Non–Urban E-Bus Pilot Operations, Data Analysis & Inference

Exploring the Role of Private Sector as a Catalyst for Accelerating Transition to E-Bus in India.

SHAKTI SUSTAINABLE ENERGY FOUNDATION

SGA sustainable mobility solutions

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1 Background

A study titled “Exploring the role of the private sector as catalyst for accelerating transitions of Electric Bus (e-bus) in India”, has been undertaken as a joint effort by S G Architects (SGA) and the knowledge partners of the study: Council of Energy Environment and Water (CEEW) and Institute of Transportation and Development Policy (ITDP) India. The aim of this study is to help iron out any bottlenecks in accelerating electrification of buses operating under State Transport Undertakings (STUs) and State Transport Authority (STA) Permits on non-urban routes and remove any doubts on viability of such vehicles for a win-win situation for both the industry and the government. This study has been undertaken in five states in India, including Kerala, Union Territory (UT) of Ladakh, Madhya Pradesh (MP), Tamil Nadu (TN) and Uttar Pradesh (UP).

This study was undertaken in three stages. The first stage documented the findings from interactions with operators, to identify the gaps and bottlenecks in electrification of stage carriage buses on non-urban routes, especially by private operators. The second stage involved a deep dive into identifying viability gap for operating electric buses on such routes by the operators. This involved data collection on specific routes, developing business models for different electric bus models on such routes and undertaking pilots (on select routes) and deriving findings on the performance of buses. The third stage involved consolidating these findings to identify policy gaps and develop policy recommendations that can help achieve the aim of this study.

This piece presents the work undertaken as a part of the second stage of the study, focussing on pilot bus operations, data collection and analysis. The pilot bus operations were conducted on seven non-urban routes around the city of Leh. Leh, the capital of the Union Territory (UT) of Ladakh, is located at an altitude of 3500 meters (11,483 ft) along a northern tributary of the Indus River in the Leh district of Ladakh (Dame et al., 2019). Leh is characterised by highly undulated terrain with frequent folds and troughs across the region. It has a severe climate, with the temperature varying from 35 °C in summers to -28 °C in the winters (Chevuturi et al., 2018).

The operation of electric buses (e-buses) in Leh therefore becomes a great challenge under these harsh geographical and climatic conditions. In such situations, the charging rate and energy consumption of e-buses become unpredictable, which has a significant impact on their operational plan. Hence, detailed study and analysis is required to understand the impacts of the terrain and weather conditions on the daily operation of the e-buses. This study examined the operation of e-bus in Leh on a few select routes to understand important factors that influence the state of charge (SoC) of an e-bus and the viability of operating e-buses in these conditions reliably.

The study was conducted on seven routes originating from Leh. Five of these seven routes were roundtrip routes (from Leh to Alchi, Upshi, Spituk, Phyang, and Pathar Sahib and back) and totalled 10 trips. Rest of the two routes were one-way circular routes (Leh-Stakna-Leh and Leh-Chuchot-Leh).

2 Pilot Route Finalization

The objective of the pilot was to validate the claims and data provided by the OEM and refine the operational plan for the selected routes, based on the findings obtained.

Parameters for route selection criteria was developed to allow selection of routes best suited for pilot implementation based on inputs from related stakeholders. These are:

- **Total trips passenger catered in a day or earning per kilometre** - weightage of these two indicators were used, as both indicate earning potential which can be useful for pilot implementation. The scale of the measure for this indicator varied between very high (ordinal scale value 5) to very low (ordinal scale value 1)
- **Total vehicle km operated in a day** - Very high (ordinal scale value 5) to very low (ordinal scale value 1)
- **Total number of buses deployed on a route** (including up and down direction) - Very high (ordinal scale value 5) to very low (ordinal scale value 1)
- **Overlapping route** (in terms of possibility of sharing charging infrastructure en-route) - 5 if 1 or more charging station shared, 1 if none (not counting the station at origin) shared
- **Length of the route**, i.e., the need for charging infrastructure enroute or at destination. 5 if no additional charging infrastructure required (except that at origin), 3 if one charging infrastructure required and 1 if two or more charging infrastructure required enroute (not including origin but including destination)

Basis this, routes were shortlisted, and business and operational plans were developed. Afterwards, various online and in-person offline meetings were held in all five geographies for vetting & finalizing these plans and for initiating pilot demonstrations. For taking permissions for conducting pilots, follow ups were undertaken with concerned authorities. As a result, the project team received the permission for conducting pilot operations in the UT of Ladakh only. However, discussions for pilot operations in other geographies are ongoing. The details of the pilot demonstration in the UT of Ladakh have been discussed in the subsequent section.

3 E-bus Pilot Operations and Data Collection

The project team conducted e-bus pilot operations for seven routes in the UT of Ladakh in two phases. As a part of the seven routes e-bus data was collected for close to 400km of operations. Buses in Ladakh are currently being operated by JKSRTC. However, the operations are in the process of being transferred to Sindhu Industrial Development Corporation (SIDCO). Currently 10, 8.5m long e-buses have been procured by Ladakh administration from PMI Foton. The pilots were conducted using these buses, with drivers provided by JKSRTC.

Pilots were conducted with the support of RITES Ltd. which currently engaged by Ladakh administration for the development of a Transport Master Plan for the state. Active assistance for the project was provided by PMI Foton, JKSRTC and Ladakh Motor Garage (responsible for maintenance and charging of these buses). Data for the pilots was collected by the project team through on-board instruments. The analysis of the data was undertaken by the Civil Engineering Department, IIT Delhi.

The pilot operations were to be conducted using a single charge. This is because the E-bus charging infrastructure is currently only available at Leh. This dictated the route selection process. The list of routes on which pilot operations were undertaken in the UT of Ladakh have been presented in Table 1.

Table 1: Ladakh UT Pilot Operation Route Details

S.no	Routes	Distance (Km)	Date	Timing	Type
1	Leh – Alchi	69.38	October 7, 2022	From 11.03 am to 3.02 pm	Two-way
2	Leh – Upshi	48.62	October 10, 2022	From 2.26 pm to 5.28 pm	Two-way
3	Leh – Stakna	27.00	October 18, 2022	From 11.00 am to 11.38 am	One-way
4	Chuchot – Leh	21.00	October 18, 2022	From 11.55 am to 12.30 pm	One-way
5	Leh – Spituk	11.00	October 18, 2022	From 4.20 pm to 5.35 pm	Two-way
6	Leh – Phyang	19.00	October 19, 2022	From 2.12 pm to 5.12 pm	Two-way
7	Leh–Pathar Sahib	25.00	October 20, 2022	From 10.40 am to 12.05 pm	Two-way

3.1 E-bus Pilot Operations and Data Recording

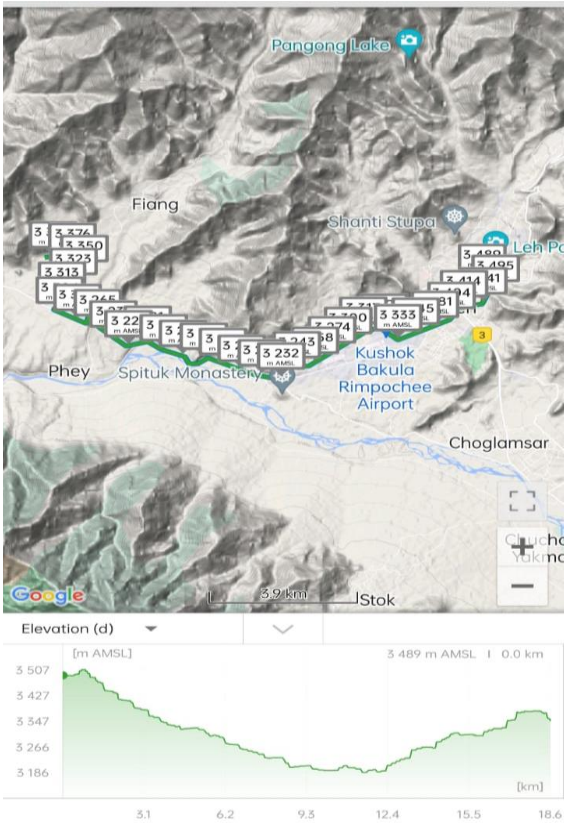
Data for host of parameters is recorded by the on-board battery management system (BMS) in the bus. However, this data was not available to the project team in a useable format. The team therefore opted for an observation-based data collection from the charger display, existing on-board instrument cluster and from added instruments in the bus. Multiple data points (Table 2) were recorded and documented to measure the impact on the e-bus performance with varying altitude, temperature, loading and distance. The data was collected in two parts. Part-one involved gathering data during pilot operations while discharging. The second part included gathering bus charging data while the charging operation was being carried out. Elapsed time, SoC, charging voltage, current, and battery temperature were among the information captured.

The onboard instrument cluster consisted of a dashboard, which displays data on state of charge (SoC), voltage, battery temperature, etc. The external instruments included a video camera for recording continuous readings from dashboard, a mobile phone camera, and ambient temperature sensor and an altimeter. The list of these instruments and the data collected from them has been presented in Table 2. A sequential step by step process was defined for data collection and recording. This process has been presented in Table 3.

Table 2: List of instruments used for data collection

Instrument and its function	Type	Type of data collected
Driver dashboard and instrument cluster, displays BMS information and vehicle information such as bus speed, RPM, etc.	Pre - Existing/ internal or fixed in the bus	Current date, current time, odometer reading, motor controller temp.(°C), motor temp.(°C), low pressure voltage(V), low pressure current(A), battery total voltage(V), battery total current (A), maximum voltage (V), minimum voltage (V), maximum battery temperature. (°C), minimum battery temperature (°C) revolutions per minute (RPM), speed (Km/h) and SoC (%)
Charger display	Pre-existing/ internal or fixed in the. Charger	SoC, charging voltage, current, and battery temperature
Mobile phone camera, used to capture geo tagged images of the dashboard and external instrument reading every 5 minutes.	External, manually operated	Geo tagged images (refer Figure 2) of dashboard, latitude and longitude, altitude (recording geotagged information to the image of the dashboard and other instruments), current date and time
Thermometer with an extendable sensor, used to capture external ambient temperature reading in the bus and of the charger (readings recorded every 5 minutes of the bis dashboard and every minute for the charger through geo tagged images from mobile phone camera)	External	Ambient temperature and relative humidity in the bus and at the charger
Altimeter mounted on top of the dashboard	External	Altitude

GoPro video camera, mounted in front of the dashboard (attached to steering column)	External	Continuous video feed of the dashboard and the altimeter.
Weighing scale for recording weight data of all occupants in the bus	External	Weight data observed and recorded on a form
Mobile phone camera used to record charging observations every 1 minute	External	Geo tagged images of charger display



The graphics on the left have been extracted through Altimeter app (which is easily available on Google App Store)

Figure 1: Snapshot of pilot & data captured during pilot operations in Ladakh UT

The camera/mobile was positioned to achieve a proper focus of the dashboard in order to capture a clear picture of the readings/display. The camera was secured using mounts or pods so that the focus doesn't shift from dashboard. The altimeter was fixed close to the dashboard so that the camera can capture display from altimeter and the dashboard. An image of placement of the instruments is presented in Figure 2, Figure 3 and Figure 4.

Figure 2: Images of instruments used for data recording

Table 3: List of tasks for Pilot operations

S. No	Data Collection Task
1	Collect secondary data on bus, charger details and performance specifications such as battery size, SoC, mileage, etc. from the OEM's or operators.
2	Seek prior permissions and approvals from the operators and concerned government authorities for conducting pilot run
3	Collect secondary information for the routes such as route length, terrain, demand etc. Finalization of the routes for the trail run based on route evaluation analysis as well in discussions with the operators and the OEMs.
4	Understand the equipment requirement for and ensure that the team trained to use these instruments as per need.
5	Develop a data collection checklist as well design forms for any specific data to be collected.
6	Chalk out a workforce allocation plan with assigned task.
7	Fix gadgets/Instruments in the bus for collecting the required data during pilot.
8	Capture images of instrument cluster or record observations at periodic intervals during the bus operations
9	Capture images of instrument cluster or record observations at periodic intervals during the charging operations
10	Recording, storage, and safe keeping of data including downloading of data from camera/video recorder and recording observations on the spreadsheet from photographs, video, survey formats (passenger weight data)

Figure 3 Fixing of Camera and Altimeter

Figure 4 Fixing of thermometer and external sensor probe

3.2 E-bus Pilot Operation Observations and Data

Observations captured as part of the data collection exercises were manually digitised and recorded in the excel format. The data recorded from bus operations comprised of SoC readings throughout the route, temperature, altitude, GPS data (Latitude and Longitude), distance travelled in kilometres, the time required to complete the trip, occupancy statistics during the pilot, and weight in the bus (CAN + BMS). The summary of all seven pilot operations have been presented in Table 4.

Table 4: Pilot Output Summary

Data Recordings						
S. No	**Route**	**Start**				
		Time	**Pax Weight**	**SoC**	**Altitude**	**Ambient Temp**
1	Leh-Alchi	11.03pm	415kg	99%	3407m	16.9˚c
2	Alchi-Leh	1.19pm	415kg	76%	3088m	13.7˚c
3	Leh-Upshi	2.26pm	760kg	70%	3447m	21.9˚c
4	Upshi-Leh	4.09pm	334kg	51%	3398m	14.4˚c
5	Leh-Stakna	11.00pm	264kg	97%	3382m	9.3˚c
6	Chuchot-Leh	11.55pm	264kg	86%	3208m	7.7˚c
7	Leh-Spituk	4.20pm	1200kg	75%	3381m	4.9˚c
8	Spituk-Leh	5.10pm	480kg	74%	3132m	5.1˚c
9	Leh-Phyang	2.12pm	1277kg	60%	3403m	11.9˚c
10	Phyang-Leh	4.40pm	1277kg	54%	3303m	14.5˚c
11	Leh-Pathar-Sahib	10.40am	293kg	56%	3419m	15.6˚c
12	Patha Sahib-Leh	11.30am	293kg	45%	3461m	10.9˚c
S. No	**Route**	**End**				
		Time	**Pax Weight**	**SoC**	**Altitude**	**Ambient Temp.**
1	Leh-Alchi	12.53pm	415kg	76%	3087m	16.9˚c
2	Alchi-Leh	3.02pm	415kg	46%	3443m	13.7˚c
3	Leh-Upshi	3.34pm	334kg	51%	3398m	14.6˚c
4	Upshi-Leh	5.28pm	334kg	23%	3433m	11.4˚c
5	Leh-Stakna	11.38pm	264kg	86%	3208m	7.4˚c
6	Chuchot-Leh	12.30pm	264kg	76%	3380m	9.7˚c
7	Leh-Spituk	5.01pm	240kg	74%	3132m	5.1˚c
8	Spituk-Leh	5.35pm	480kg	65%	3381m	3.1˚c
9	Leh-Phyang	2.45pm	1277kg	54%	3303m	15.5˚c
10	Phyang-Leh	5.12pm	1277kg	42%	3435m	6.4˚c
11	Leh-Pathar-Sahib	11.15pm	293kg	45%	3460m	10˚c
12	Patha Sahib-Leh	12.05pm	293kg	36%	3402	11.8˚c

To capture the charging data, one designated person captured the readings from charger screen monitor every minute (Figure 5). A total sample size for this data was three. This has been presented in Table 5.

Table 5: Charging Data Summary

Date	Starting SoC	End SoC	Time Duration
12/10/2022	30%	85%	34.7minutes
12/10/2022	76%	99%	21minutes
21/10/2022	43%	99%	47.6minutes

Figure 5 Charging Data Collection

4 Data Analysis

This section presents the analysis of the data (collected from the pilots) conducted by the Civil Engineering Department at IIT Delhi. The investigation comprised analysis of the effect of topography, loading, and ambient temperature on the state of charge (SoC)/depth of discharge (DOD) and rate of discharge of the battery, as well as the effect of ambient temperature on charger efficiency. The data analysis was undertaken for all seven routes. Additionally, analysis of data recorded from three observations for bus charging was also analysed.

Factors such as terrain conditions, temperature ranges, loading weights (passenger and luggage), driving condition as well as auxiliary loads such as those required for heating, ventilation, and air-conditioning (HVAC) are key factors in estimating the energy consumption for an e-bus. In non-urban e-bus operations, driving condition is not likely to be a significant factor though. However, energy regeneration can be achieved if the e-bus driver slowly and steadily decelerates from a higher speed. Overall, the scope of the data analysis is summarised as follows:

- Study of the impact of terrain and loading on the SoC and rate of discharge
- Study of the impact of ambient temperature on the SoC and rate of discharge
- Study of the impact of ambient temperature on the charger efficiency

The route length and altitude details of the trips on which data was collected are presented in Table 6.

Table 6: Summary of Route Data

S.N.	Route	Length (km)	Travel time (Min)	Altitude difference (m)
1	Leh-Alchi	67	110	-320
2	Alchi-Leh	67	103	+354
3	Leh-Upshi	48.6	68	-49
4	Upshi-Leh	48.6	78	+49
5	Leh-Stakna	27	38	-174
6	Chuchot-Leh	21	38	+171
7	Leh-Spituk	11	41	-249
8	Spituk-Leh	11	25	+249
9	Leh-Phyang	19	33	-100
10	Phyang-Leh	18	32	+111
11	Leh-Pathar Sahib	25	35	+49
12	Pathar Sahib-Leh	25	35	-59

4.1 Route Profiles

Data was collected through dash-board images and readings recorded from various on-board instruments such as altimeter and temperature devices. Route profiles were developed from the altimeter and trip distance readings. The distance between Leh and Alchi is about 67 km. The terrain between Leh and Alchi is highly undulating, as evidenced by the route profiles shown in Figure 6 and Figure 7.

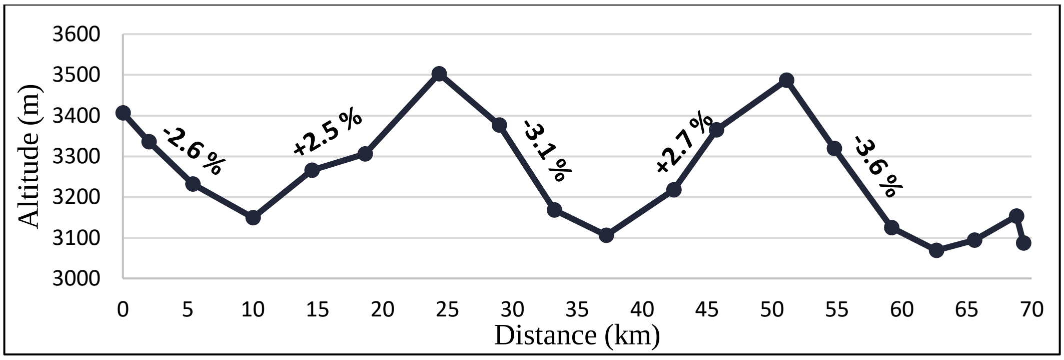


Figure 6: Route Profile for Leh – Alchi

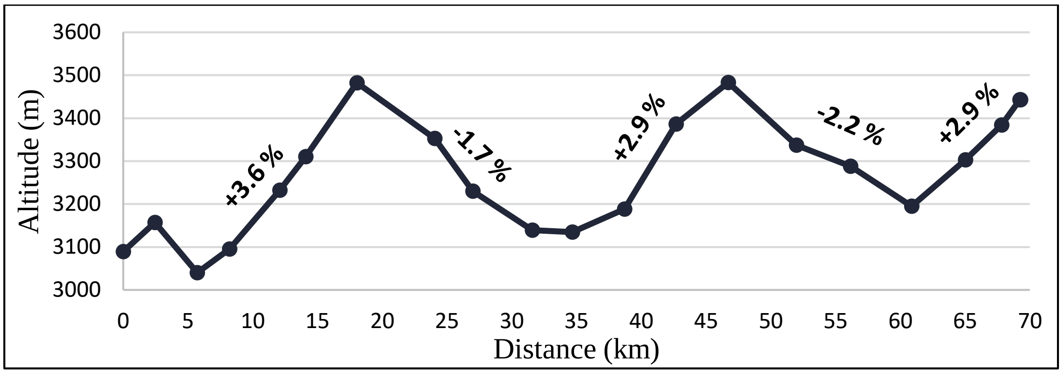


Figure 7: Route Profile for Alchi – Leh

Although the average gradient for the Leh-Alchi route is about 2.8% downhill, it does not show the full picture of the route. The route comprises of several uphill and downhill segments with gradients ranging from 1.7% to 3.6%. The estimation of energy consumption is therefore not straightforward as energy consumption reduces in the downhill sections due to energy regeneration. On steep downhill sections, the SoC of the e-bus may increase due to higher rates of energy regeneration. Therefore, the net energy consumption for such routes cannot be estimated by using the average slope for the entire route.

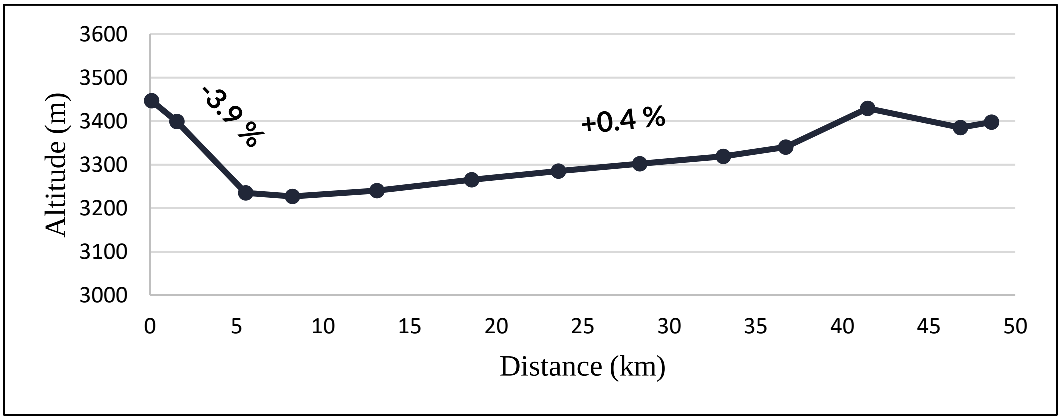


Figure 8: Route Profile for Leh – Upshi

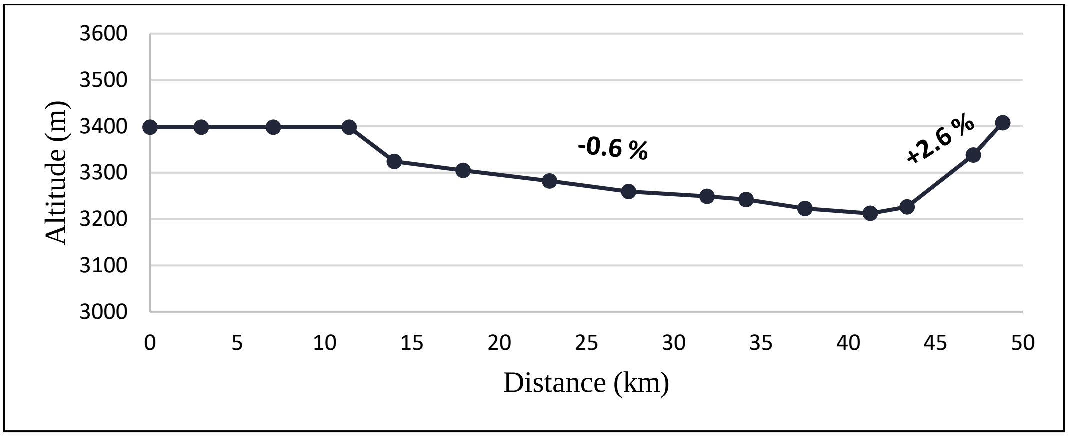


Figure 9: Route Profile for Upshi - Leh

The distance between Leh and Upshi is about 49 km. In contrast to Leh-Alchi, the route, as depicted in Figure 8 and Figure 9 is nearly flat, except for the segment of route closer to Leh (about 5 km), where the route is steep at around 3.9% gradient.

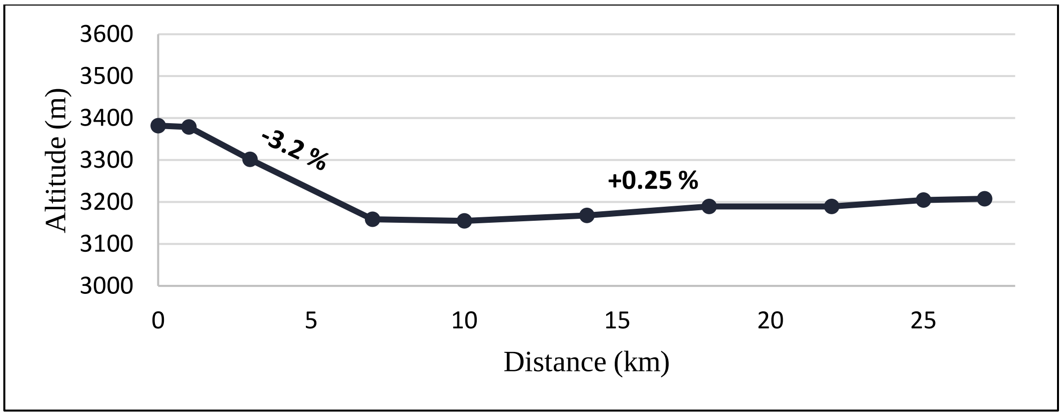


Figure 10: Route Profile for Leh - Stakna

The distance between Leh and Stakna is around 27 km. It was observed that the route starts flat, followed by a sharp downhill section of around 3.2% gradient (Figure 10). Rest of the route is relatively flat with an average gradient of 0.25% uphill.

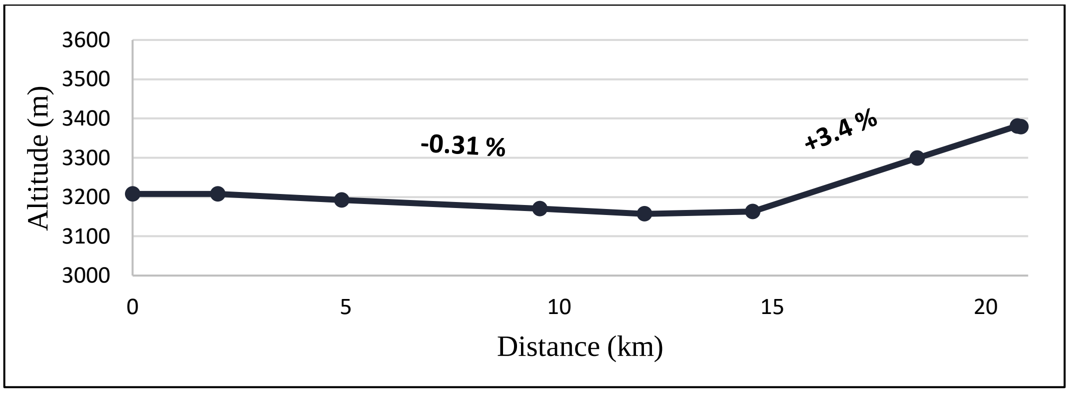


Figure 11: Route Profile for Chuchot - Leh

The distance between Chuchot and Leh is around 21 km. It can be observed from Figure 11 that the route has an almost flat terrain for about 75% of its length with an average gradient of about – 0.31% followed by a significant upgrade of about 3.4%.

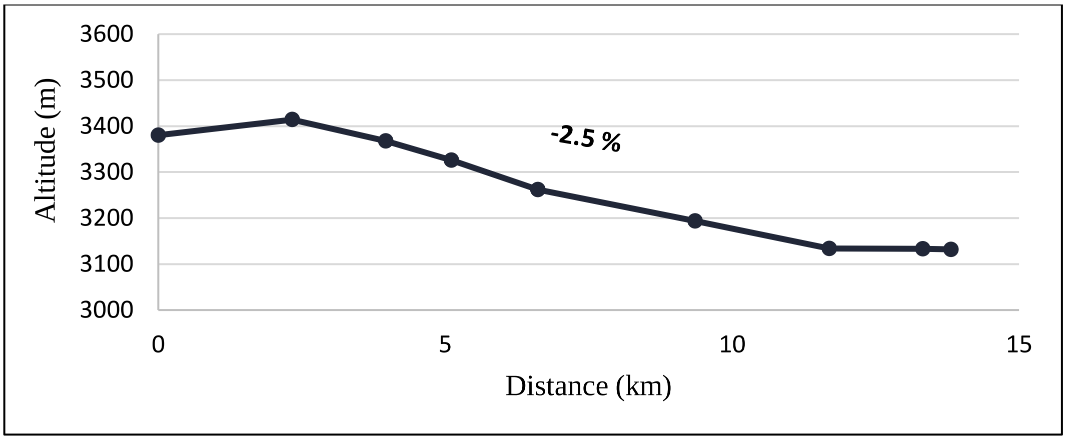


Figure 12: Route Profile for Leh-Spituk

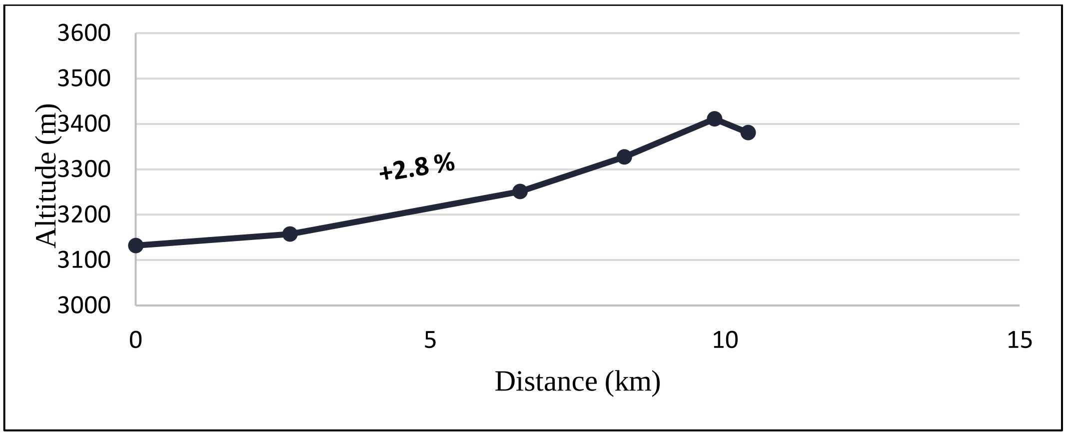


Figure 13: Route Profile for Spituk – Leh

The distance between Leh to Spituk is roughly 13 km. As shown in Figure 12 and Figure 13, the route follows an almost constant upgrade/downgrade of about 2.8%. As the returning route was not the same as going to Spituk the distance recorded in Figure 12 and Figure 13 is different.

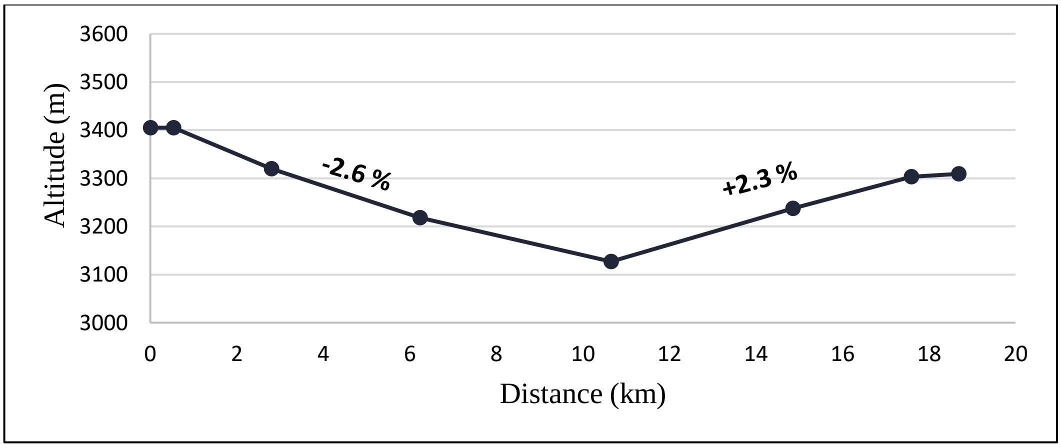


Figure 14: Route Profile for Leh – Phyang

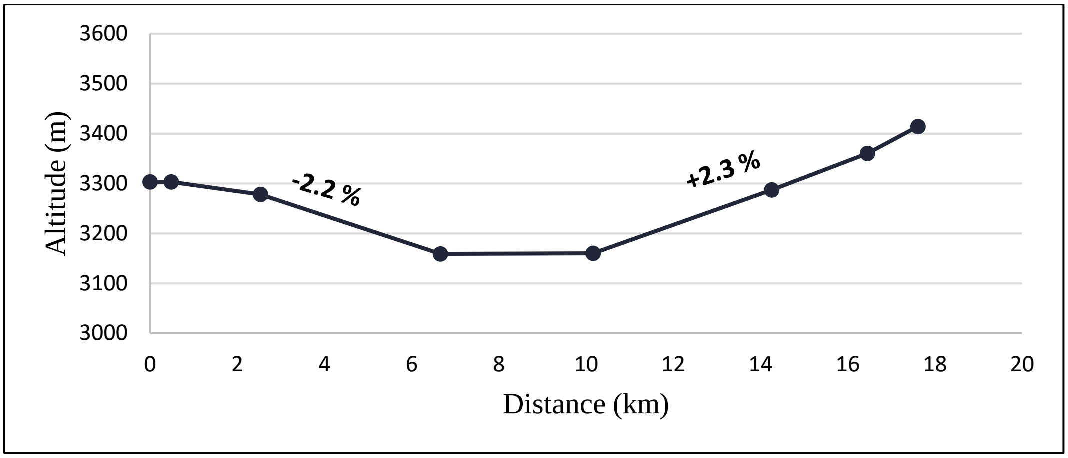


Figure 15: Route Profile for Phyang – Leh

The distance between Leh and Phyang is about 18 km. The route from Leh follows a downgrade for 10 km and then climbs uphill with an average gradient of 2.3% until the end as shown in Figure 14 and Figure 15.

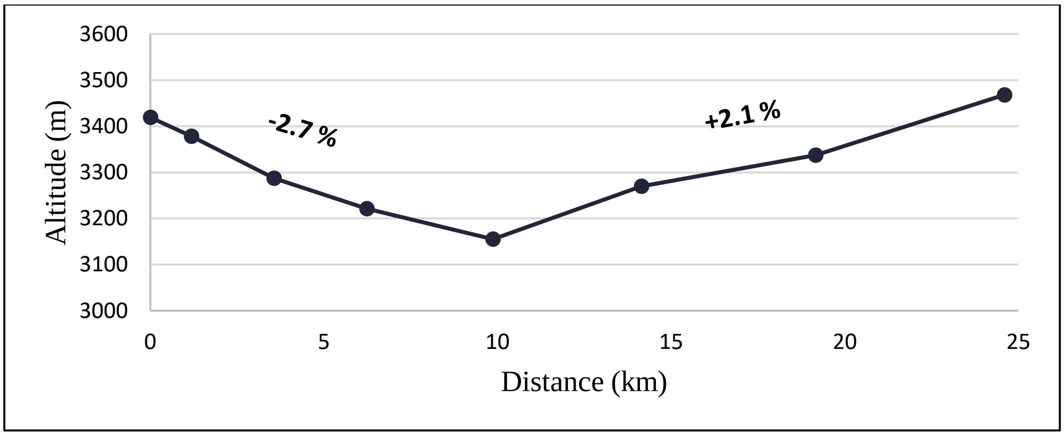


Figure 16: Route Profile for Leh-Pathar Sahib

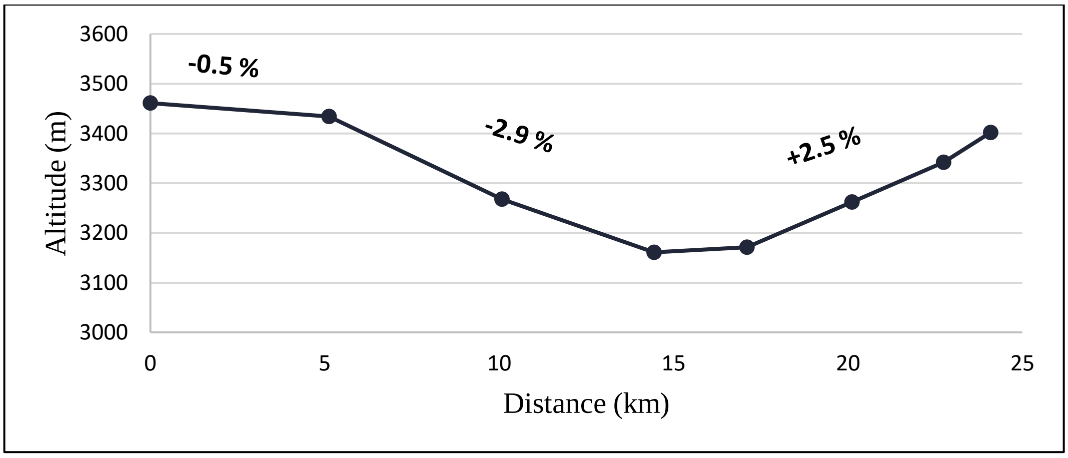


Figure 17: Route Profile for Pathar Sahib - Leh

The distance between Leh and Pathar Sahib is about 25 km. The route from Leh – Pathar Sahib (Figure 16 and Figure 17) follows a somewhat similar trend like Leh – Phyang.

4.2 Operational Data Analysis

Data was collected on seven routes to study the impact of various factors such as trip length, altitude, gradient, temperature variations, etc. on SoC consumption rate of the e-buses during operation. The routes are listed in Section 1 (Route Details) above.
As the study area is a hilly terrain, to determine the effects of the terrain on the energy consumption of the e-buses, linear regression analysis was done using the average gradients of the route segments between consecutive data readings. The analysis was done for the overall dataset and disaggregated for positive and negative gradient as well. Figure 18 and Figure 19 show the variation in change in SoC (%)/km in negative (downhill) and positive (uphill) gradient conditions, respectively. Figure 20 shows the variation for the entire study area across the seven routes.

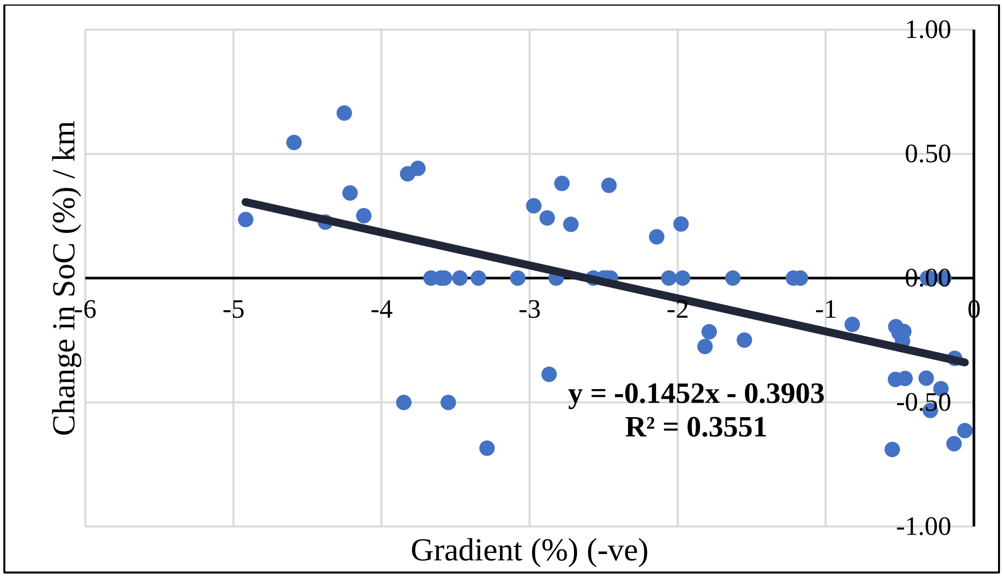


Figure 18: Variation in Change in SoC (%)/km in Downhill Terrain

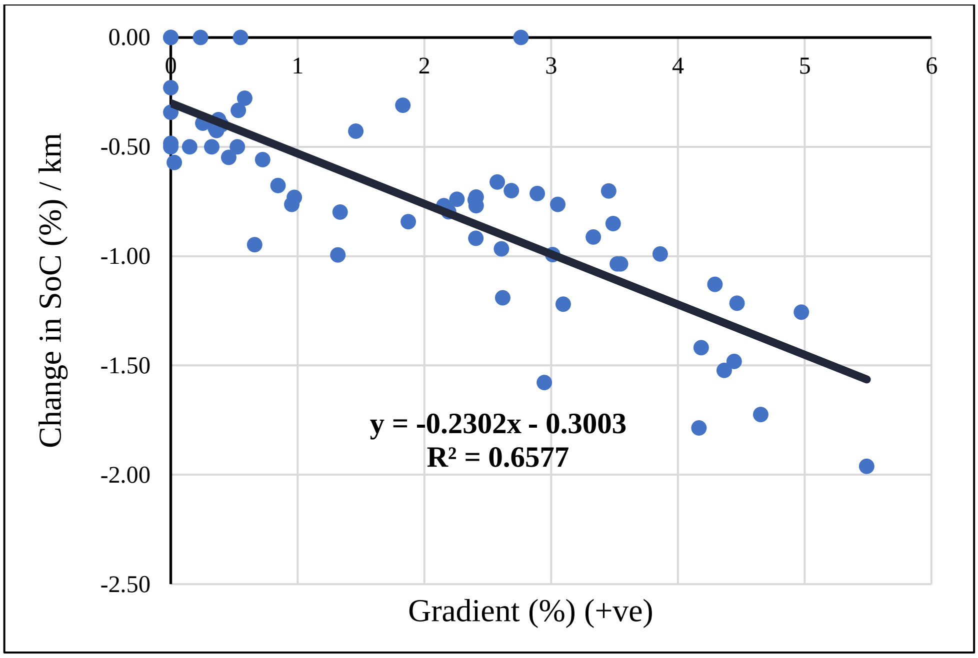


Figure 19: Variation in Change in SoC (%)/km in Uphill Terrain

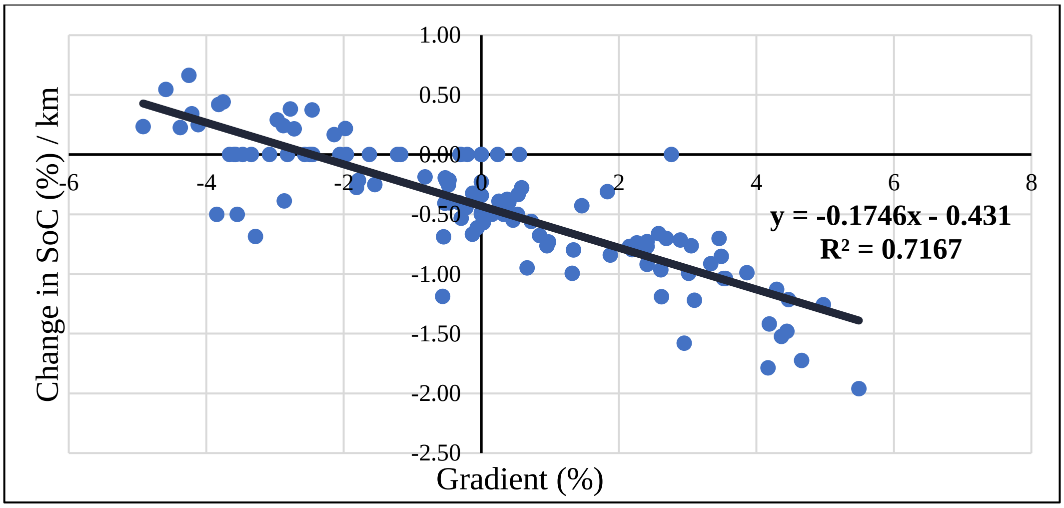


Figure 20: Variation in Change in SoC (%)/km for Overall Terrain

Observations indicate that as the gradient increases in the positive direction, the change in SoC/km increases in negative magnitude, which means that the energy consumption rate of the e-buses increase with increase in the uphill gradient. While going downhill, the SoC consumption rate decreases due to energy regeneration in the battery. For high negative gradients (steep downhill segments) the energy regeneration rate equals energy consumption rate (around -2.4 to -2.6 % gradient) or even surpasses the energy consumption rate leading to a net increase in the battery's SoC.

4.3 Regression Models for Operational Data

The relation of change in SoC (%)/km with significant variables is shown in equations (1) to (3) below. It was observed that gradient, along with passenger loading were the most influential factors for variation in energy consumption of the e-buses. Due to limited data, these equations were derived for a load range of 260 – 760 kgs.

Total data:

$$Change\ in\ SoC\ (\%)/km = -0.309 - 0.0003\ Pass.load\ (kg) - 0.165\ Gradient(\%)$$

(R^2 = 0.69) (1)

Uphill conditions:

$$Change\ in\ SoC\ (\%)/km = -0.073 - 0.0005\ Pass.load\ (kg) - 0.233\ Gradient(\%)$$

(R^2 = 0.68) (2)

Downhill conditions:

$$Change\ in\ SoC\ (\%)/km = -0.396 - 0.131\ Gradient(\%)$$

(R^2 = 0.30) (3)

The data analysis of the pilot e-bus runs in Leh indicates that the battery discharge rate, is approximately 0.33% SoC/km (considering average weight of the driver as 80 kg) on a flat terrain with no passenger load. Equation 1 suggests that the consumption rate increases by 0.02 % for each passenger onboard with the assumed average weight. Regression model based on overall data (inclusive of uphill and downhill sections both) shows that energy consumption is significantly influenced only by two factors, i.e., gradient and passenger loading. As the amount of energy required to ascent uphill is greater, the discharge rate increases by 0.16 % SoC/km for each 1 % increase in uphill gradient with driver's presence only (Equation 1).

In downhill situations, battery recharging through energy regeneration comes into the picture after the application of brakes. This further reduces the net energy consumption, sometimes recharging the battery more than consumed at steeper sections. Model shows that as the terrain grows steeper (~3%) in downhill conditions, the energy regenerated balances energy consumption. The passenger loading comes out to be an insignificant factor for energy consumption/regeneration while steering downhill.

Equation 2 and 3 shows factors significantly influencing SoC consumption rate exclusive for uphill and downhill conditions respectively.

4.4 Charging Analysis

Charging of batteries occurs in the Constant Current (CC) phase, followed by the Constant Voltage (CV) phase. During the CC phase, SoC increases linearly with the charging duration until the battery's terminal voltage reaches a threshold (this typically happens between 80 – 90% SoC). After this, the CV phase starts in which the charging slows down, and it has a nonlinear (concave) relation with the charging duration (Sassone et al., 2014).

We studied three different charging instances of e-buses ranging from 32 to 99 % SoC to determine the approximate charge rate of the buses in the Constant Current (CC) and Constant Voltage (CV) phases and the SoC level at which the phase change occurs.

Figure 21, Figure 22 and Figure 23 show the variation of SoC charged/min with SoC level in the battery for the three instances.

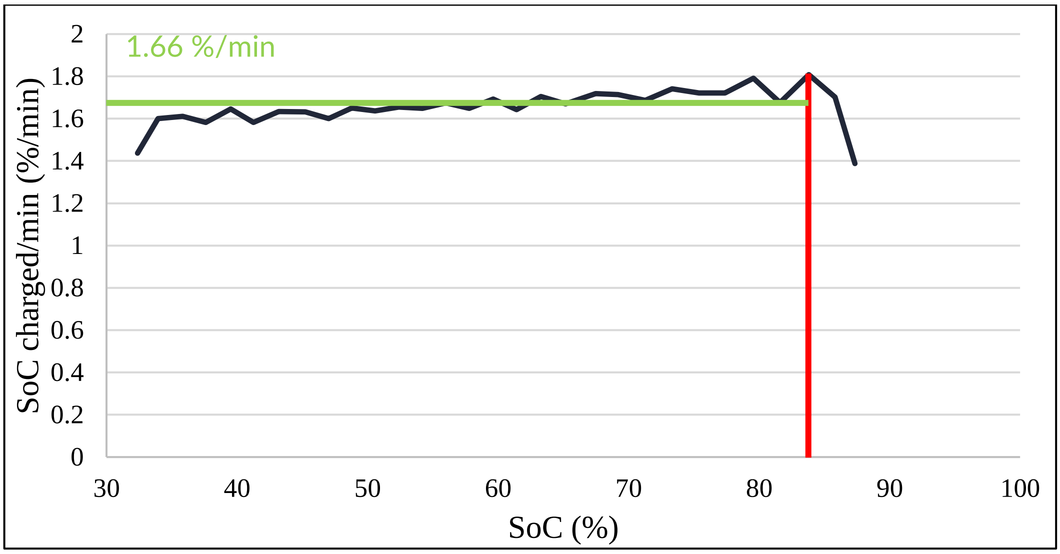


Figure 21: Charging Instance 1

The horizontal green line shows the average charge rate in CC phase and the vertical red line shows the SoC level at which the phase switch takes place.

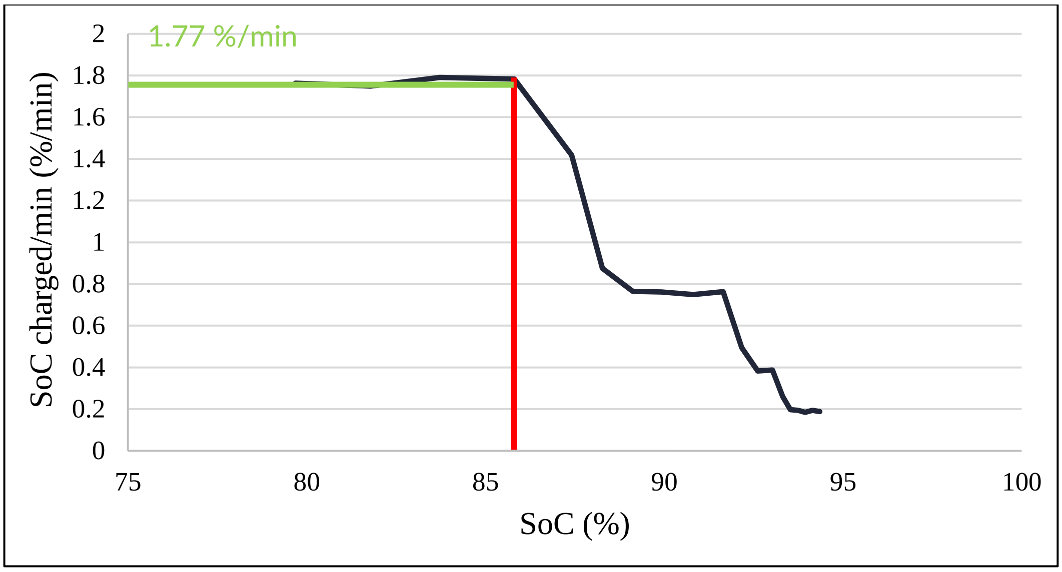


Figure 22: Charging Instance 2

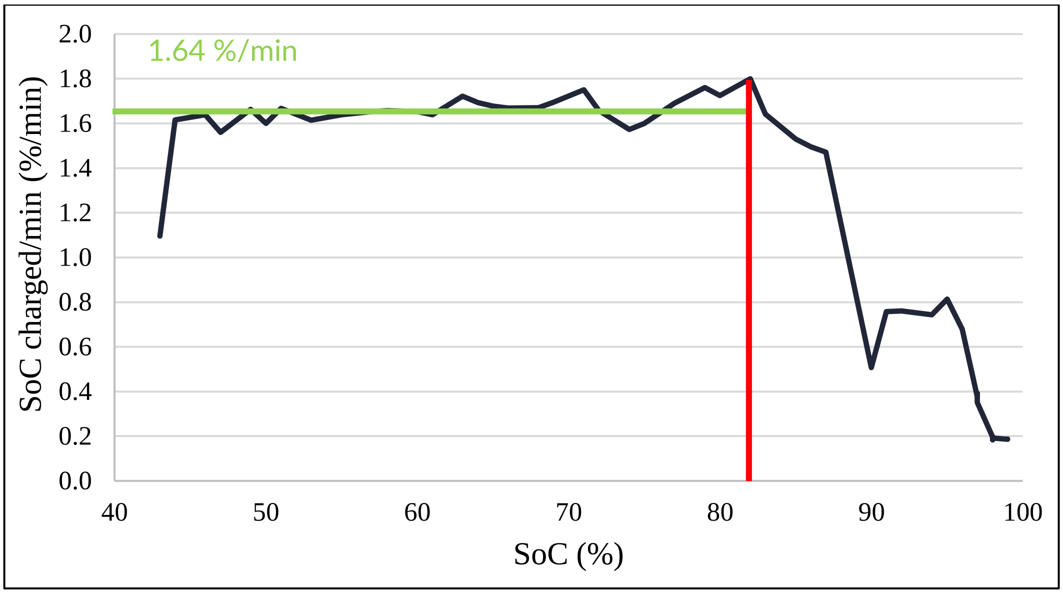


Figure 23: Charging Instance 3

In all charging instances, a significant drop in the charge rate was observed at the SoC level where the charging shifts from CC to CV phase. The switch of charging from CC to CV phase was observed at 81-86 % SoC. The average charge rate was observed around 1.64-1.77 % SoC/min in the CC phase, which reduced to as low as 0.2 % SoC/min in the CV phase.

Hence, if the operator wants to charge the e-bus above 90 % SoC, the charging duration will be longer than in the CC phase for the same amount of charge. Moreover, charging e-buses in the CV phase could be detrimental for battery's state of health. Table 7 presents the estimated time durations for set ranges of SoC to be charged. These estimated times may vary due to temperature variation. Temperature has a bearing on the charging phases of the Li-ion batteries as at low temperature, terminal voltage for CV phase can become lower leading to a prolonged CV phase (Liu et al., 2020).

Table 7: Estimated Time to Charge SoC Range

SoC range (%)	Estimated time (min)
20-80	36.6
80-85	3.1
85-90	4.2
90-95	10.5
95-100	16.6

5 Key Findings

The data suggests that charging switches from the constant current (CC) to constant phase (CV) phase between 80-86% SoC. Charging slows down considerably in the CV phase and might also lead to battery health deterioration. Hence, the usable battery capacity should have a reasonable range to keep the charging time as efficient as possible. It can thus be assumed that a maximum SoC of 90% can practically be achieved during opportunity charging, while achieving an SoC of 80% may be desirable to limit the layover time.

In operation, the predominant factor influencing the energy consumption of the e-buses is the gradient, i.e., the terrain conditions of the study area. Passenger loading also came out to be an influencing factor. However, the coefficient of passenger loads was small enough not to make a remarkable difference in energy consumption estimation e-buses (for the range of passenger loads observed).

The study had limited charging data with respect to variations in battery and ambient temperatures, which might lead to a reduced charging rate than estimated and lead to higher than anticipated charging duration for the operator. The temperature range of the study area in winters is a critical factor for the batteries used in the e-buses (Ge et al., 2016; Motoaki et al., 2018), and similar study in the winter condition would result in better policy recommendations.

In operational e-buses, more data regarding varying passenger loading and varying temperature conditions would be helpful in making more accurate prediction of their impacts on energy consumption rate in the study area's terrain.

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