From Chalkboards to Chargers - Vehicle Electrification in South African Schools

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Abstract: This paper investigates the electricity demand implications of vehicle electrification within South Africa's education sector, with a specific focus on school-based electric vehicle (EV) charging. Recognising schools as spatially dispersed, schedule-predictable, and increasingly technology-intensive energy users, the study positions them as a strategic yet underexplored domain for managed electrification. A system dynamics model developed in iSee Stella is used to simulate how EV adoption among educators and Grade 12 learners (at 10% and 50% penetration levels) would affect provincial and national electricity demand across weekday and weekend charging patterns aligned with daytime solar availability. Baseline school electricity consumption is estimated at 3.5 TWh per year, distributed across provinces using school counts and population growth data. Results show that additional EV-related demand remains modest—approximately 1.83 GWh/year under the 10% scenario and 9.15 GWh/year under the 50% scenario—dominated by three provinces: Gauteng, KwaZulu-Natal, and the Western Cape. The findings suggest that schools present a low-risk, high-value entry point for coordinated EV deployment, particularly when integrated with on-site solar photovoltaic (PV) and storage.

Keywords: System dynamics modelling, schools, vehicle electrification

1. Introduction

South Africa's electricity system is under sustained structural pressure, characterised by constrained generation capacity, rising demand, and an urgent need to decarbonise energy end-use sectors. While electrification is widely recognised as a cornerstone of long-term sustainability and climate mitigation strategies, its large-scale deployment presents a critical planning challenge: new electrical loads must be integrated without exacerbating system instability or peak demand stress. Understanding where, how, and at what scale electrification can occur safely is therefore a central concern for energy system planners and policymakers.

Within this context, the education sector—and schools in particular—represents a distinctive and largely underexamined electrification domain. Schools are geographically widespread, embedded within local distribution networks, and operate according to highly predictable daily and seasonal schedules. At the same time, they are experiencing a gradual increase in energy-intensive technologies, including information and communication systems, electric transport, and on-site renewable generation. These characteristics differentiate schools from residential and commercial consumers and position them as a potentially strategic sector for managed electrification rather than unmanaged demand growth.

This paper examines the electricity demand implications of vehicle electrification within the South African education sector, with a specific focus on school-based electric vehicle (EV) charging. A system dynamics modelling framework is employed to capture the structural interactions, time-dependent behaviour, and feedback mechanisms that govern electricity demand growth under different EV adoption scenarios. The analysis quantifies incremental demand at provincial and national levels, identifies dominant regional drivers, and evaluates whether school-based vehicle electrification poses a systemic risk to the electricity system or offers a low-risk opportunity for coordinated demand expansion. By explicitly modelling the education sector as an active participant in the energy transition, the study contributes new evidence to inform electrification policy, distribution planning, and sector-specific decarbonisation strategies in South Africa.

2. Background and Literature Review

Electricity consumption in education buildings has historically been underrepresented in national and regional energy system models, primarily due to data scarcity, institutional diversity, and aggregation challenges. Unlike residential or commercial sectors, education facilities vary widely in size, operating hours, infrastructure quality, and governance structures, making them difficult to model using standard demand archetypes. As a result, schools are often subsumed within broader "public buildings" or "commercial" categories, obscuring their specific load characteristics and policy relevance.

Where empirical studies do exist, the literature consistently finds that schools exhibit relatively stable and predictable daily load profiles, largely driven by lighting, information and communication technology (ICT) equipment, plug loads, and, to a lesser extent, space conditioning (Chung, 2011). Peak demand typically aligns with daytime teaching hours, with limited evening and weekend consumption, distinguishing education buildings from residential loads with pronounced morning and evening peaks (Michael-Ahile, Samuels, & Booysen, 2024). This temporal alignment has been highlighted as particularly relevant for demand-side management and renewable energy integration.

In the South African context, available empirical analyses indicate that public schools collectively consume approximately 3.5 TWh of electricity annually, corresponding to an average national hourly demand of nearly 400 MWh (Samuels, van Rooi, Booysen, & Grobbelaar, 2021). Although modest relative to total national electricity consumption, this demand is spatially dispersed and closely linked to daytime activity, making it operationally significant at local distribution network levels. Studies further note substantial heterogeneity between urban and rural schools, as well as between public and private institutions, driven by disparities in electrification levels, appliance ownership, and infrastructure investment.

Parallel to building energy research, the literature on transport electrification has expanded rapidly in recent years but remains heavily concentrated on residential, fleet, and commercial charging environments. Most modelling efforts prioritise household charging behaviour, workplace charging in commercial offices, and high-power public charging infrastructure, reflecting both data availability and market priorities. Institutional settings such as schools, universities, and public-sector workplaces have received comparatively little attention, despite their growing relevance in electrification strategies.

Nevertheless, emerging studies suggest that education campuses possess several characteristics that distinguish them from other charging environments. These include centralised ownership and management, predictable daily schedules, controlled parking access, and increasing deployment of on-site solar photovoltaic (PV) systems (Lottu, Ehiaguina, & Ndiwe, 2023). Together, these features enable coordinated charging strategies, reduce behavioural uncertainty, and lower the risk of unmanaged peak demand growth. In contrast to residential charging, where user behaviour is highly heterogeneous, school-based charging can be shaped through institutional policies and infrastructure design.

Recent energy transition literature increasingly recognises the value of such low-risk, policy-controllable sectors as early adopters of electric mobility. Education facilities, in particular, are often positioned as demonstration sites for clean energy technologies, combining educational, social, and operational objectives. The alignment between daytime EV charging demand and on-site PV generation further strengthens the case for schools as a strategic entry point for managed EV integration, potentially reducing grid impacts while maximising renewable energy utilisation.

Despite these advantages, the intersection of education-sector electricity demand and transport electrification remains underexplored, especially in developing-country contexts. Existing national EV roadmaps and power system models rarely disaggregate institutional demand or explicitly account for sector-specific charging behaviour. This gap limits the ability of policymakers and planners to assess distribution-level impacts, design targeted interventions, or leverage the education sector as a catalyst for broader electrification efforts.

By addressing this gap, the present study contributes to the literature by explicitly modelling the electricity demand implications of EV adoption within the education sector, situating schools not merely as passive electricity consumers but as active nodes in the energy transition. The additional demand was calculated per each of the nine provinces in South Africa: Eastern Cape, Free State, Gauteng, KwaZulu-Natal, Limpopo, Mpumalanga, North West, Northern Cape and the Western Cape**.** The focus on South African schools further responds to calls for context-specific modelling approaches that reflect infrastructure constraints, institutional realities, and emerging renewable energy trends in the Global South.

System dynamics has been increasingly applied to energy transition studies due to its ability to capture feedback loops, time delays, and non-linear growth patterns. In the context of electrification, this approach enables integrated analysis of infrastructure growth, behavioural adoption, and load evolution across temporal and spatial scales.

3. Methodology

A system dynamics model was developed to simulate electricity demand impacts arising from electrification in the education sector, using iSee Stella Architect software. A system dynamics (SD) modelling approach was selected for this study rather than a conventional spreadsheet-based model because the electrification and charging of vehicles in the education sector was not a simple linear addition of load. It required feedback loop structures and spanned multiple temporal scales including hourly charging behaviour, monthly and annual demand aggregation, and temporal separation between weekday and weekend charging.

MS Excel models can approximate these effects only through complex, manual formulas that become opaque and error-prone as model scope increases. The SD approach provides a transparent and internally consistent way to simulate these temporal dynamics over 744 time steps, as required by the study. In order to set up the simulator, data analysis was conducted from other research and studies and is explained in the next section.

3.1 Education Building Electricity Consumption

A study was conducted based on energy usage of 13 schools in the Western Cape, which indicated that public schools consume 3.5 TWh per year (Samuels, van Rooi, Booysen, & Grobbelaar, 2021). The study concluded an average consumption of 450 kWh per school day in an average school. Based on 3.5 TWh, the hourly energy consumption would be 399.54 MWh (i.e., 3.5 TWh divided by 8 760 hours per year). The number of schools per province in 2022 are shown in Table 1 (Cowling, 2024) (Department of Education, 2023) and this was used to calculate the fraction distribution of electricity consumption in the various provinces.

Table 1: Schools per province in 2023 (Cowling, 2024) (Department of Education, 2023)

PROVINCE	NUMBER OF SCHOOLS	FRACTION OF TOTAL
Eastern Cape	5 285	0.2135
Free State	1 021	0.0414
Gauteng	2 979	0.1203
KwaZulu-Natal	6 020	0.2421
Limpopo	3 839	0.1547
Mpumalanga	1 771	0.0717
North West	586	0.0622
Northern Cape	1 549	0.0235
Western Cape	1 786	0.0705
Total	24 836	

The number of new schools would be multiplied by the consumption per hour (0.0188 MWh/hr). An "Adjustment factor" was also included since it is expected that the government schools would consume less electricity than the private schools. The actual value of this factor would have to be tested through surveys to get the empirical data but once that information is obtained, it can be calibrated in the model. The drivers that will likely affect the number of school goers (which would in turn impact the number of schools) is the rate of population growth in each of the provinces. Calculations were made to determine the significance of population growth on the growth of schools. The data obtained for the last couple of years was used to calculate the provincial population growth (Stats SA, 2024) shown in Table 2.

Table 2: Population change per province (Stats SA, 2024)

POPULATION	Apr-22	Apr-23	Apr-24
Eastern Cape	7 230 150	7 290 838	7 352 691
Free State	2 964 413	2 981 941	2 999 613
Gauteng	15 099 428	15 360 734	15 627 688
KwaZulu Natal	12 423 857	12 619 290	12 818 479
Limpopo	6 572 727	6 695 290	6 822 375
Mpumalanga	5 143 331	5 250 868	5 361 261
North West	3 804 550	3 828 637	3 852 976
Northern Cape	1 355 960	1 377 004	1 398 650
Western Cape	7 433 018	7 586 223	7 743 151

The population growth rate per year based on the data in Table 3, is shown in Table 3.

Table 3: Population growth rate per province (Stats SA, 2024)

POPULATION	From April 2022 to April 2023	From April 2023 to April 2024	Average annual growth (%)
Eastern Cape	0.8394	0.8484	0.8439
Free State	0.5913	0.5926	0.5920
Gauteng	1.7306	1.7379	1.7342
KwaZulu Natal	1.5730	1.5784	1.5757
Limpopo	1.8647	1.8981	1.8814
Mpumalanga	2.0908	2.1024	2.0966
North West	0.6331	0.6357	0.6344

Northern Cape	1.5520	1.5720	1.5620
Western Cape	2.0611	2.0686	2.0649

The number of school-going learners is shown in Table 4.

Table 4: Fraction of school goers per province (Stats SA, 2024)

POPULATION	NUMBER OF SCHOOL GOING LEARNERS (2023)	FRACTION OF THE POPULATION OF SCHOOL GOING AGE
Eastern Cape	1 806 119	0.279271
Free State	723 621	0.242948
Gauteng	2 628 047	0.160548
KwaZulu Natal	2 875 858	0.243897
Limpopo	1 799 294	0.291609
Mpumalanga	1 150 356	0.235801
North West	306 653	0.208059
Northern Cape	880 080	0.236519
Western Cape	1 269 655	0.172161

If the population increases, then the number of school-going learners will increase and possibly the number of schools. However, there are also a number of matriculant graduates leaving the school system as more enter based on the population and learner growths. If the number of grade 1 learners is 1.2 million a year and the number of matriculants who leave the school system is 691 000 (The Conversation, 2024) then approximately 5.76% exit the school system on average. This means that the average growth rate of students can be accommodated by existing school infrastructure, and this dynamic could be excluded. The factors that could impact the pass rate and thus the exit rate of learners becomes important. Some of these factors include lack of books, poor quality of teaching, lack of teaching, bad conditions of learning, fees too high, and classes too large (Mhleb, 2011) (DBSA, 2024).

3.2 Vehicle Electrification Model

EV adoption scenarios were defined at 10% and 50% penetration levels among educators, and senior learners using private transport. Charging behaviour was disaggregated by weekday and weekend patterns, with charging times aligned to daytime hours (7am, 11am, and 2pm) to avoid evening peaks and coincide with solar availability. The model allocates EV charging demand across the nine provinces in South Africa and simulates monthly and annual electricity impacts. Charger availability, charging power, and battery state-of-charge assumptions were parameterised based on published estimates.

Figure 1 shows the model structure for EV charging at the premises of the sectors. The same model structure was developed for the different sub-sectors and different vehicle categories, but only one will be used to illustrate the model design. Separate structures were constructed for weekday charging and weekend charging. There are also options to choose the charging times and residual vehicle battery capacities for these vehicles per province.

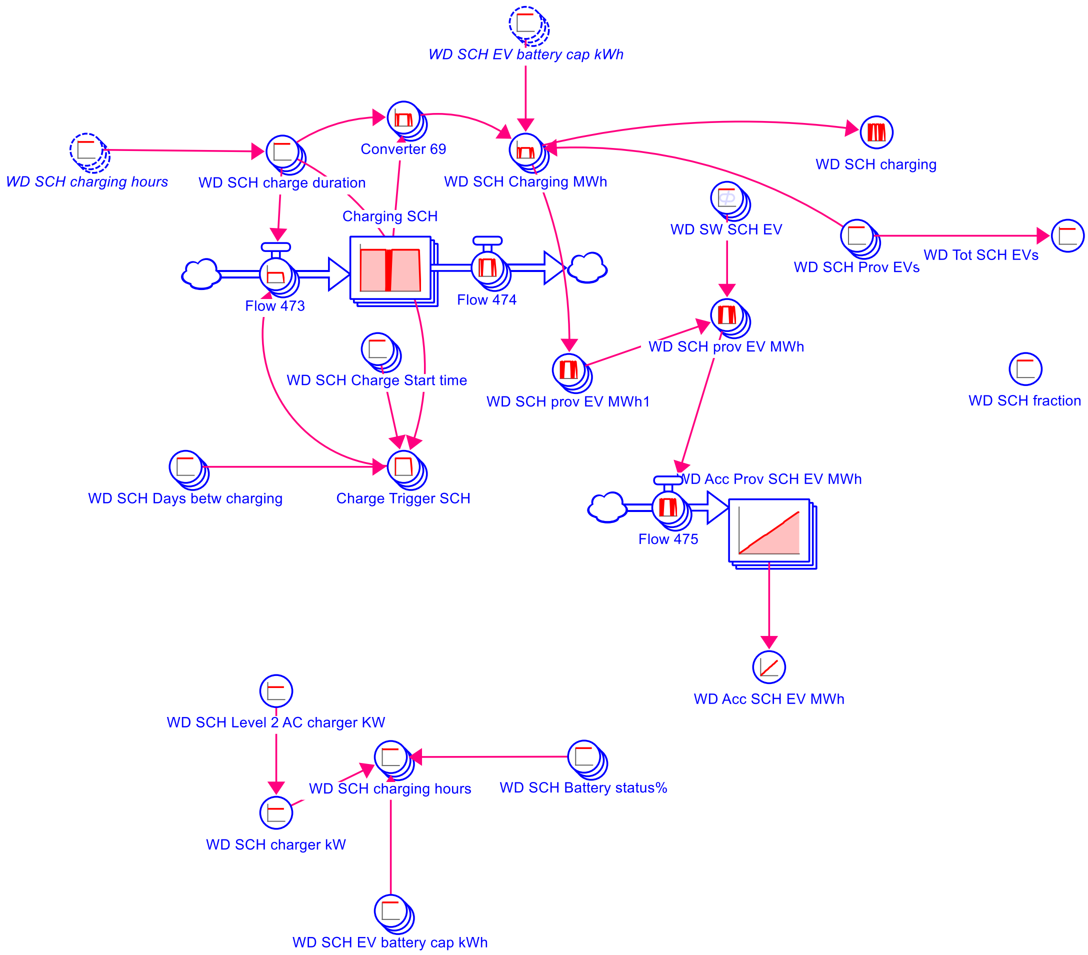

Figure 1: EV charging model structure (weekday charging)

Figure 2 shows the charging behaviour over a period of 200 hours.

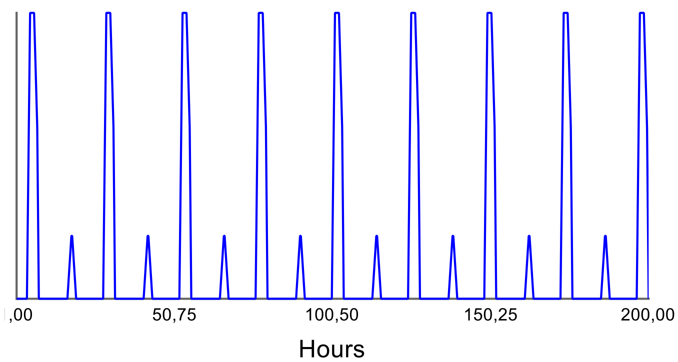

Figure 2: EV charging (no distinction between weekday and weekend)

The problem with the model structure in Figure 2 was that it created the same charging behaviour over weekdays and weekends, so a mathematical equation was required to distinguish between weekdays and weekends Figure 3.

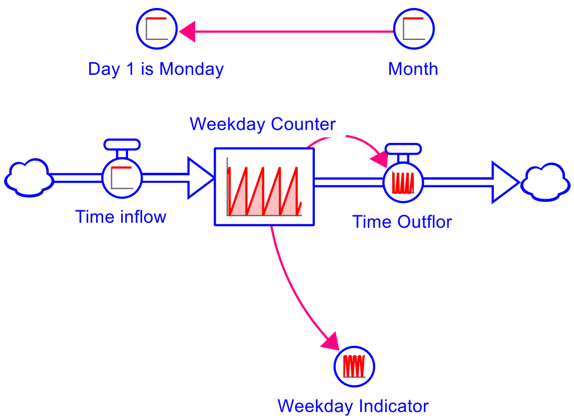

Figure 3: Weekday allocator model structure as a function of the month

The structure in Figure 4 (with the integration of a day allocator) shows the exclusion of weekends.

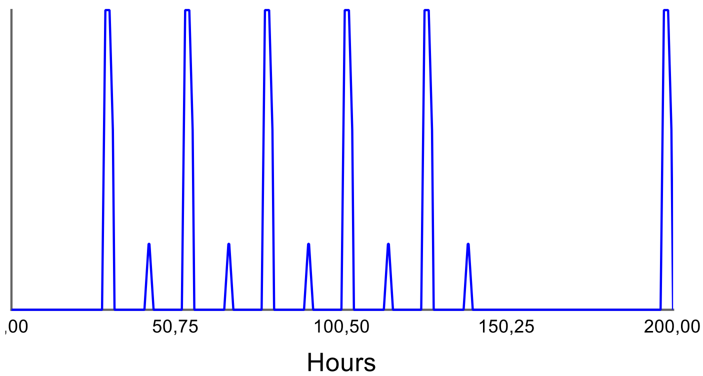

Figure 4: EV charging (distinction between weekday and weekend)

A similar model structure was set up for weekend charging. Table 5 shows the number of schools, learners and educators per province.

Table 5: Independent schools, learners and educators (Department of Education, 2022)

Province	Independent Schools	Educators	Learners	Matriculants
Eastern Cape	265	3 895	74 654	3 564
Free State	83	1 229	21 180	929
Gauteng	935	21 487	357 250	19 328
KwaZulu-Natal	220	4 352	60 828	3 830
Limpopo	201	3 993	83 516	2 309
Mpumalanga	135	2 460	35 821	2 751
Northern Cape	41	540	7 042	320
North West	100	1 691	28 051	982
Western Cape	302	5 720	66 743	3 953
Total	**2 282**	**45 367**	**738 085**	**37 966**

Assumptions:

- It is expected that not every educator will replace their ICE with an EV, only a fraction.
- Staff, students and parents at independent schools are more likely to purchase EVs, since they may have higher disposable income than their counterparts at government schools.

- The number of chargers per 10 EVs was estimated at 1.8 (Bharadwaj, 2023), however, if it is assumed that there is at least one slow charger and 1 fast charger per school, then the number of chargers would be twice the number of schools per province.
- The total number of EVs per province would be divided into 3 different charging times to see the impact of EV charging on the load profile on a provincial level.
- It is assumed that the parents will charge their vehicles at their workplace or at home.
- There would be 3 charging times, 7am, 11am and 2pm which would avoid evening residential peaks, coincide with solar PV availability and spread the load across the school day.

In order to do scenario analysis, the number of EVs per province was based on a percentage of the number of educators (Table 6).

Table 6: Number of EVs owned by Educators at schools

Province	10% EVs	50% EVs
Eastern Cape	390	1 948
Free State	123	615
Gauteng	2 149	10 744
KwaZulu-Natal	435	2 176
Limpopo	399	1 997
Mpumalanga	246	1 230
North West	54	270
Northern Cape	169	846
Western Cape	572	2 860
Total	**4 537**	**22 684**

In 2019, statistics reveal that 9.6% of matriculants drove to school in private vehicles (Table 7) (Statista, 2025).

Table 7: Number of EVs owned by Matriculants at schools

Province	9.6% ICEVs	10% of ICEVs	50% of ICEVs
Eastern Cape	7 167	717	3 583
Free State	2 033	203	1 017
Gauteng	34 296	3 430	17 148
KwaZulu-Natal	5 839	584	2 920
Limpopo	8 018	802	4 009
Mpumalanga	3 439	344	1 719
North West	676	68	338
Northern Cape	2 693	269	1 346
Western Cape	7 167	717	3 583
Total	**64 161**	**6 416**	**32 080**

Based on the data in Table 6 and Table 7, the following EV numbers were used to run scenarios per province (Table 8).

Table 8: Number of EVs at schools

Province	SCENARIO 1 10% (Educators & Grade 12)	SCENARIO 2 50% (Educators & Grade 12)	AVG EVS PER SCHOOL 10%	AVG EVS PER SCHOOL 50%
Eastern Cape	424	2 119	2	8

Free State	132	659	2	8
Gauteng	2 334	11 671	2	12
KwaZulu-Natal	472	2 360	2	11
Limpopo	421	2 107	2	10
Mpumalanga	272	1 362	2	10
Northern Cape	57	285	1	7
North West	179	893	2	9
Western Cape	610	3 050	2	10
Total	4 901	24 506	2	11

4. Results and Discussion

Figure 5 shows the provincial distribution of electricity consumption for school buildings for January 2022. The simulator is able to generate similar results for each of the months for each province.

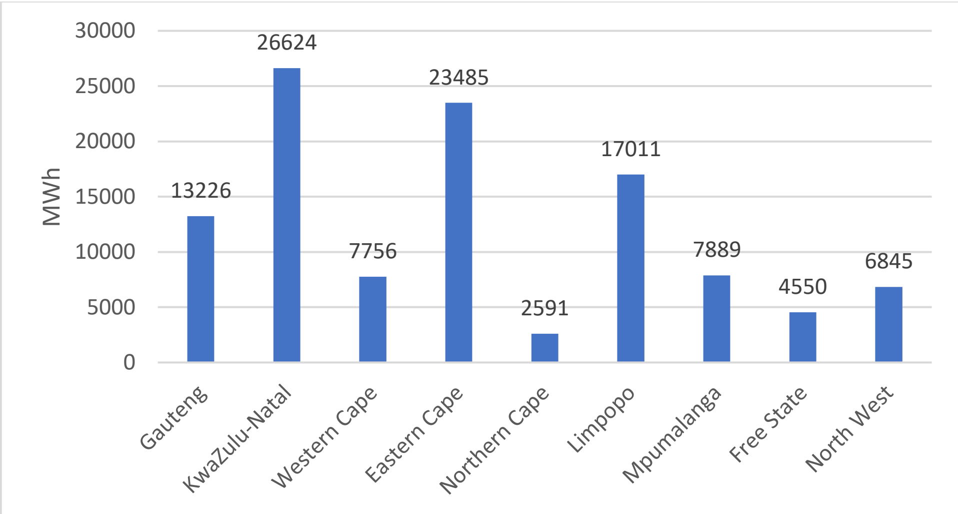

Figure 5: Energy consumption of schools per province

Baseline electricity consumption in the education sector is non-trivial at a national scale, with provincial demand strongly concentrated in Gauteng, KwaZulu-Natal, and the Eastern Cape. This spatial concentration reflects underlying demographic and institutional factors, including learner population size, the number of public schools, and the degree of electrification and infrastructure development across provinces. Gauteng, in particular, exhibits the highest baseline demand due to its dense concentration of large urban schools and higher levels of appliance penetration.

Despite this concentration, the temporal structure of school electricity demand is relatively flat and predictable. Daily load profiles are dominated by daytime usage during teaching hours, with limited evening and weekend consumption. This predictable behaviour reduces operational uncertainty for the power system and distinguishes school demand from residential or commercial sectors that exhibit sharper peaks and greater behavioural variability. As a result, while the absolute magnitude of school electricity consumption is significant, its impact on system stability is comparatively low. The results are shown in Table 9 for a period of a month.

Table 9: Additional demand per month due to EV charging at schools

Province	SCENARIO 1 10% EVs (MWh)	SCENARIO 2 50% EVs (MWh)
Eastern Cape	13.1	65.5
Free State	3.79	18.9
Gauteng	62.7	314
KwaZulu-Natal	30.1	150
Limpopo	12.4	62.2
Mpumalanga	7.26	36.3
Northern Cape	1.76	8.81
North West	4.49	22.5
Western Cape	16.8	83.9
Total	**152.4**	**762.11**

Table 9 presents the estimated additional monthly electricity demand attributable to EV charging at schools under two electrification scenarios: a conservative 10% EV penetration (Scenario 1) and a higher 50% penetration (Scenario 2). The results indicate a near-linear scaling of additional demand with EV uptake, reflecting the assumption of similar vehicle usage and charging behaviour across scenarios.

At the provincial level, Gauteng, KwaZulu-Natal, and the Western Cape dominate incremental demand, together accounting for the majority of school-based EV charging load. Under the 50% EV scenario, Gauteng alone contributes approximately 314 MWh per month, representing roughly 40% of total national school EV demand. This dominance mirrors the province's share of baseline school electricity consumption and its higher concentration of educators and staff likely to adopt electric vehicles.

In contrast, provinces such as the Northern Cape, Free State, and North West exhibit relatively modest increases in demand, consistent with smaller school populations and lower absolute vehicle numbers. Importantly, no province experiences a disproportionate increase relative to its baseline demand, suggesting that EV charging loads scale coherently with existing electricity consumption patterns.

When aggregated nationally, the additional electricity demand from school-based EV charging amounts to approximately 1.83 GWh per year under the 10% EV scenario and 9.15 GWh per year under the 50% scenario. Even at the higher penetration level, the total number of electric vehicles associated with schools is estimated at approximately 24,500 vehicles nationwide, which remains small relative to national vehicle stock and overall electricity demand.

From a system-wide perspective, these values are modest when compared to baseline school electricity consumption and negligible relative to total national electricity generation. This indicates that school-based EV electrification does not constitute a material demand shock to the power system, even under relatively ambitious adoption assumptions.

5. Conclusions

Schools are social multipliers, not just electricity consumers. Electricity demand from EV charging at schools is 1.83 GWh/year (10% EV uptake) and 9.15 GWh/year (50% EV uptake).

The results show that schools are low-to-moderate electricity demand contributors, even under relatively aggressive EV adoption scenarios (50%). However, they are highly influential from a load-shaping, infrastructure planning, and behavioural perspective.

Across schools demand remains small relative to provincial electricity consumption and if charging occurs during daytime hours, it would be systemically advantageous. It would also make the education sector an ideal "early transition" environment for managed EV charging. These institutes also have large roof areas for solar PV installation and EVs would improve the utilisation of the renewable energy sources.

Overall EVs strengthen the business case for distributed energy in education. System dynamics modelling reveals that the sector is not an electricity risk but rather an opportunity for controlled demand growth, innovation, and learning within the national electrification pathway.

Beyond numerical outputs, this research aimed to understand system behaviour, not merely calculate energy totals. System dynamics supports causal loop and stock–flow representations that make assumptions explicit and traceable. This was particularly important given:

- Data uncertainty in school-level electricity consumption,
- The use of adjustment factors for public versus private schools, and
- Behavioural assumptions around charging patterns.

An Excel model would obscure these structural assumptions within cell formulas, whereas the SD model allows reviewers and policymakers to visually inspect and interrogate the logic of the system, improving credibility and interpretability of the results

6. Recommendations

The following recommendations can be considered for vehicle electrification in the education space:

1. Education institutions should be early EV priority zones since they are low risk, high visibility, and high learning value.
2. Planning should focus on metros and large campuses particularly Gauteng and Western Cape.
3. EV rollout should be integrated with solar and storage strategies especially for resilience and cost reduction.
4. Education EVs should be treated as demonstration projects and lessons learnt can be fed into broader C&I and residential planning.

Although energy demand is small, education-sector EVs can normalise EV use among young people, signal institutional leadership and influence household purchasing decisions.

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