost, by 2040, suggesting a cost-optimal horizon for a V2G minibus fleet representing 84 percent of the total vehicle population. The No-V2G+GridCost scenario, which includes additional network augmentation costs with inflexible charging presents the least incentives for adopting eMBTs. For this scenario, hydrogen fuel-cell vehicles, decoupled from the electricity network are preferred.

Table 5: Minibus technology portfolio for the benchmark years (1000s)

			Year	
		2020	2030	2040
Minibus-V2G (Reference)	MinibusElectric		28,8	227,2
	MinibusGas		13,0	
	MinibusOil	317,8	281,9	42,1
Minibus-V2G+noTS	MinibusElectric		62,5	225,1
	MinibusOil	317,8	260,2	41,7
No-V2G	MinibusElectric		64,3	228,0
	MinibusOil	317,8	258,6	40,1
No-V2G+GridCost	MinibusGas		14,6	
	MinibusHydrogen		27,1	228,6
	MinibusOil	317,8	281,7	40,2
No-V2G+noTS	MinibusElectric		75,8	226,8
	MinibusOil	317,8	246,9	40,0

The impact on the network with regard to final demand is shown in Figure 4 which highlights the relative magnitude of demand by the main sectors for this study. Annualised results are shown to indicate the rate of change across the sectors with total transport demand shown.

Figure 4: Electricity demand for coupled sectors: Residential, Commercial and Transport



Residential and Commercial sector demand remains relatively unaffected by transport sector perturbations, while the magnitude of transport demand reflects the size growth in the EV fleet. Although minibus taxis are the focus in this analysis, the demand depicted in Figure 4 represents demand for the entire transport sector. The total transport demand is included to holistically gauge the impact on national power generation capacity requirements, given a minibus V2G fleet of differing scale as represented by the years 2030 and 2040.

Excluding the no-V2G+GridCost scenario, the reference V2G case results in the lowest electricity demand with difference in demand of ~20 PJ relative to the no-V2G scenario.

Table 6 suggests that the key affected segments are passenger and freight road vehicles with travel-time and charging demand a pivotal driver in regard to uptake of EVs. This is evident when considering the capacity expansion in the power sector.

Table 6: Electricity demand by transport subsector

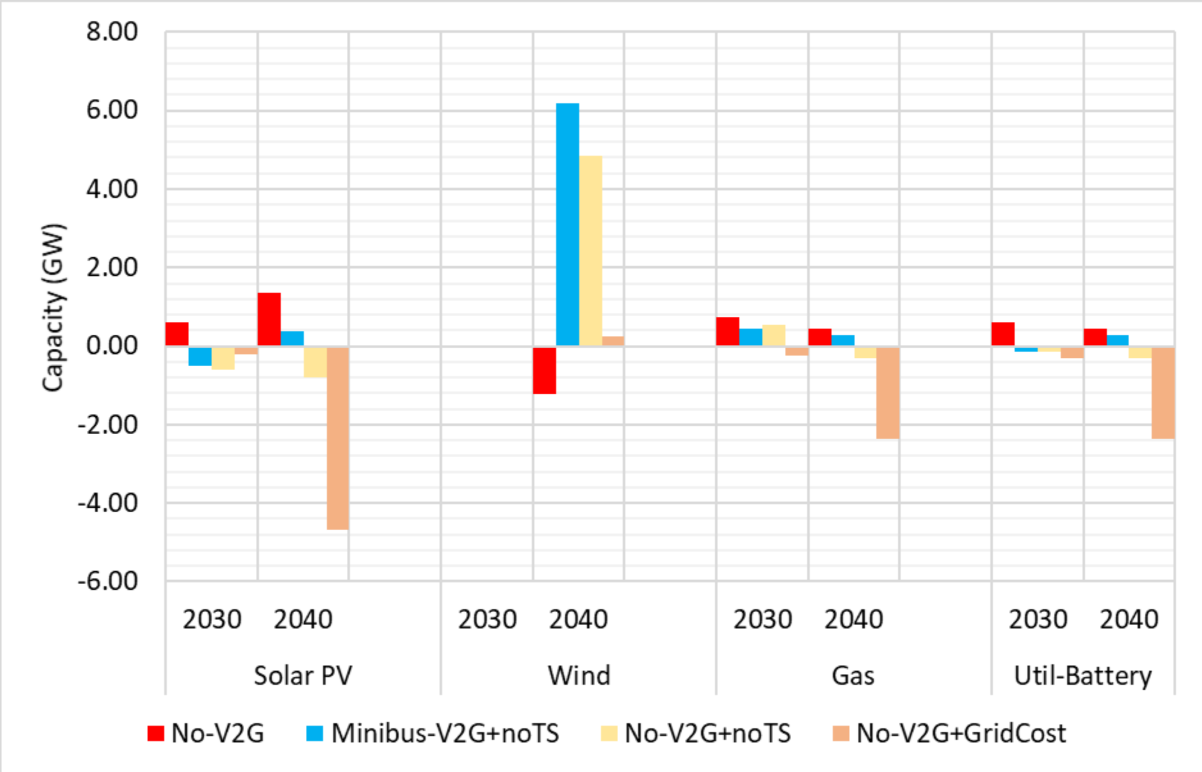
			Year		
			2020	2030	2040
Electricity (PJ)	Minibus-V2G (Reference)	FreightRoad		3,52	41,72
		PassPriv	0,00	0,18	0,74
		PassPub	1,41	2,60	8,68
	No-V2G	FreightRoad	0,02	11,74	45,05
		PassPriv	0,00	4,05	11,94
		PassPub	1,44	6,03	15,30
	Minibus-V2G+noTS	FreightRoad	0,02	14,93	65,65
		PassPriv	0,00	1,83	43,04
		PassPub	1,45	5,96	15,18
	No-V2G+noTS	FreightRoad	0,02	18,72	66,11
		PassPriv	0,00	4,59	47,56
		PassPub	1,45	6,37	15,22
	No-V2G+GridCost	FreightRoad			7,01
		PassPriv	0,00	0,18	1,31
		PassPub	1,41	1,48	1,48

Total generation capacity by scenario is given in Table 7 while Figure 5 shows the relative capacity, by key technology shift, when compared to the reference minibus-V2G scenario. The total capacity difference for the no-V2G scenario varies from ~ 2GW for the 10 percent EV fleet changing to ~1GW when the EV share rises to 84 percent. As noted earlier, however, this is primarily due to the reduction in electricity demand from the transport sector in response to demand pricing which would give preference to hydrogen fuel-cell vehicles in the extreme case. With flexible charging, as with the Minibus-V2G+noTS scenario, a high penetration of wind occurs with an increase of ~6GW for 2040. Wind peaking capacity shoulders Solar-PV peaking capacity – i.e. pre-winter time-block 2 and winter time-blocks 2 and 3 – suggesting a preference for pre-dawn and sunset charging.

Table 7: Total capacity for the power sector

Scenario	Capacity (GW) 2020	2030	2040
Minibus-V2G (Reference)	49,68	53,13	117,28
No-V2G	49,68	55,10	118,33
Minibus-V2G+noTS	49,68	52,92	124,40
No-V2G+noTS	49,68	52,94	120,70
No-V2G+GridCost	49,68	52,38	108,09

Figure 5: Capacity expansion relative to the reference Minibus-V2G scenario



The V2G as presently configured in the model, therefore, would indicate that V2G with an emphasis on the minibus taxi as an energy service provider could potentially play a role in the electricity sector given the year 2040 if network augmentation costs are addressed along with flexible charging infrastructure. Without these two pillars, V2G, in the context of electricity provision, does not feature as cost optimal investment strategy.

III. Concluding remarks

We have presented above a first-cut modelling assessment of the Minibus V2G policy proposal in comparison with alternative scenarios that include business-as-usual (No-V2G+GridCost), V2G without controlled charging stipulations (Minibus-V2G+noTS), no provision of additional charging infrastructure (No-V2G), and neither V2G nor controlled charging stipulations for private vehicles (No-V2G+noTS). From the exclusive perspective of maximizing generation capacity (and thus, over time, maximizing the proportion of RE generation capacity), the most preferable scenario would be Minibus-V2G+noTS, followed by No-V2G+noTS, No-V2G, then minibus V2G, with business-as-usual (No-V2G+GridCost) being the least preferable.

Apart from a further refinement of our definition of variables, however, there are several other caveats to be made regarding these results. Most obviously, network augmentation and flexible charging infrastructure costs remain unknown, and could go down as advantages of scale, scope, and experience increase. Secondly, the importance of an economic stimulus multiplier that the addition of these factors (together with that of increased RE capacity) and the ensuing a broadened employment base would entail, is not fully accounted for. Thirdly, the full benefits of avoided surplus gas- and coal-based generation costs, health gains from electrification, transport savings from reduced congestion, are not fully internalised (with even greater savings over the long term).

Space constraints also prevent our exploring all possible avenues toward realisation of V2G policy. For example, retrofitting old ICE vans with electric motors is less expensive than new purchases; as well, government tenders (placing a premium on construction and assembly in current factories in the Eastern Cape) could also reduce costs. In the wake of state-owned Chinese automaker BAIC Group’s recently announced plans to produce electric vehicles in South Africa, it may be less than a decade before they become the norm. Currently, the Department of Transport mini-bus taxi scrapping allowance is R124,000 per vehicle. If this were increased to R140,000 per vehicle, plus R10,000 covering interest-free loans over ten years, conversion of the total minibus fleet would cost the public R4.5 billion/ year over ten years, assuming any price difference were covered by minibus owners. Traded-in ICE minivans could then be initially repurposed for subsidised, under-served rural areas for the life of the vehicle. Charging station infrastructure would cost an additional R130 million / year over ten years (R130,000/station x 10,000 stations), yielding a total cost of roughly R4.7 billion/ year over ten years.

Against this cost, there are multiple savings. Imported petroleum (both crude and refined) represents the largest category of imports, costing over $9 billion (R150 billion) in 2017.[18] With minibuses consuming almost 8 percent of petrol, fleet electrification would save almost R10 billion per year in imported fuel costs. A reduction in demand for liquid fuels brought about by EVs and by the current period of low economic growth suggests that SA may never achieve the level of liquid fuels demand that would justify further investment in refinery capacity expansion, saving several additional billion rands per year.

V2G would also be less expensive than the R10.175 billion annual cost of peaking power plants such as the Ankerlig gas turbine power plant (i.e. R175 million/year for the R3.5 billion cost of construction over twenty years, plus R10 billion of fuel costs per year) with a capacity of 1338 MW (similarly designed to operate 3 hours / day); while at the same time, fleet electrification could yield greater storage capacity. Furthermore, grid stabilisation would yield hundreds of millions of rands a year in avoided blackout and load-shedding costs, which have totalled more than R3 trillion over the past decade.[19]

The plan would continuously stimulate employment demand, and promote large-scale RE infrastructure, with knock-on economic stimulus effects at the SMME level. Local fleet construction, retrofitting, and /or assembly could generate over 1,000 jobs a year for at least ten years, based on an industry average of 10-20 vehicles per worker per year. Spurred RE demand yields over 25,000 jobs per 100TWh per year – 30 percent more jobs than new coal power plants provide per MW generated.[20]

As well, increased and rationalised minibus transport would also decrease congestion costs and deaths from traffic accidents and air pollution; each year of life saved from avoided pollution and traffic costs adds the yearly value of GDP per capita. These savings of lives and associated costs are estimated as follows.

Ambient air pollution is the leading environmental health risk factor globally, resulting in nearly 3.5 million premature deaths in 2017 from stroke, ischemic heart disease, chronic obstructive pulmonary disease, lung cancer, lower respiratory infections, and diabetes. The global transportation sector is a major source of this health burden through its contribution to elevated fine particulate matter (PM2.5), ozone, and nitrogen dioxide concentrations. Transportation activities produce tailpipe emissions, evaporative emissions, resuspension of

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[18] Two of South Africa's top imports are Crude Petroleum ($6.54 billion) and Refined Petroleum ($2.55 billion). OEC 2017.

[19] Head 2019.

[20] DoE 2016. IEP Annexure B: Macroeconomic Assumptions.

road dust, and particles from brake and tire wear. Other important health impacts of the sector include noise, physical activity effects, and road injuries.[21]

Although communicable diseases still impose the largest burden in South Africa, non-communicable diseases (NCDs) are projected to become the leading cause of death by 2030, compounding the high burden of infectious diseases.[22] Nearly half of the population in sub-Saharan Africa already suffers from hypertension, a major contributor to heart attacks and strokes.[23] The third and fourth major causes of death in South Africa are heart and cerebrovascular NCDs; and the tenth, lower respiratory diseases. All NCDs in South Africa combined contribute the greatest number of years of life lost (YLLs) of all causes. In 2010, NCDs accounted for more than one third of YLLs nationally[24].

In addition to coal-generated and indoor smoke pollution, traffic-generated air pollution is among the biggest contributory factors of the thousands of deaths attributable to air pollution in South Africa each year.[25] Vehicle fleet electrification would reduce air pollution by at least ten percent. Avoided emissions from increased RE generation spurred by V2G, permitting the early retirement of coal-generated power plants and thus also reduced mining-related morbidity and mortality rates, would further improve health outcomes. Estimates for the value of a statistical life (VSL) for South Africa, derived using a standard benefit-transfer approach, is slightly more than $1 million (2015 USD).[26] Thus with 1,400 transportation-attributable air quality deaths in 2015 (overwhelmingly from on-road vehicles), the cost in transportation health damages from air pollution alone is estimated at $1.5 billion (or R24 billion).[27]

Traffic accident fatalities are even higher, as the third highest non-natural cause of death in South Africa (12.5 percent), totalling more than 14,000 traffic fatalities in 2016, the highest figure in a decade, with pedestrians nearly 40 percent of victims. An estimated R13billion+ productivity is lost per year in traffic jams alone.[28] Both of these negative outcomes could be ameliorated, if not dispensed with altogether, by means of a rationalised,

[21] Anenberg et al. 2019.
[22] Farrington 2013; WHO 2009.
[23] WHO 2014.
[24] Nojilana et al. 2016.
[25] Holland 2017 estimates impacts in terms of early death, chronic bronchitis, hospital admissions for respiratory and cardiovascular disease, and other factors including lost productivity, at over 10,000 lives and $2.4 billion each year.
[26] Viscusi & Masterman 2017.
[27] Anenberg 2019: 10, 19.
[28] BusinessTech 2017.

more pedestrian-friendly transport policy. Several studies of the minibus industry concur that its informalized and precarious-employment model have contributed to increased user- and traffic-related hazards and deaths,[29] although somewhat paradoxically, its labour market is not competitive, despite being low-wage and comparatively low-skilled in a high-unemployment context.[30] This has led to calls for increased government regulation and oversight.[31] However, government attempts at formalisation have thus far met with stiff resistance on the part of minibus owners and (to a lesser extent) drivers.[32] Among the salient factors for this outcome is the absence of effective regulatory structures and interventions, combined with inadequate incentives for drivers.[33] By providing access to new and superior vehicles, dedicated routes and charging bays, and possibly also provision of subsidised fares, V2G thus represents an opportunity to provide both adequate regulation and adequate incentives. If we conservatively estimate the effect of a rationalised, more pedestrian-friendly transport policy spurred by V2G implementation at a ten percent reduction of traffic fatalities and congestion costs, this would save a further R25 billion each year.

Table 8: Additional saved costs and employment creation summary

Factor	Saved costs (/year)	Jobs created (/year)
fleet construction, retrofitting, and assembly	Emplymt multiplier	1,000
Spurred RE demand	Emplymt multiplier	25,000
New MBT routes spurring rural development	Emplymt multiplier	thousands
Avoided fuel import/ currency-related costs	R50 billion	
Avoided transport air pollution deaths (1,400)	R24 billion	
Avoided traffic deaths (1,400)	R24 billion	
Avoided peaking power costs	R10 billion	
Avoided refining costs	R1 billion	
Avoided congestion costs	R1 billion	

Potential barriers to implementation, and strategies for overcoming them

Because the Department of Transport mini-bus taxi scrapping policy already exists, implementation would be very straightforward. Each minivan would be assigned a dedicated charging / offloading bay; loan and scrapping terms would depend on continuous provision of stored electricity at peak hours, possibly on a sliding, incentive-based scale. Vehicle

[29] Ahmed 2004; Fobosi 2013; Lomme 2008; Randall 2019.
[30] Antrobus and Kerr 2019.
[31] Fourie 2005; Govender and Allopi 2006; Randall 2019.
[32] Fobosi 2013, 2019; Venter 2013.
[33] Akpa, Booysen, & Sinclair 2019; Lomme 2008; Motingwe & Brijlal 2020; Plano 2020; Schlüter et al. 2020.

construction infrastructure is also already substantially in place. Barriers identified can thus be summarised as follows:

(i) the cost of V2G, particularly that of infrastructure implementation, network augmentation, and battery degradation, is often too high in comparison to the current electricity market conditions;

   a. Response: internalising avoided load-shedding, health and safety, etc. costs of BAU can serve as basis for subsidised conversion.

(ii) it is not settled under which business and aggregation model V2G could capture most economic value;

   a. Response: municipalities (in conjunction with retail and commercial enterprises with a minimum capacity reserve) to experiment with different models to determine for themselves; assessing environmental and climate attributes of a V2G transition in addition to the role of consumer acceptance and knowledge of V2G systems is key.[34]

(iii) EV owners may be concerned about the loss of range or availability of their vehicles if engaged in V2G programmes.

   a. Response: Subsidies explicitly linked to peak-demand offloading periods/ trough period charging, plus flexible (tariff-based) offloading / recharging schedules could spread this burden evenly across the fleet. Since, at any given time, only a minority of minibuses are in active use on the road, these offloading / recharging schedules would be minimally cumbersome.

[34] Sovacool et al 2018.

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