Going Green

Technical and Investment Analytics for Sajha Yatayat's First Electric Bus Fleet

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ABBREVIATIONS

AC	Alternating Current
ADB	Asian Development Bank
BEV	Battery Electric Vehicle
BMS	Battery Management System
BPKM	Billion Passenger Kilometers
BYD	Build Your Dreams
CO_2	Carbon Dioxide
DC	Direct Current
DoD	Depth of Discharge
DoE	Department of Environment
DoED	Department of Electricity Development
DoTM	Department of Transport Management
EPI	Environmental Protection Index
EV	Electric Vehicle
EVAN	Electric Vehicle Association of Nepal
EVC	Electric Vehicle Charging
EVI	Electric Vehicles Initiative
EVSE	Electric Vehicle Supply Equipment
FAME	Faster Adoption and Manufacturing of Electric Vehicles
FLA	Flooded Lead Acid
GBP	Great Britain Pound
GDP	Gross Domestic Product
GESI	Gender Equality and Social Inclusion
GGGI	Global Green Growth Institute
GHG	Greenhouse Gas
GVW	Gross Vehicle Weight
kWh	Kilowatt hours
LIB	Lithium-Ion Battery
MoFE	Ministry of Forests and Environment
MoPIT	Ministry of Physical Infrastructure and Transport
MoUD	Ministry of Urban Development
MW	Megawatts
NEA	Nepal Electricity Authority
NDC	Nationally Determined Contribution
PM	Particulate Matter
PM-DC	Permanent Magnet-Based Motors
PV	Photovoltaic
ROI	Return on Investment

SMG	Seoul Metropolitan Government
SoC	State of Charge
TCO	Total Cost of Ownership
TOD	Time of Day
UNFCCC	United Nations Framework Convention for Climate Change
USD	United States Dollars
WB	World Bank
WHO	World Health Organization

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EXECUTIVE SUMMARY

Part A – Introduction to the Opportunity

Background

The share of private fossil fuel vehicles in Nepal is on the rise, effectively displacing larger public vehicles. Since 1990, vehicles in the country have increased at an average growth rate of 14%. In this period, a substantial increase in two- and four-wheelers have caused the share of public transport in the total vehicle stock to decrease from 11% in 1990 to 5% in 2018. Much of this growth is centered in the Bagmati Zone, where 30% of the total vehicle stock is registered, and out of which more than 90% is comprised of private vehicles.

This growth in fossil fuel vehicles has had a significant direct impact on the environment, in terms of air and noise pollution, the economy, and the energy security of the country. The rise in fossil fuel vehicles and their negative impacts on the environment and economy are a stark reality in Nepal. Greenhouse gas emissions from the transport sector increased at the rate of 11% during the 1994-2014 period and contributed to 44% of all energy-related emissions in 2014. PM2.5 levels were observed to exceed WHO standards by more than 10 times in 2017 alone. In addition, the share of petroleum imports contributed to 15% of the trade deficit in 2018/19, which is increasing every year.

Although ownership of fossil fuel vehicles is on the rise, a shift toward the use of efficient transport systems is also underway. Although still minimal, the share of electric vehicles has been increasing during recent years in Nepal. This is evident from the 714 electric three-wheelers (Safa Tempos), more than 26,000 e-rickshaws, 1,000 electric cars and 1,500 electric two-wheelers already in operation in the country as of 2018. This growing interest from private consumers has been a result of fiscal incentives provided by the government in terms of increased loan-to-value ratio and decreased import duties. In addition, public bus operators are becoming increasingly interested in operating electric buses due to their lower operation and maintenance costs, when compared to diesel buses.

Sajha Yatayat Building a Fleet of Electric Buses

Sajha Yatayat is consistently aiming to provide clean transport services. Sajha Yatayat, the only public transport cooperative in Nepal, is one such operator that is aiming to electrify its fleet by 2025. Sajha Yatayat currently operates a fleet of 71 diesel buses along 10 routes within Kathmandu Valley and 2 intercity routes, servicing over 26,000 passengers daily. The cooperative, which was revived in 2011, maintains EURO III and EURO IV standard buses in its fleet and provides clean transport services. In line with Sajha Yatayat's ambitious target of electrifying its entire fleet by 2025, the Federal Government of Nepal committed to an investment of NPR 300 crore (USD 27.3 million), in addition to the Province 3 Government, Kathmandu Metropolitan City and Lalitpur Metropolitan City's investment of NPR 42.5 crore (USD 3.9 million) in Sajha Yatayat for the procurement and deployment of electric buses across the country.

Current Assignment

The current assignment aims to provide advisory and analytical assistance to Sajha Yatayat on the procurement and deployment of electric buses within Kathmandu Valley. Sajha Yatayat aims to procure and operate a fleet of 16 electric buses in the initial phase, with investment support from the Province 3 Government, Kathmandu Metropolitan City (KMC) and Lalitpur Metropolitan City (LMC).

Part B- Options Analysis

Literature Review

Understanding Macao's electric bus service and its application in a similar terrain in Kathmandu. A study by Zhou et al. (2016) was referenced for the purpose of developing an energy consumption benchmark for electric buses in Sajha Yatayat's routes in Kathmandu Valley. Zhou et al.'s study (2016) which was conducted in Macao in People's Republic of China, shows that a bus of 8m in length consumed 80 kWh per 100 km when traveling under a full load. This increased to 100 kWh per 100 km traveled when air conditioners (AC) were deployed on the vehicle. Similarly, for a 12m bus, energy consumption was 191 kWh/100 km, increased to 211 kWh/100 km when AC was switched on.

Factors affecting battery health and life for efficient operation of the vehicle. Various factors have an impact on battery operation. An extreme state of charge, extreme battery and environment temperatures, a state of high current charging and discharging, as well as high discharge all affect the battery performance in the long run. These factor should be considered in order to ensure that batteries last longer and are operated at optimum levels.

Lithium-Iron Phosphate identified as superior battery choice for Sajha Yatayat. A lot of emphasis is usually placed on choice of battery. However cell technology should also be taken into account. For this reason, three mainly lithium-based battery types have been identified in this study: (i) lithium nickel manganese cobalt oxide (NMC), (ii) lithium-iron phosphate (LFP), and (iii) lithium titanium oxide (LTO). Among the three battery types, lithium-iron phosphate has been identified as a superior option for Sajha Yatayat due to its lower cost, high safety standards, and a reliable lifetime. The battery is also widely favored by manufacturers in China and India for their electric bus fleets.

Viable Route Options

Two *intercity* routes and four *intracity* routes were initially identified during this study. The intercity routes were identified as Kathmandu Valley-Bharatpur and Kathmandu Valley- Hetauda. The intracity routes were designated as Lagankhel-Budhanilkantha, Swayambhu-Suryabinayak, Ringroad, and Lagankhel-Kirtipur.

The Lagankhel-Budhanilkantha and Swayambhu-Suryabinayak routes were identified as the most viable options for the first phase of electric bus deployment. Out of the combined six routes, the two intercity routes of Lagankhel-Budhanilkantha and Swayambhu-Suryabinayak are prioritized due to their high performance against selected criteria such as maximum gradient, travel distance appropriateness, extent of passenger demand, extent of service supply, visibility potential, and road surface quality. The intercity routes have been recommended for the second phase of electric bus deployment.

Charging Regime Comparative Analysis

Various charging regimes can be adopted to optimize performance of electric buses along the selected routes. Three main charging regimes are currently being implemented around the world. The first one is the *Overnight Charging Regime* whereby buses with full battery sizes are charged overnight at the depot. The second is the *Terminal Station Charging Regime* whereby high-capacity fast chargers are installed at terminal stations along the route where overnight charging is *not* an option, but also includes an option for low-capacity terminal chargers to be installed at terminal stations where overnight charging *is* available. The third option is the

Opportunistic Charging Regime whereby buses with low battery capacity are charged by fast chargers at intermediate stops along the route.

Depot charging and terminal charging regimes identified as viable options for the selected routes. Two charging regime scenarios were found to be the most viable among the three options discussed above. Scenario A represented the *Overnight Charging Regime* and Scenario B reflected the *Terminal Station + Dept Charging Regimes*. In Scenario A, the battery is required to last a full day of operation and in Scenario B, the battery bank size has been assumed to be 50% of that of Scenario A due to the availability of additional charging stations at the terminals. Depot chargers were assumed to be of the same capacity for both scenarios.

Scenario A is deemed as the most viable and least risky charging regime. When Scenarios A and B were compared, Scenario A was the superior option in terms of financial performance, whereas Scenario B revealed higher operational risks. In Scenario A, the buses are more expensive due to their (full) battery sizes, whereas the terminal station installation costs in Scenario B are more CAPEX-intensive. The capital investment in Scenario B is around 7% and 12% lower for mid- and large-sized buses respectively, when compared to that of Scenario A. The operational expense of Scenario A, however, is around 17% lower than that of Scenario B. The cost of maintaining terminal stations adds to the operational expense (OPEX) of Scenario B.

Weighing the financial and operational risks for both scenarios, Scenario B has higher costs due to uncertainty in acquiring land to implement terminal charging stations, traffic uncertainty, and (potential) electricity supply interruptions resulting in charging schedule disruptions at terminals. In Scenario A, since the vehicles are charged overnight at the depot, these risks are minimal to negligible. Therefore, due to these perceived operational risks, Scenario A is deemed to be more cost effective.

Market Review of Electric Buses and Chargers

Market review of electric buses and charging stations heavily favors scenario A. Apart from a few models, the majority of mid-sized as well as large buses are manufactured with larger battery banks to maximize their range. The market review also supports Scenario A, since it is assumed that buses in this scenario will contain full battery packs. However, some manufacturers such as JBM and Kinglong claim to offer customizable battery banks, depending on requirements.

Charging infrastructure is dependent on the type of bus that is procured. Selection of plug and type (AC or DC) charger and charging standard is completely dependent on the bus that will be operated. Choosing buses and charger plug with 'winning' standards will have benefits in the form of an established global supply chain and an extensive (dealer? maintenance?) network.

Charging Station Installation at Sajha Yatayat Depot

Available substation capacity at Sajha Yatayat depot is sufficient for supply electricity to the first lot of electric buses. Two feeder lines supply a total of 2,910 kVA to the Sajha Yatayat depot, which is considered sufficient for the first fleet of 16 electric buses, which have been estimated to require around 886 kVA. Although, substation capacity is adequate for the time being, a larger capacity 1,200 kVA transformer needs to be installed at the depot for efficient operations. This transformer will be owned and operated by Sajha Yatayat.

Parking space outside of Sajha Yatayat depot is required for an additional 16 buses. Since around 45 buses are currently being parked at the Sajha Yatayat depot, only 10 additional buses can be accommodated within the depot. Sajha Yatayat is keen taking land on lease to park additional buses that will be purchased in the future.

Proposed Vehicle Specification

The proposed bus specifications complement the assessments made in the preceding chapters.

Several factors are necessary for understanding battery bank size, which is a key component of the electric bus. The suggested specifications, all related to bus dimensions, the vehicle's energy consumption, and the battery bank, are critical for efficient bus operation. For electric buses, a solid understanding of the vehicle's driving range, implications of adding air conditioners, as well as the Gross Vehicle Weight (GVW) are all required in order to be able to determine the capacity of the battery banks needed and their required efficiency.

The manufacturer will be able to best specify viable battery bank options for a bus with AC to cover the 166 km drive range for the Lagankhel-Budhanilkantha route specified above.

Several bus features are required for operation in Nepal. Features such as right-hand-drive, minimum ground clearance of 170 mm, minimum 15% gradient climbing ability, availability of an air suspension system and shock absorbers, and minimum speed of 60 km/h are based on general driving requirements in both country and local road conditions. Without these specifications, vehicles will accrue very high maintenance costs and may not be viable for the Lagankhel-Budhanilkantha and Swayambhu-Suryabinayak routes.

General safety features are a must in electric buses. Specification of general safety features are vital in the bus in case of fires. Additional features such as labeled seats and wheelchair access areas should encourage gender equality and social inclusion.

Part C - Financial Analysis

There are numerous economic and environmental benefits of switching to electric transport. With zero emissions from electric buses, local air quality will improve significantly. In addition, the operation of electric buses brings economic benefits due to their lower O&M costs, when compared to traditional diesel buses.

Revenue from the operation of electric buses significantly exceeds operating costs. Over a 15-year operational period, the cash balance is around NPR 63 Million (USD 406,000), which shows that operation of the buses is financially viable. Revenue, however, is mostly constant as it has been assumed that overall passenger load will reach a maximum at the end of three years of operation. The positive cashflow however presents a strong case to increase the fleet size for selected routes.

Savings of approximately NPR 6 Million (USD 38,000) per year are required to be set aside for major maintenance activities. Since most manufacturers maintain a battery warranty of 8 years, it has been estimated that savings of NPR 6 Million each year will safely cover battery replacement costs in year 8 and any other maintenance costs.

The projected cash balance is adequate for extending the operational life of the buses for an additional five years. A cash balance of NPR 89 Million (USD 454,000) will accrue at the end of the 15-year operational life of the buses. This is adequate to continue operation of the buses for an additional five-year period, in addition to covering any maintenance activities until the end of a 20 year period. This is also enough to cover any shortfall in passenger fare revenue during the additional five years.

PART A. INTRODUCTION TO THE OPPPORTUNITY

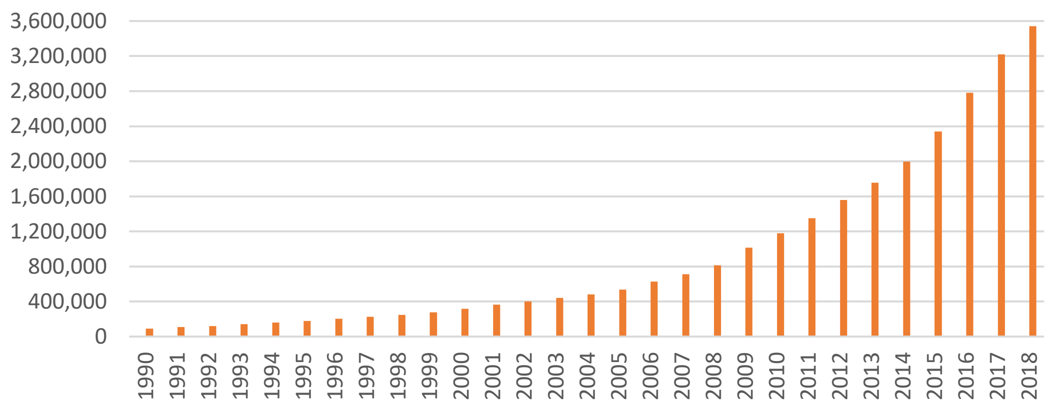
Chapter A1. Transport Sector in Nepal

1. Transport at the National Level

Since 1990, the number of vehicles operating in Nepal has risen significantly. National vehicle registration numbers, a good indicator of national transport demand, show an annual average growth rate of 14% during 1990-2018, as shown in Figure A1.1 below. Growth over more recent years has been particularly high, driven by urbanization and rising incomes. As a result, road transport is now the predominant form of transport in the country, accounting for some 90% of all trips.[1] Average annual growth rates of 9% for personal cars and of 17% for two-wheelers (motorcycles) was recorded between 1991-2018).[2]

It's worth noting that these growth rates are based on cumulative datasets maintained by the national Department of Transport Management, which does not take into account vehicles that have been scrapped due to age. While much of the growth in vehicle registration numbers is the result of acquisition for private personal use, the number of *public* transport vehicles has also risen. In 1990, there were around 4,000 buses in Nepal, and this number rose to more than 49,000 buses by 2018. Although the number of public transport vehicles - namely bus, minibus, microbus, and tempos - has increased in absolute terms, its share of the total vehicle stock has decreased from 11% in 1990 to 5% in 2018.

Figure A1.1: Total Cumulative Registered Vehicles in Nepal



Source: (MOPIT, 2019)[3]

[1] UNCRD. 2015. National Sustainable Transport Strategy (NSTS) for Nepal (2015~2040). NINTH REGIONAL ENVIRONMENTALLY SUSTAINABLE TRANSPORT (EST) FORUM IN ASIA.

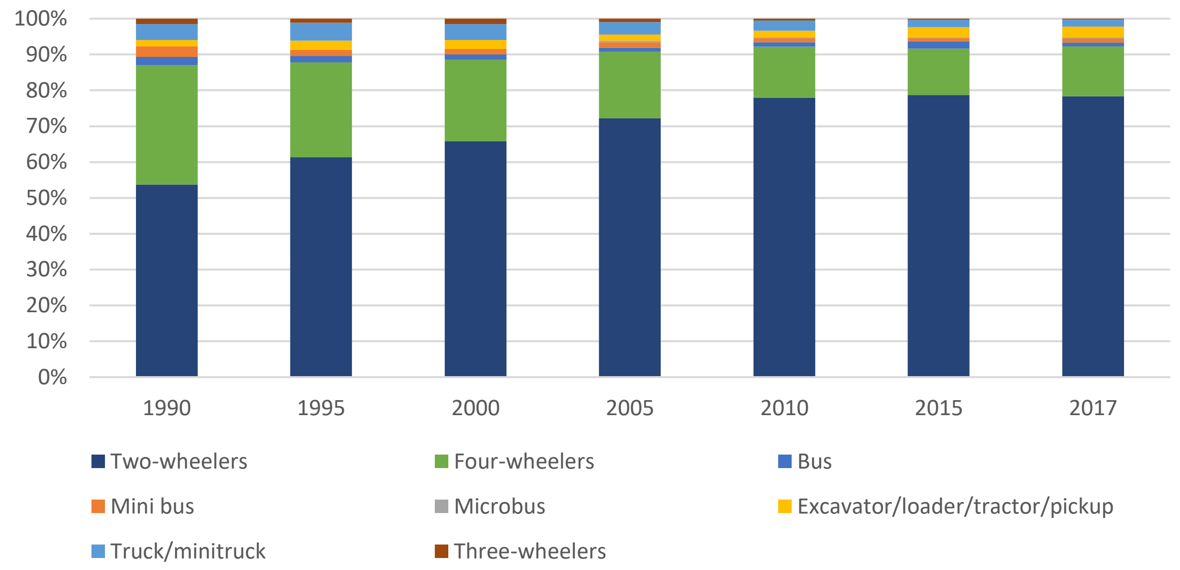
[2] MOPIT. 2019. Vehicles Registered in Nepal. Department of Transport Management. Ministry of Physical Infrastructure and Transport.

2. Transport at the Local Level

Much of the growth in the transport sector of Nepal has occurred in the Bagmati Zone, and specifically in Kathmandu Valley, which is home to Nepal's largest metropolitan region. Vehicles registered in the Bagmati Zone now comprise some 30% of total registered vehicles in Nepal. According to a study by Bajracharya and Bhattarai (2016), approximately 24,000 vehicles were registered in Kathmandu Valley in 2000. This number had risen to over 67,000 vehicles by 2014 – a threefold increase.[3] Of the total registered vehicles in the Valley, more than 90% are for personal use.[3,4]

Within the Bagmati zone, the share of public transport - including bus, mini and micro bus - has decreased considerably from 5% to 2% in the period between 1990-2017, although the number of vehicles increased from 2,322 in 1990 to 26,279 in 2017. The share of two-wheelers in the total vehicle fleet increased from 54% in 1990 to 78% in 2017. Registration of additional three-wheelers has been banned due to perceived traffic congestion on all routes. Since then, the number of three-wheelers, including Safa Tempos, have remained constant.

Figure A1.2. Modal Distribution of Passenger Transport Between 1990-2017 in the Bagmati Zone



Source: MOPIT, 2019[3]

3. Impact of the Growing Transport Sector

The rising numbers of vehicles in Nepal has been exacerbated by insufficient planning and (traffic) management and is leading to a range of environmental and social challenges. These include air and noise pollution, as well as worsening congestion on metropolitan roads. A report released in 2015 by the Government of Nepal and United Nations Center for Regional Development on National Sustainable Transport Strategy (NSTS) for Nepal emphasized that this rapid growth in motorization is threatening the energy security of the country.

[3] MOPIT. 2019. Vehicle registration data. Department of Transport Management. Ministry of Physical Infrastructure and Transport.

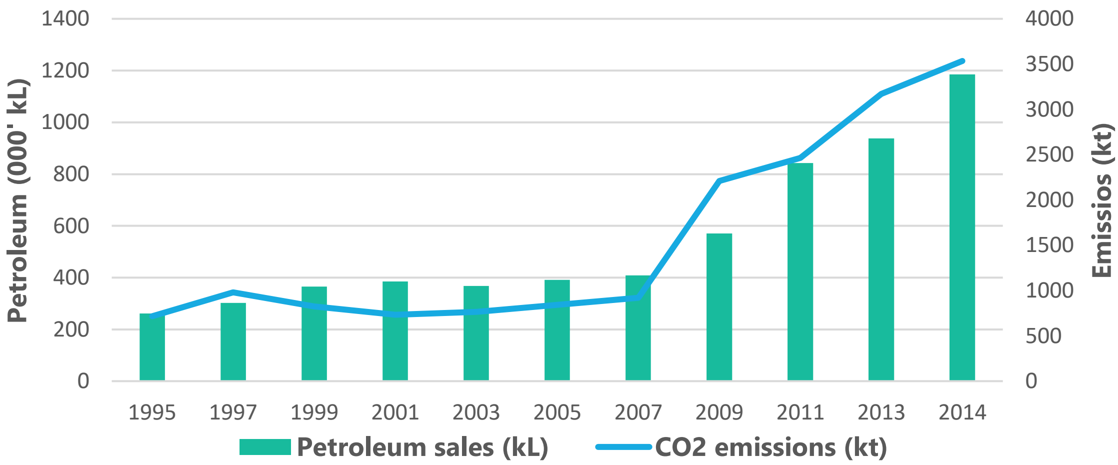
[4] Bajracharya, I., & Bhattarai, N. 2016. Road Transportation Energy Demand and Environmental Emission: A Case of Kathmandu Valley. *Hydro Nepal: Journal of Water, Energy and Environment*, *18*(18), 30–40. https://doi.org/10.3126/hn.v18i0.14641.

Impact on Economy and Energy Security

Energy security has been mainly threatened by petroleum imports. Consumption of petroleum products, mainly in the transport sector, has increased by an average annual growth rate of 7% between 1993/94 and 2017/18. More importantly, emissions from the transport sector are on the rise. Growth in emissions from the transport sector broadly aligns with petroleum consumption. However, it is growing at a more rapid annual average rate of 11% during the 1994-2014 period.[5]

In addition, increasing petroleum imports contribute significantly toward the growing trade deficit in Nepal as well as decreasing energy security. The country's annual trade deficit increased by 27.5% in FY 2017/18, resulting in a total deficit of NPR 1,163.86 billion. In the first eight months of FY 2018/19, the country spent NPR 135.42 billion on petroleum imports, accounting for 15% of the trade deficit.[6]

Figure A1.3. Trend in petroleum consumption vs. transport sector emissions during 1995-2014



Source: (World Bank, 2019) and (NOC, 2019)

Impact on Environment and Society

In addition to greenhouse gas emissions, other air pollutants are also rising, particularly in Nepali cities. In Kathmandu Valley, 24 hour average exposure to fine particulate matter (PM2.5) according to the Department of Environment was 226 µg/m^3 in 2017. That's close to nine times higher than the WHO standard of 10 µg/m^3.[7] The growing number of fossil fuel vehicles in Nepal has had severe negative implications on the quality of the environment and economy of the country. Air quality has been especially impacted PM10 and PM2.5 emissions and has been particularly low in Kathmandu Valley during the dry season. The annual average exposure to PM2.5 in Nepal was recorded as 99.73 µg/m^3 in 2017 by the Global Burden of Disease Study. That's close to 10 times higher than the WHO standard of 10 µg/m^3.[8] In addition, Nepal was ranked by the EPI as having the worst

[5] Ministry of Science and Technology, 2014. Second National Communication to the UNFCCC. Government of Nepal

[6] MOF. 2019. Economic Survey.

[7] Department of Environment (DoEnv), "Air quality monitoring," 2017, http://pollution.gov.np/ 7

[8] Brauer, M. et al. 2017, for the Global Burden of Disease Study 2017.

air quality among 180 countries in 2019.[9] Coronary heart and lung disease, both linked to air pollution, are the primary causes of death in Nepal.[10]

In 2013, more than 22,000 deaths in Nepal were attributed to indoor and outdoor air pollution. In that same year, air pollution-induced loss of welfare was recorded at USD 2.8 billion, equivalent to nearly 5% of the country's GDP.[11] This is also equivalent to approximately 40% of the losses and damages caused by the 2015 earthquake which was estimated at USD 7 billion. It is important to note that these economic losses due to air pollution occur annually. The projected increase of PM 2.5 will have a substantial effect on the economy resulting in higher healthcare cost, lost working days thereby affecting labor productivity, and declining crop yields.[12]

Furthermore, the transport sector has the highest energy-related emissions in the country, which is caused by the increasing trend in petroleum consumption. The sector contributed 1,709 kilo tons of CO_2 (which is 36% of the total national CO_2 emissions) in 2011.[13] In addition, the World Bank estimated that transport sector emissions had increased to 44% of the total emissions in Nepal in 2014.[14]

4. The Emergence of Electric Vehicles

Nepal has tremendous potential in hydropower generation which can offset petroleum imports, and can result in improved air quality and increased the security of the country. The Ministry of Energy, Water Resources and Irrigation has set an ambitious target of adding 5,000 MW to the grid by 2023 in order to make the country's energy secure. As of August 2019, hydropower plants with a total capacity of 1,038 MW have already been connected to the grid. In this scenario, as the country becomes self-sufficient in electricity production, a transition toward electric vehicles has tremendous strategic value and can also be imminent.

This transition is already evident in the transport sector. A small but growing share of the total vehicle is electric. For example, there are some 714 electric three-wheelers (Safa Tempos) on the streets of Kathmandu and 26,466 e-rickshaws in Terai.[15] In addition, a growing number of electric car manufacturers, including Kia, Hyundai, Mahindra, MG, and BYD are importing electric cars for private sale. Estimates for the number of electric cars in Nepal vary, but tend to be around 600 units in May 2019.[16] Currently, around 400 Mahindra E2O and e-Verito, more than 40 Hyundai Kona, and 10 BYD E6 have been sold in the market.[17] In addition to electric cars, there are more than 1,500 electric two-wheelers in the country as of November 2018.[18]

Furthermore, private transport operators are highly interested in building a fleet of electric buses. Sundar Yatayat is a private transport operator that is currently operating two electric buses on the ring road. In addition,

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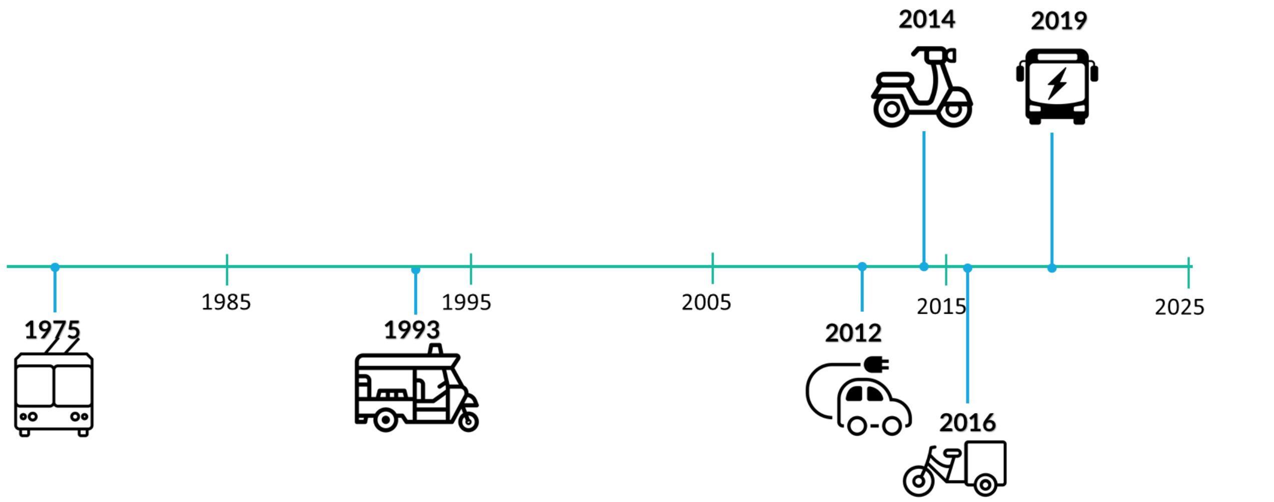
[9] Environmental Protection Index, Yale University. 2019. https://epi.envirocenter.yale.edu/epi-indicator-report/AIR?country=&order=field_epi_rank_new&sort=desc
[10] The Himalayan Times. 2019. https://thehimalayantimes.com/kathmandu/nepal-ranks-second-in-lung-ailment-deaths/
[11] Clean Energy Nepal, 2014. Air Quality Status and Management in Kathmandu Valley. Make the City Air Breathable. Manav-kendrit Yatayat Abhiyan (MaYA) Fact Sheet #5. Clean Air Network Nepal. UNHABITAT.
[12] OECD. 2016. The economic consequences of outdoor air pollution. Policy Highlights. Organisation for Economic Co-operation and Development.
[13] Tribhuvan University (2017). *Nepal's GHG Inventory- For Third National Communication to UNFCCC.*
[14] World Bank. 2019. CO2 emissions from transport (% of total fuel combustion). World Bank Group.
[15] MOPIT. 2019. Vehicle registration data. Department of Transport Management. Ministry of Physical Infrastructure and Transport.
[16] The Himalayan Times. 2019. NEA plans to set up 10 electric vehicle charging stations in Valley. Retrieved from https://thehimalayantimes.com/business/nea-plans-to-set-up-10-electric-vehicle-charging-stations-in-valley/
[17] AUTO & CELL. 2019. 190 units of Electric Cars sold within 10 months in Nepal. Retrieved from https://www.autoncell.com/detail/news/190-unit-electric-car-sold-10-months-nepal-which-first
[18] Nepali Times. 2018. Electri-City Cars: Do your bit for the ecology and economy by switching to a battery car, and save money too. Retrieved from https://www.nepalitimes.com/banner/electri-city-cars/

five electric buses were procured in 2018 by the Lumbini Development Trust, with financial support from ADB, to service Bhairahawa Airport which is currently under construction.

Investment in electric buses has also been fueled by lower import duties – currently at 1% for electric buses. Total taxes levied on imported fossil fuel vehicles are extremely high, amounting to 230% of the cost of the vehicle.

Figure A1.4. Emergence of Electric Transport in Nepal



Chapter A2. Introduction to Sajha Yatayat

1.Overview of Sajha Yatayat

Sajha Yatayat is Nepal's largest public transport operator and one of its best known companies, operating a fleet of iconic dark green full size diesel buses. It's 71 buses operate primarily in Kathmandu Valley, servicing around 26,000 passengers daily across the metropolitan region. The fleet covers over 74,000 kilometers daily and connects two metropolitan cities, namely Kathmandu Metropolitan City and Lalitpur Metropolitan City. It also covers seven municipalities, namely, Budhanilkantha Municipality, Madhya Thimi Municipality, Bhaktapur Municipality, Dakshinkali Municipality, Karyabinayak Municipality, Mahalaxmi Municipality, and Godawari Municipality. The organization also services an increasing number of districts neighboring Kathmandu Valley, including Baglung District, Butwal and Bhairahawa in Rupandehi District, as well as Kushma in Parbat District.

Sajha Yatayat is a cooperative. It began operations in early 1962 with the aim of providing affordable transportation to the population of Kathmandu Valley and increasing connectivity with surrounding districts. The 1990s and 2000 was a period of intense instability, with the cooperative facing significant operational challenges, resulting in the cooperative finally closing operations in 2007. At the time, Sajha Yatayat owned a fleet of 183 buses. However, in 2011, the organization was revived and in April 2013, 16 new buses were procured for operation. In 2016, a further 30 buses were procured and deployed and between 2018 and 2019, 23 additional diesel buses were added to the fleet. By August 2019, a fleet of 68 full size buses were operating across ten metropolitan and municipality routes, as shown in Table A1.1 overleaf. In addition, Sajha Yatayat also provides nighttime service on three metropolitan routes.

2. Current Fleet and Operations

Sajha Yatayat's fleet is comprised of two models. One has been procured from Ashok Leyland and the other from Tata Motors, both Indian vehicle manufacturing firms. With the financial contribution of Kathmandu Metropolitan City, a further 23 buses were procured in 2018-19. Currently, Sajha Yatayat has a fleet of 71 buses. As shown in Table A2.1, these buses currently operate across 12 metropolitan and intercity routes. These routes traverse the Kathmandu metropolitan region, connecting the northern and southern, as well as and eastern and western extremities, thereby integrating neighboring municipalities and communities into the wider Kathmandu metropolitan region.

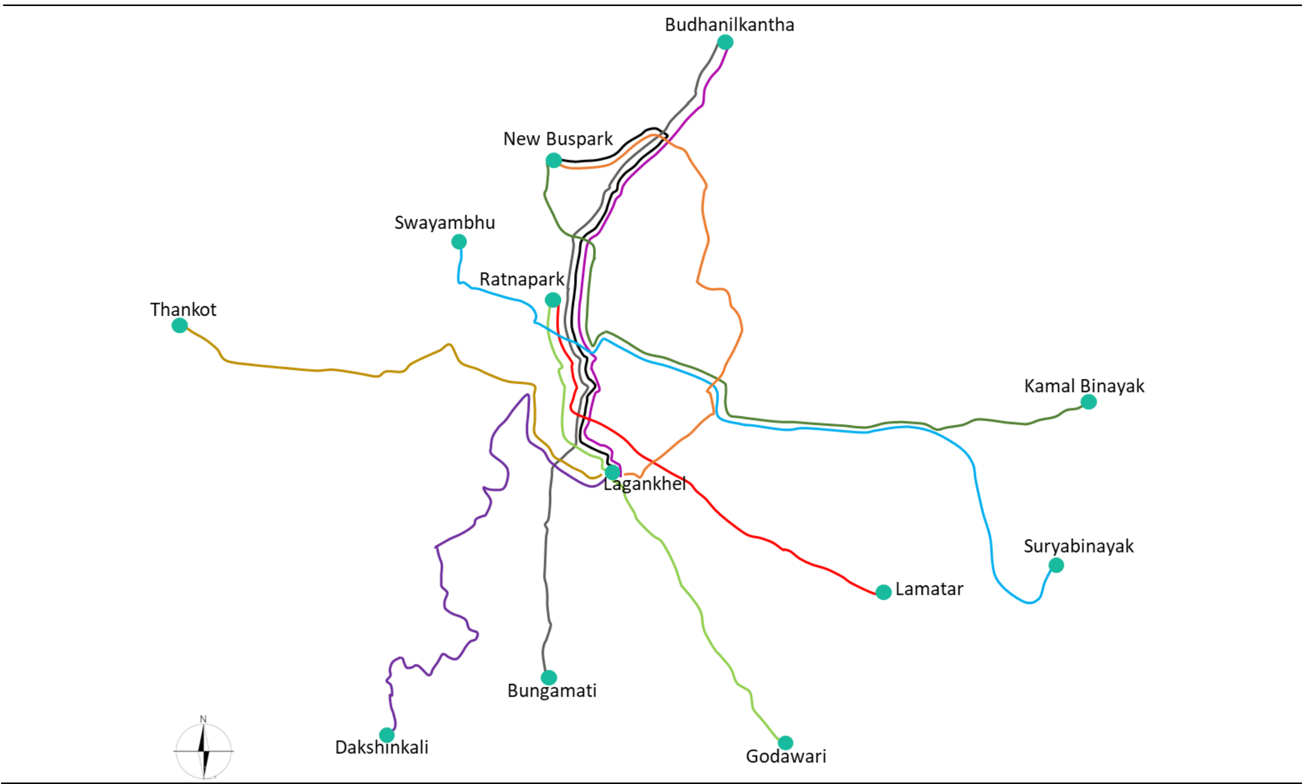


Figure A2.1. Intercity route map of Sajha Yatayat

Table A2.1: Current Operational Routes of Sajha Yatayat

Route type	No.	Route	Distance (km)	Number of buses	Daily Passenger	Daily Revenue ('000 NPR)
Intracity routes	1	Lagankhel-Buspark	14	14	5,909	96
	2	Lagankhel-Budhanilkantha	17	10	4,544	72
	3	Bungmati-Budhanilkantha	20	3	1,047	16
	4	Ratnapark-Godawari	15	7	2,760	43
	5	Ratnapark-Lamatar	13	7	1,650	25
	6	Lagankhel-Thankot	16	4	1,339	20
	7	Swayambhu-Suryabinayak	27	6	2,490	33
	8	New Bus Park-Kamalbinayak	28	6	1,875	30
	9	New Bus Park- Lagankhel-Airport	15	8	2,387	38
	10	Lagankhel-Dakshinkali*	14	2		
Intercity routes	11	Kathmandu-Bhairahawa	272	2	40	36
	12	Kathmandu-Baglung	282	2	50	26

*Note 1: Sajha Yatayat is yet to begin operations on the Lagankhel-Dakshinkali route.
*Note 2: The information on passenger count and revenue is average of data received in September 2019.

An intercity route between Kathmandu and Banglung was introduced in late 2016. Currently, there are two intercity routes being serviced by Sajha Yatayat. Passenger traffic on these routes is significantly lower than on local routes, with the buses only reaching full capacity during special occasions and national holidays such as Dashain and Tihar. These services have seen steady growth in passenger numbers. Since 2013, annual average growth in passenger numbers across all routes has been around 25%. Growth is due to management's sustained decision to provide a high-quality public transport experience that combines a range of policies to ensure passenger comfort. Naturally, the additional 20 buses introduced in 2019 generated a significant rise in passenger numbers.

3. Transition to Electric Mobility

Sajha Yatayat has set an example in the transport sector by introducing EURO III and now EURO IV emission standard buses after its revival in 2011. In line with its vision of providing convenient and clean transport services, the cooperative is set to electrify its entire fleet by 2025. In addition, Sajha Yatayat is making significant changes to its fleet by including features for differently-abled passengers such as designated wheelchair areas and reserved seats for elderly and pregnant passengers by procuring semi-low floor buses. Sajha Yatayat is also the first public bus operator to introduce a smart card payment system which has gained popularity among passengers since its introduction in March 2019.

The Federal Government of Nepal has long been supportive of electrifying the transport sector as demonstrated through its fiscal and monetary policies. In mid-2019, the Federal Government committed an investment of NPR 300 crore (USD 27.3 million) in Sajha Yatayat for the procurement and deployment of electric buses across the country. In addition, the Province 3 Government, along with the Kathmandu Metropolitan City and Lalitpur Metropolitan City are inspired by Sajha Yatayat's leadership in the transport sector and are investing NPR 42.5 crore (USD 3.9 million) in the cooperative for procurement and operation of electric buses on both intracity and intercity routes within Province 3.

Furthermore, Sajha Yatayat has been working closely with GGGI since 2017 on Electric Mobility initiatives. The Pre-Feasibility Study on Deploying Electric Bus in Kathmandu Valley was carried out on Sajha Yatayat's Lagankhel-Budhanilkantha route. In 2019, further activities in addition to this feasibility study were carried out. To cement the relationship around strong mutual interests of going electric, Sajha Yatayat signed an MOU with GGGI in 2019. As a first step, Sajha Yatayat is looking to procure between 20 and 50 electric buses.[19] These buses may service its primary metropolitan routes due to their high visibility with passenger traffic along those routes. This first fleet of electric buses in Nepal will prove to other transport operators that an electric vehicle will accrue savings on fuel and maintenance. This fleet will have long-term transformative potential which is yet to be strategically valued.

[19] For the purposes of the study, GGGI, in consultation with Sajha Yatayat, have agreed to analyze a volume of 20 buses.

Chapter A3. Electric Mobility Program and Current Assignment

1. Electric Mobility Program

The Global Green Growth Institute, in partnership with the Nepalese Government's Ministry of Forests and Environment, the Ministry of Physical Infrastructure and Transport, and Sajha Yatayat, is providing technical assistance to support the implementation of a range of ambitious targets for sustainable, green transportation. This partnership has led to the design and implementation of the Electric Mobility Program (EMP), comprising of a number of phases:

Phase I: 2017-2018

- **National Action Plan for Electric Mobility**: In this component, GGGI, in collaboration with the Ministry of Forests and Environment and the Ministry of Physical Infrastructure and Transport, developed actions to accelerate implementation of targets specific to electric vehicles, as outlined in Nepal's Nationally Determined Contribution. These actions will pertain specially to improving governance, mitigating greenhouse gas emissions, and improving monitoring, reporting, and verification.
- **Investment Projects for Electric Mobility**: This component is designed to introduce financially viable project ideas concerning electric vehicles in the transport sector. The project design will be optimized according to the availability of investment opportunities.
- **Deploying Electric Buses in the Kathmandu Valley, A Pre-feasibility Study**: In this component, GGGI and Sajha Yatayat assessed the viability of operating electric buses in the Lagankhel to Budhanilkantha route in Kathmandu. This initiative can be a potential model to public bus operators, including Sajha Yatayat, in proving the viability of electric buses in Nepal.

Phase-II: 2019-2020

- **Provincial Electric Mobility Strategy**: Province 3 has committed to electrifying the transport sector of its major cities by 2030. GGGI, in partnership with the Ministry of Forests and Environment and the Ministry of Physical Infrastructure and Transport, is providing the required technical assistance to develop Nepal's first Provincial Electric Mobility Strategy for Province 3. This strategy assesses the impacts of electrification of Province 3's transport sector by the year 2028 on energy consumption, fuel expenditure savings, local air pollutants, and GHG emissions.
- **Knowledge Exchange Program to India**: With the objective of sharing experiences and understanding key technical aspects related to electric bus operation, GGGI, in coordination with the Ministry of Forests and Environment and Sajha Yatayat, organized a knowledge exchange tour to India in July 2019.
- **Electric Bus Procurement and Deployment Advisory Report**: GGGI in partnership with the Ministry of Forests and Environment and the Ministry of Physical Infrastructure and Transport, will undertake further technical and investment analytics to support the electrification of Nepal's transport sector.

- **Going Green - Technical and Investment Analytics for Sajha Yatayat's First Electric Bus Fleet**: This component analyzes the technical and financial parameters required for Sajha Yatayat to deploy its first fleet of electric buses. From an operational point of view, this component assesses suitable routes for deploying e-buses, determines the most appropriate charging regime, assesses the viability of constructing charging stations at Sajha Yatayat's depot, and conducts regional market reviews to identify suitable bus models available. More importantly, this component also analyzes the financial viability of running electric buses in selected routes within Kathmandu Valley.

2. Assignment

Recently, as an impetus for electric mobility in the country, Government of Province 3, Lalitpur Metropolitan City (LMC) and Kathmandu Metropolitan City (KMC) have invested in Sajha Yatayat. Sajha Yatayat and its governmental partners are keen on procuring and operating a fleet of electric buses. As part of the technical support committed by GGGI, this component aims to provide advisory and analytical assistance to Sajha Yatayat on how best to procure and operate electric buses. The major objectives of this assignment are listed below. Several sub-objectives are also presented and are highlighted at the beginning of each chapter.

Objectives of the Assignment

- Operational feasibility assessment of electric bus deployment in Kathmandu valley as well as in Province 3.
- Identification of the most appropriate charging regime and drafting of technical specifications for the buses.
- Analysis of the market situation and the availability of electric buses in the region, together with their specifications.
- Viability assessment of charging station installations at Sajha Yatayat's depot.
- Financial assessment, with a focus on cash flow from projects from electric bus fleet operations and adequacy of passenger revenue to meet annual operational expenses (and targets?).
- Estimation of the Total Cost of Ownership (TCO) of deploying the electric bus fleet.

3. Consultation Process

This report builds on GGGI's and Sajha Yatayat's report on *Deploying Electric Buses in Kathmandu Valley*. Province 3's commitment to Sajha Yatayat for an envelope budget to procure and operate electric buses in Province 3 provided impetus to Sajha Yatayat and GGGI in developing a comprehensive report on the analysis of electric bus operations and their associated infrastructure requirements.

Overall, a highly participatory approach was taken that combined both qualitative and quantitative data. Data gathering methods included key informant interviews with the provincial and local governments and focus group discussions with over twelve priority stakeholders that included academic and research institutions, small businesses, and government agencies.

Several key stakeholders from the Kathmandu Metropolitan City, Province 3 government and Sajha Yatayat were consulted during the process. Furthermore, extensive discussions with Sajha Yatayat, KMC and Kathmandu University were held on numerous occasions to discuss progress and receive feedback.

Preparation of this report followed the process outlined below:

1. **Preliminary Meeting with Sajha Yatayat**: A meeting between Sajha Yatayat and GGGI was held in February 2019 to discuss general specifications and Sajha Yatayat's requirements for the procurement

of electric buses. The meeting was attended by Sajha Yatayat, Kathmandu Metropolitan City, Kathmandu University, and GGGI.

2. **Review of Technical Literature**: A range of journal articles, datasets, manufacturers documentation, grey literature, and other sources were reviewed and assessed.
3. **Conduct Market Survey**: A market review was carried out in China and India to understand the availability of different types of electric buses and their specifications, in addition to specific features of available charging stations and batteries being used.
4. **Consultations with Government of Nepal**: Three rounds of consultations with officials in Province 3, KMC, and other government partners were carried out.
    a. Consultation 1: Preliminary bus specifications and Province 3's requirements in terms of route and infrastructure were discussed.
    b. Consultation 2: Six routes, including Provincial and Metropolitan routes, were identified and presented to stakeholders from Sajha Yatayat and representatives from the Province 3 Government. Suggestions and feedback from the stakeholders were assessed. Conclusions were drawn on the feasibility of these routes, based on key operational and environmental aspects, and financial opportunities.
    c. Consultation 3: Discussions on KMC's preferences on routes and vehicle specifications were held between KMC, Sajha Yatayat, and GGGI.
5. **Technical Consultation Workshop**: Results from the draft financial and operational analysis of two scenarios in relation to electric bus charging infrastructure regimes discussed in Chapter B3 was presented to stakeholders from academic and research institutions, government agencies, and the private sector. Input from stakeholders was integrated into the scenarios and charging regimes suitable for meeting the needs of Sajha Yatayat were identified.
6. **Study Tour to India**: As part of a wider knowledge exchange with India, key operational and manufacturing aspects of electric bus deployment were assessed. Based on this tour, lessons were gathered and integrated into the current analysis.
7. **Presentation of Draft Specifications**: Results of specifications were presented to Sajha Yatayat's Procurement Committee as suggestions for consideration.
8. **Final Technical Presentation**: The proposed technical specification of electric buses was presented to the procurement committee of Sajha Yatayat. Feedback from the committee was incorporated into the final report.

Table A3.1: Key Consultations and Meetings Related to the Assignment

Date	Activities
Feb 2019	Consultation with Sajha Yayatat
Mar 2019	Meeting with Government of Province 3
Apr 2019	Technical Consultation Workshop
May 2019	Formal consultation with Province 3
June 2019	Meeting with the Mayor of KMC

Table A3.2: Stakeholders Consulted by Type and Engagement Modality

Type of stakeholder	Number consulted	Engagement Modality	
		KII	FGD
Government bodies	6	×	×
Academic and research institutions	3	×	×
Private sector businesses	3		×

4. Report Structure

This report presents the findings and result of the assignment undertaken and is structured as follows:

Part A: Introduction to the Opportunity: This chapter briefly introduces Nepal's transport sector and points out the importance of growth in the electric mobility sector in the country, along with the opportunities that lie ahead. It provides a brief background of Sajha Yatayat and its ambition to electrify its fleet. It outlines GON and GGGI's ongoing collaboration to electrify the transport sector. Finally, the chapter introduces the objectives of the assignment.

Part B: Options Analysis: This section begins with a literature review on the energy consumption of electric buses, available battery technology options, and existing charging regimes. This is followed by an assessment of viable metropolitan and provincial routes for deploying electric buses. An analysis of financial and operational details of various charging regimes is discussed in the next part. The chapter then presents the findings of a regional market review related to bus and charging stations, technical specification of mid- and large-sized electric buses, and the viability of installing charging stations at Sajha Yatayat's depot in Pulchowk. Proposed electric bus specifications are outlined at the end.

Part C: Investment Analysis: Part C builds on the previous sections to demonstrate the financial viability of mid-and large-sized electric buses in the Lagakhel-Budhanilkantha and Swayambhu-Suryabinayak routes by analyzing associated operational costs and revenue generation. It also assesses the long-term benefits to Sajha Yatayat of deploying a fleet of electric buses.

PART B. OPTIONS ANALYSIS

Chapter B1. Literature Review

1. Introduction

The objective of this chapter is to undertake a review of current literature to:

- benchmark the energy consumption of both mid-size (8-9.5 meter) and full size (11-12 meter) electric buses;
- identify factors impacting battery health and positive and negative elements of lithium-ion battery technologies; and
- compare cost-effective charging regimes for electric buses.

This literature review was conducted from a range of 23 academic articles and grey literature. Literature was not limited in geographic scope. Of the 23 total articles reviewed, only 10 were retained for their usefulness and relevance to their research queries, and these are presented in Table B1.1 below:

Table B1.1: Summary of Literature Reviewed

Author and Year of Publication	Article Title
Charging Regime	
Rothgang et al (2015)	Battery design for successful electrification in public transport.
Bak, Bak, and Kim (2019)	Strategies for implementing public service electric bus lines by charging type in Daegu Metropolitan City, South Korea.
Elin (2016)	Charging infrastructure for electric city buses: An analysis of grid impact and costs.
Olsson, Grauers, and Pettersson (2016)	Method to analyze cost effectiveness of different electric bus systems.
Battery Life and Health	
Vetter, Nov, Wagner, and Veit (2005)	Aging mechanisms in lithium-ion batteries.
Farmann et al. (2015)	Critical review of on-board capacity estimation techniques for lithium- ion batteries in electric and hybrid electric vehicles.
Rezvanizaniani et al.(2014)	Review and recent advances in battery health monitoring and prognostics technologies for electric vehicle (EV) safety and mobility.
Al-karakchi and Lacey (2015)	A method of electric vehicle charging to improve battery Life.
Legrand et al. (2014)	Physical characterization of the charging process of a Li-ion battery and prediction of Li plating by electrochemical modeling.
Energy Consumption	
Zhou et al. (2016)	Real-world performance of battery electric buses and their lifecycle benefit with respect to energy consumption and carbon dioxide emissions.

2. Summary of Review Findings

A. Benchmarking Energy Consumption of Electric Buses

A real-world performance test to find the actual energy consumption and carbon emission of different size of buses was conducted in the downtown and business center of Macao, People's Republic of China.[20] The test route was 8.8 km in length, and for each bus, the accumulated testing distance was more than 500 km. The maximum speed for the buses was limited to 50 km/h, which is generally the maximum allowed speed for transit buses providing service in a congested city. This route was then compared with the Lagankhel-Budhanilkantha route being analyzed in the Pre-feasibility Study by GGGI and Sajha Yatayat. A quick analysis using Google Earth showed that Macau's route and Lagankhel-Budhanilkanta route[21] (highlighted in later sections) had similar terrain, with no hilly or very steep portions. Figure B1.1 presents the terrain.

The study is based on first-hand data collected in relation to electricity bills from the local power utility. The data also included several dedicated on-board diagnostics decoders which captured parameters such as: real time current and voltage of the battery bank, energy consumption and power output of the electric motors, as well as chargers, operating conditions such as vehicle speed, passenger load, and AC operation. The study collected data from three different models, two of which were large 12m buses and one 8.2 mid-sized bus. Details are described in Table B1.2 below.

Findings from the study showed that an 8m (mid-sized) bus consumed 80 kWh per 100 km when traveling under a full load, inclusive of system charging losses. Consumption increased to 100 kWh per 100 km traveled with AC switched on and with maximum passenger loads. Similarly, for a 12m bus[22] under full passenger load with AC turned off, energy consumption was reported to be 191 kWh/100 km. Consumption increased to 211 kWh/100km under full load with AC in operation. It should be noted here that energy consumption decreases by 20% on a BYD bus under full load with AC in operation, when compared to the ANKAI bus. The study also claimed that AC exerted greater impact on energy consumption than passenger load. These results are summarized in Figure B1.2.

Table B1.2: Summary of Buses Tested

Manufacturer	Ankai	BYD	Dongfeng Yangzijiang
Model	HFF6128G03EV	K9D	WG6820BEV HK
Length (m)	12	12	8.2
Gross vehicle weight (kg)	18,000	18,000	12,500
Battery capacity (kWh)	170	324	104

Source: Zhou et al., (2016)[23]

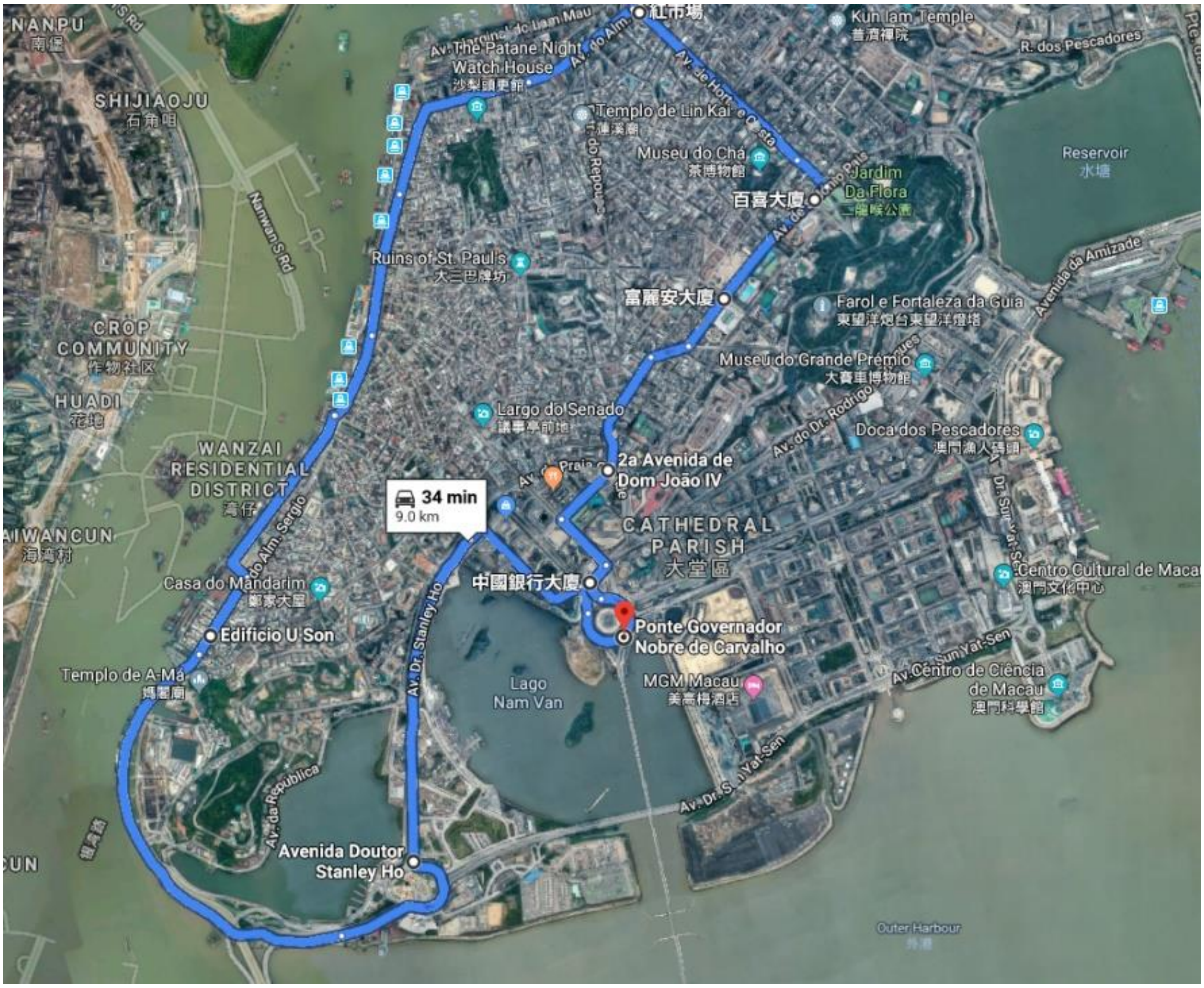
[20] Zhou, B., Wu, Y., Zhou, B., Wang, R., Ke, W., & Zhang, S. (2016). Real-world performance of battery electric buses and their life-cycle benefits with respect to energy consumption and carbon dioxide emissions, *96*(2016). https://doi.org/10.1016/j.energy.2015.12.041

[21] The Pre-feasibility Study on Deploying Electric Bus in the Kathmandu Valley assesses viability of deploying an electric bus on the Sajha Yatayat's Lagankhel-Budhanilkantha route.

[22] The values are for Ankai bus (HFF6128G03EV). Energy consumption varies across manufacturers and models.

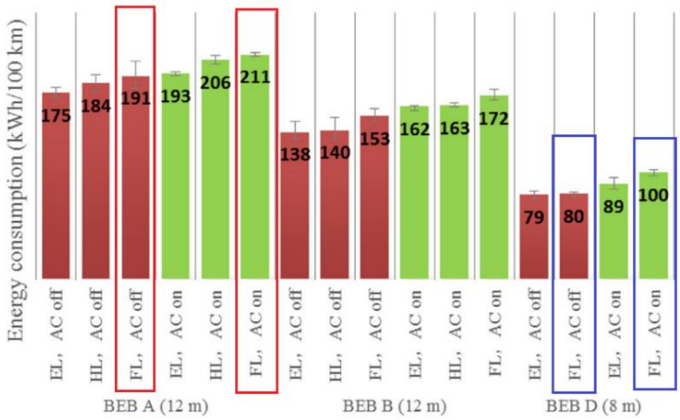
[23] Zhou, B., Wu, Y., Zhou, B., Wang, R., Ke, W., & Zhang, S. (2016). Real-world performance of battery electric buses and their life-cycle benefits with respect to energy consumption and carbon dioxide emissions, *96*(2016). https://doi.org/10.1016/j.energy.2015.12.041.

Figure B1.1: Route and Terrain of Macao Study



Source: Google Earth

Figure B1.2. Energy Consumption by Electric Bus Under Several Operating Conditions



Source: (Zhou et al., 2016)[23]

B. Identifying Factors Impacting Battery Health and Life

Maintaining optimum battery health is essential for smooth operation of electric vehicles. The study emphasized that decreasing energy storage capacity and power fading of a lithium-ion battery do not result from a single cause. Rather, they are the result of numerous processes and their interaction. Zhou et al. concluded that this complicates the study of battery aging, particularly because these processes cannot be studied independently.[24]

Various factors impact the life of lithium-ion batteries in automotive applications.[25,26] These included:

- **Battery temperature:** batteries operating at temperatures higher or lower than the design window also risk being damaged earlier than their designed lifetime.
- **Environmental temperature:** batteries perform best at near room temperatures. Prolonged exposure to extreme high or low environments decreases battery life.
- **Charging and discharging current:** batteries have a threshold value of charging and discharging current. Charging and discharging batteries by currents higher than intended battery thresholds also impacts the battery health.
- **Low and high state of charge:** the state of charge can be viewed as the amount of energy stored in the battery, relative to its capacity. If batteries spend most of their time either in a low or high state of charge, they are more prone to damage. Today, this is controlled by battery management systems.
- **Depth of discharge:** this refers to the percentage of the battery's discharged capacity, relative to its overall capacity. If the batteries are used at a higher depth of discharge, battery life may decrease. However, this also depends on the material of the cell. Studies have also found that depth of discharge has no influence on a cell's aging for Lithium-iron Phosphate material.
- **Time interval between full charge cycles:** continuous operation of batteries without introducing "breaks" can also impact battery health. In addition, introducing rest periods during battery charging reduces degradation in two ways.[27] Firstly, the rate of change of the battery's internal resistance is reduced. Secondly, the rate of capacity fading is also reduced. More importantly, impacts due to high

[24] Vetter, J., Nov, P., Wagner, M. R., & Veit, C. (2005). Ageing mechanisms in lithium-ion batteries ☇, *147*, 269–281. https://doi.org/10.1016/j.jpowsour.2005.01.006

[25] Farmann, A., Waag, W., Marongiu, A., & Uwe, D. (2015). Critical review of on-board capacity estimation techniques for lithium- ion batteries in electric and hybrid electric vehicles. *Journal of Power Sources*, *281*, 114–130. https://doi.org/10.1016/j.jpowsour.2015.01.129

[26] Rezvanizaniani, S. M., Liu, Z., Chen, Y., & Lee, J. (2014). Review and recent advances in battery health monitoring and prognostics technologies for electric vehicle (EV) safety and mobility. *Journal of Power Sources*, *256*, 110–124. https://doi.org/10.1016/j.jpowsour.2014.01.085

[27] Al-karakchi, A. A. A., & Lacey, G. (2015). A Method of Electric Vehicle Charging to Improve Battery Life, 31–33.

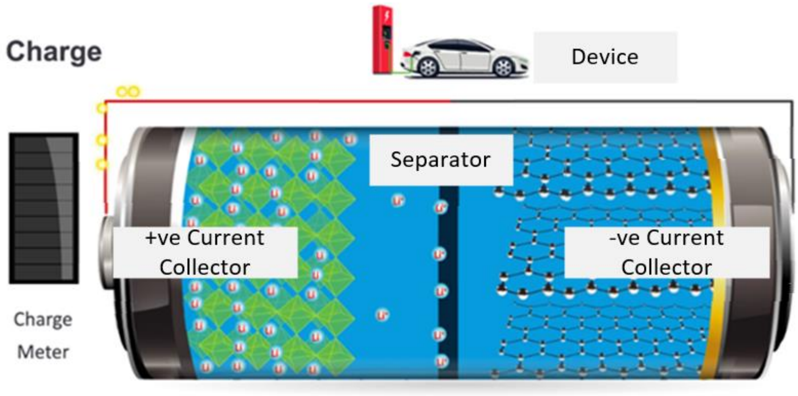
temperatures are also reduced as a result of lower battery temperature. This improves the overall life of the battery.

Among numerous other aging mechanisms, growth of solid electrolyte interfaces are considered to be the most detrimental under normal usage. Simply put, a solid layer which covers a useful area of battery is formed. This layer formation is accelerated by plating of lithium which is observed during charging and particularly in case of fast charging and charging at low temperatures.[28]

Box B1.1 How a Lithium-Ion Battery Works

General construction of lithium-ion consists of an anode, cathode, electrolyte, separator and two current collectors (positive and negative). Lithium is stored in anode and cathode. The electrolyte carries positively-charged lithium ions from the anode to the cathode and vice versa through the separator. This movement of lithium-ion creates free electron in the anode which in turn creates charge (or potential) at positive current collector. Current (or charges) then flows from positive current collector to negative current collector via device to be powered (e.g. electric motors). The role of separator is to prevent the flow of electrons inside the battery.

The figure below shows the flow of battery charge while powering a device:



Source: (OEERE, 2019)[29]

Types of lithium-based batteries and their features

Lithium-ion based batteries have gained an important place in electric mobility as they are now considered the battery of choice in most electric vehicles. There are several types of lithium-ion batteries available in the market. It is important to select appropriate cell technology to meet the specific requirement of the vehicle. Comparison of the most promising technologies used in public transport has been shown in table B1.3.[30] Each battery type is assessed according to its performance against five major criteria and these include the following:

- **Energy density:** energy density of a battery is the amount of energy stored per unit mass. In other words, battery type with a higher energy density can offer more energy storage for the same weight than batteries with a lower energy density.

[28] Legrand, N., Knosp, B., Desprez, P., Lapicque, F., & Raël, S. (2014). Physical characterization of the charging process of a Li-ion battery and prediction of Li plating by electrochemical modelling. *Journal of Power Sources*, *245*, 208–216. https://doi.org/10.1016/j.jpowsour.2013.06.130

[29] OEERE. (2019). How Does a Lithium-ion Battery Work? Office of Energy Efficiency and Renewable Energy. Retrieved from https://www.energy.gov/eere/articles/how-does-lithium-ion-battery-work

[30] Rothgang, S., Rogge, M., Becker, J., & Sauer, D. U. (2015). Battery Design for Successful Electrification in Public Transport. *Energies*, 6715–6737. https://doi.org/10.3390/en8076715

- **Admissible charging power:** batteries with the ability to accept higher charging and discharging currently offer an advantage whereby charging time is limited (or very fast charging is needed).
- **Cycle lifetime:** the battery cycle is complete when it is discharged and then recharged. All batteries have a finite cycle life after which performance starts to degrade drastically. However, cycle lifetime varies, depending upon battery type.
- **Deep temperature behavior:** frigid temperatures increase internal resistance and lower battery capacity. The magnitude of capacity decrease varies with battery type. Similarly, high temperatures also impact performance.
- **Safety:** considering the high amount of energy stored in them, batteries can be dangerous if they are abused or improperly designed.

The comparison of different lithium-based battery types against these criteria is summarized in Table B1.3.

Table B1.3: Comparison of Different Lithium-Based Battery Types

Chemistry	Energy Density	Admissible Charging Power	Cycle Lifetime	Deep Temperature Behavior	Safety	Production Cost
Lithium nickel manganese cobalt oxide (NMC)	Good	Neutral	Good	Poor	Neutral	High
Lithium-iron phosphate (LFP)	Poor	Neutral	Good	Poor	Good	Medium
Lithium titanium oxide cells (LTO)	Poor	Good	Very Good	Good	Good	High

Source: (Rothgang et al., 2015[30]; Berckmans et al., 2017[31])

Additionally, the way that a battery is charged impacts its life. If fast chargers are used for charging, lithium titanium oxide cells-based batteries would be more suitable. Since lithium plating does not occur in these batteries, they can be charged with very high power without significantly damaging them.[30] Lithium titanium oxide cells-based batteries also have a better battery lifetime. But, if energy density is a priority, as may be required in the case of long route planning, then lithium nickel manganese cobalt oxide batteries may be a better option due to their superior energy density. The cost of NMC and LTO batteries are higher than LFP batteries.[31]

C. Comparison of Charging Regimes

For optimal operation of an electric bus fleet, the charging regime and charging infrastructure must be carefully considered, in addition to consideration of buses. Here, charging regime refers to type, time, and location of charging. Buses can be charged using slow chargers or fast chargers, and they can be charged overnight either at the depot or at stopping stations. All these factors combined can be called the “charging regime.” It is also sometimes called “charging strategy” or “charging program.”

There is no standard best charging regime valid for all cases. The optimal charging regime depends on the operational environment (such as route characteristics, distance, available charging time, etc.). As a result, it is imperative to consider the environmental characteristics when designing both charging infrastructure and regimes.[32] A recent study compared the economic efficiency of three charging infrastructures: plug-in, battery

[31] Berckmans, G., Messagie, M., Smekens, J., Omar, N., Vanhaverbeke, L &Mierlo, V. (2017). Cost Projection of State of the Art Lithium-Ion Batteries for Electric Vehicles Up to 2030. *energies*.

[32] Rothgang, S., Rogge, M., Becker, J., & Sauer, D. U. (2015). Battery Design for Successful Electrification in Public Transport. *Energies*, 6715–6737. https://doi.org/10.3390/en8076715

swapping, and wireless charging for Daegu city, South Korea.[33] The results show that the best charging regime for the same bus depends on the specific operating environment, such as route type, charging time, operating distance, and initial infrastructure investment. Furthermore, rather than focusing on just individual trips, it is necessary to focus on operations of the entire fleet while analyzing the battery and charging power requirements.[34]

Similarly, Elin (2016) has compared the cost of three charging scenarios for electrification of all the bus fleets in Stockholm, Sweden. The study focuses on the cost of grid connection for chargers, battery costs, and charger costs. The scenarios are:

- depot chargers only with bigger battery bank;
- a combination of depot chargers and terminal station chargers with smaller battery bank; and
- a combination of depot chargers and future charging technologies at selected bus stations.

The result shows that the most cost-effective option is a combination of depot chargers and terminal station chargers, while the scenario utilizing only the depot chargers was found to be the most expensive of the three options.

Similarly, there is a possibility of introducing top-up charging at the depot during periods when only a few numbers of buses are in operation.[35] In case of overnight charging, if the required size of the battery bank is too big, or if reducing battery bank size is a top priority, then such off-peak periods can be capitalized to develop a charging schedule where a few buses return to the depot, get charged for some time, and then resume their service. This strategy can also reduce the size of overnight chargers required at the depot.

3. Conclusion

A charging strategy that takes into account both operational and environmental factors can significantly reduce the operating costs of electric buses. For metropolitan routes, it is necessary to consider operations of the entire fleet rather than a single bus when selecting charging infrastructure. Also, the total investment cost of a charging regime employing a combination of depot and terminal station chargers can be lower than a regime that just deploys overnight depot chargers. But if terminal station charging is not a possibility, then scheduled non-simultaneous charging of buses during the off-peak hours could reduce the size of battery packs as well as the size of the depot chargers. Finally, the introduction of rest periods during battery charging could limit battery aging.

Cell technology must be carefully chosen while selecting the lithium-based battery type. For metropolitan routes with terminal station fast charging regimes, lithium titanium oxide (LTO) batteries and Lithium nickel manganese cobalt oxide (NMC) may be more suitable, given their high charge absorbing capacity and cycle lifetime. But they're very costly. Based on the comparison between different cell technologies, lithium-iron phosphate is a superior option due to its lower cost and better safety features.

[33] Bak, D., Bak, J., & Kim, S. (2019). Strategies for Implementing Public Service Electric Bus Lines by Charging Type in Daegu Metropolitan City , South Korea. https://doi.org/10.3390/su10103386

[34] Rogge, M., Wollny, S., & Sauer, D. U. (2015). Fast Charging Battery Buses for the Electrification of Urban Public Transport—A Feasibility Study Focusing on Charging Infrastructure and Energy Storage Requirements, 4587–4606. https://doi.org/10.3390/en8054587

[35] Olsson, O., Grauers, A., & Pettersson, S. (2016). Method to analyze cost effectiveness of different electric bus systems, 1–12.

Chapter B2. Analysis of Routes

1. Introduction

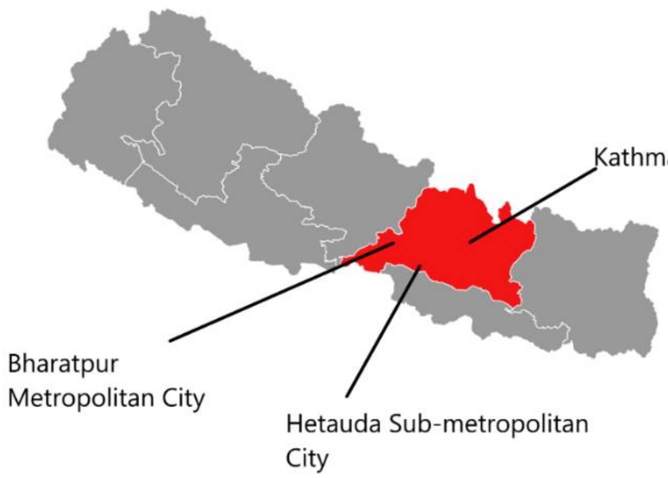
This study is part of the Provincial and Metropolitan government's, as well as Sajha Yatayat's efforts to procure and deploy electric buses. Therefore, the routes being considered below are mainly in Province 3.

The objectives of this chapter are:

- to study various metropolitan and province routes, and
- to select routes for further analysis.

Home to the national capital of the country, Province 3 has three metropolitan cities: Kathmandu, Lalitpur, and Bharatpur. The province also hosts one sub-metropolitan city (Hetauda), forty-one municipalities, and seventy-four smaller local bodies. Based on the latest census, around 18% of the total population of Nepal resides in this province.[36]

Figure B2.1: Province 3 and location of Kathmandu valley, Bharatpur Metropolitan City and Hetauda Sub-metropolitan City



Source: (Anand, 2019)[37]

* Note: Lalitpur Metropolitan City and Kathmandu Metropolitan City are located within Kathmandu Valley.

[36] OCMCM. (2019). Introduction. Office of the Chief Minister and Council of Ministers-Province 3. Retrieved from https://ocmcm.p3.gov.np/?page_id=134

[37] Anand, B. (2019). Nepal Province 3 Map. Retrieved from https://commons.wikimedia.org/wiki/User:Biplab_Anand

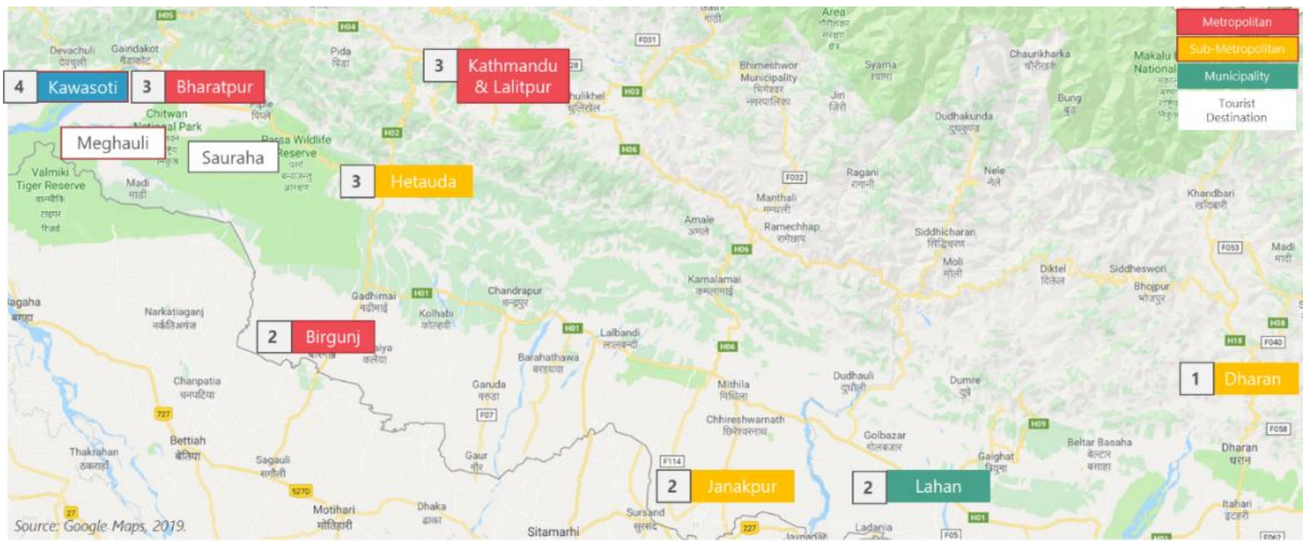
Among the seven provinces in the country, Province 3 is well ahead of others in terms of social and economic indicators. Province 3 has the highest per capita income at USD 1,534, the highest province-wise share in the total GDP (31.9 %), and also the highest concentration of industries (965 out of 4,076) in the country.[38]

2. Inter-City Provincial Routes

For provincial routes, a rapid survey of major urban town centers in the province was carried out and routes connecting these centers to Kathmandu Valley were explored. The route connecting Kathmandu Valley to Bharatpur Metropolitan City via Prithvi Highway (PR1) and the route linking Kathmandu Valley to provincial capital Hetauda via Kulekhani-Bhimphedi (PR2) were identified as possible options for provincial routes. In addition, possible extensions of these routes to other major nearby centers are also presented.

Altogether, with Kathmandu Valley as the starting or ending destination, nine other possible cities were identified for deploying inter-city electric bus routes for Province 3. Figure B2.2 presents these identified destinations. Destinations consist of metropolitan cities (Bharatpur and Birgunj), sub-metropolitan cities (Hetauda, Dharan and Janakpur), municipalities (Lahan and Kawasoti), and popular tourist destinations (Sauraha and Meghauli). While Hetauda and Bharatpur are primary destinations for provincial routes, other cities are possible extensions from these two cities. Some cities even lie in Province 1 and Province 2. Details of these routes are discussed in the following sections.

Figure B2.2. Key Urban Centers In and Around Province 3



Note**:** The numbers beside the city name denote the province number.

[38] My Republica. (2018). Province 3 way ahead in economic, social indicators: Report. Retrieved from https://myrepublica.nagariknetwork.com/news/province-3-way-ahead-in-economic-social-indicators-report/

Route PR1. Kathmandu Valley to Bharatpur Metropolitan City

Table B2.1: Key Route Stats (Kathmandu Valley-Bharatpur Metropolitan City)

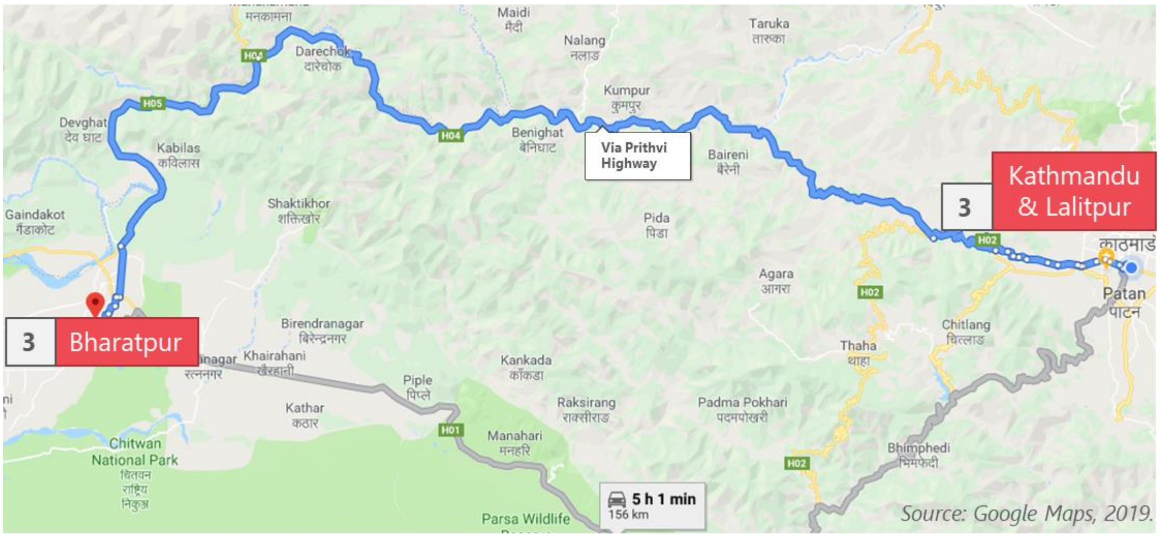
Route Type/Code	Provincial / PR 1
Route Length	152 km
Estimated Travel Time	4 hrs 40m – 5 hrs

Bharatpur Metropolitan city (BMC) is the fifth largest city in the country with a population of 280,802[39] representing one of the fastest growing cities. BMC is located in the middle of the country's only east-west highway (Mahendra Highway), which is the back-bone of Nepal's transportation network. BMC is easily accessible from major cities like Kathmandu, Pokhara, Butwal, Hetauda, and Birgunj, and all within a 155km travel distance. The city is also the commercial and service center of central-southern Nepal and is a popular regional destination for health care and education.

The total travel distance between Kathmandu Valley (Lagankhel Bus Park) and Bharatpur via Prithvi Highway is around 152 km. The estimated total one way travel time for PR 1, including time spent by buses to pick up passengers, is estimated to be around 4 hours and 40 minutes to 5 hours. Besides Kathmandu Valley and BMC, major cities and municipaliteis that are serviced by buses operating on this route are listed in Table B2.2.

In addition, in order to connect PR1 to major nearby tourist destinations, it is worthwhile considering an extension of services beyond Bharatpur. A provincial route extension to nearby cities is outlined in Table B2.3 below.

Figure B2.3: Kathmandu Valley to Bharatpur Provincial Route (PR1)



[39] MoFAGA. (2019). Nepal GIS map of local bodies. Ministry of Federal Affairs and General Administration, Government of Nepal. Retrieved from http://103.69.124.141/

Table B2.2: Major Transit Municipalities in the Kathmandu Valley -Bharatpur Route

Major Transit Municipalities	Population
Chandragiri	85,198
Dhunibesi Municipality	31,029
Thakre Rural Municipality	32,914
Galchi Rural Municipality (Baireni, Kalleri & Goganpani)	27,784
Gajuri Bajar Rural Muncipality	27,084
Benighat Rorang Rural Muncipality	31,475
Icchyakamana Rural Muncipality	25,012
Total	260,496

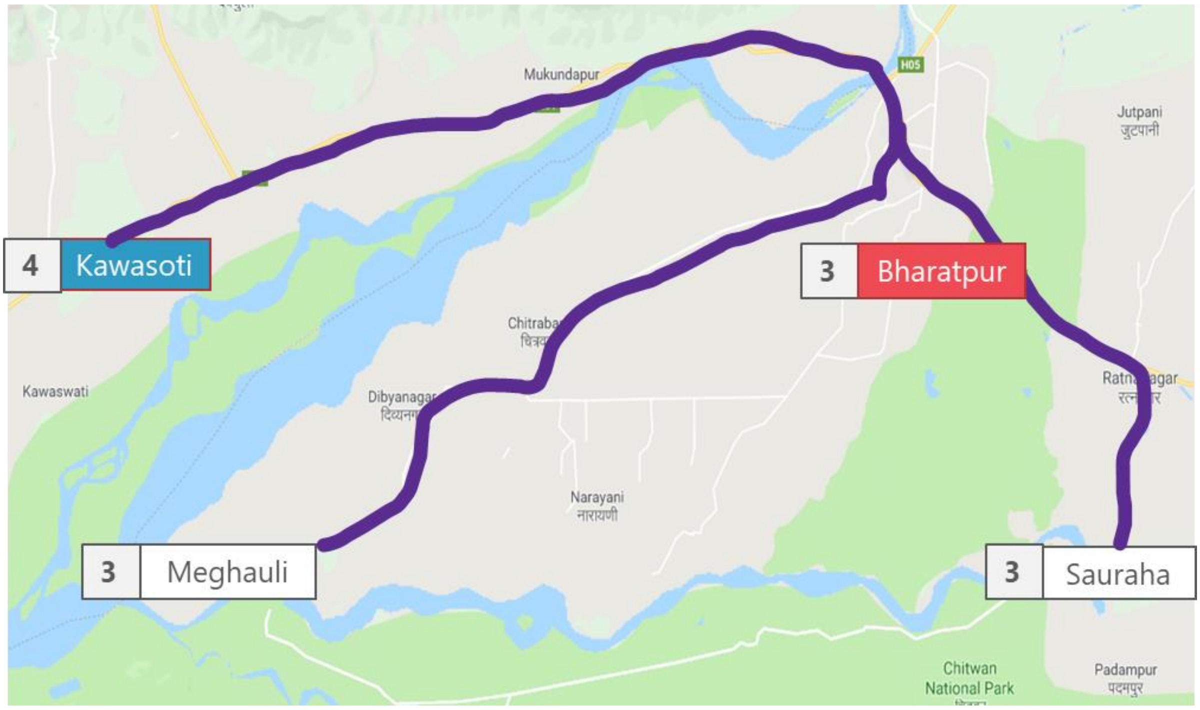
Table B2.3: Possible Extensions from Bharatpur Metropolitan City

Destination	Distance	Travel Time	Comments
Kawasoti	38 km	1h 30m	The combined population of municipalities (Kawasoti , Devchuli, Gaidakot & Madhyabindu Municipality) which lie within the service proximity of the route is more than 218,000.[40] Additionally, this section of route is also part of Nepal's only E-W highway (Mahendra highway).
Meghauli	25 km	1h 15m	Meghauli is emerging as a growing tourist destination in the country. Furthermore, buses must go to Meghauli via Rampur Campus. So student passengers may also use service.
Sauraha	17 km	1h	Sauraha is a well-known tourist destination in the country and is the gate-way to Chitwan National Park. More than 150,000 tourists visited the park in F.Y 2074/75 alone.[41]

[40] MoFAGA. (2019). Nepal GIS map of local bodies. Ministry of Federal Affairs and General Administration, Government of Nepal. Retrieved from http://103.69.124.141/

[41] Chitwan National Park. 2018. Ministry of Forests and Environment. Retrieved from https://www.chitwannationalpark.gov.np/

Figure B2.4: Possible Extensions from Bharatpur Metropolitan City



Route PR2. Kathmandu Valley-Hetauda Sub-Metropolitan City

Table B2.4: Key Route Stats (Hetauda Sub-Metropolitan City)

Route Type/Code	Provincial / PR 2
Route Length	82 km
Estimated Travel Time	4 hrs 30m – 5 hrs

Hetauda Sub-Metropolitan City (HSMC) is the one of the largest cities in the country with a population of 152,875.[42] It is also the interim state capital of Province 3 and links the Kathmandu Valley to southern parts of Nepal (Terai) and India.

HSMC is located on the confluence of Nepal's two major highways. The East-West Mahendra Highway is the backbone of Nepal's transportation system, while the Tribhuvan Highway is one of the oldest highways in the country, connecting the outskirts of the Kathmandu Valley (Naubise) to the Nepal/Indian border town of Birgunj in the South. The Kantilokpath Highway, a 90km long road connecting Lalitpur to Hetauda, is also nearing completion and will be the shortest and quickest link connecting Hetauda and the Kathmandu Valley.[43]

[42] MoFAGA. (2019). Nepal GIS map of local bodies. Ministry of Federal Affairs and General Administration, Government of Nepal. Retrieved from http://103.69.124.141/

[43] The Kathmandu Post. (2019). Kanti Highway expected to be fully operational by October. Retrieved from http://kathmandupost.ekantipur.com/news/2019-04-21/kanti-highway-expected-to-be-fully-operational-by-october.html

Based on suitable topographical conditions and existing infrastructure facilities, and taking into account the regionally-balanced economic development of the country, GoN had identified 11 industrial districts across the country, of which Hetauda was categorized as one in 1963. Currently it has around 100 industries.[44]

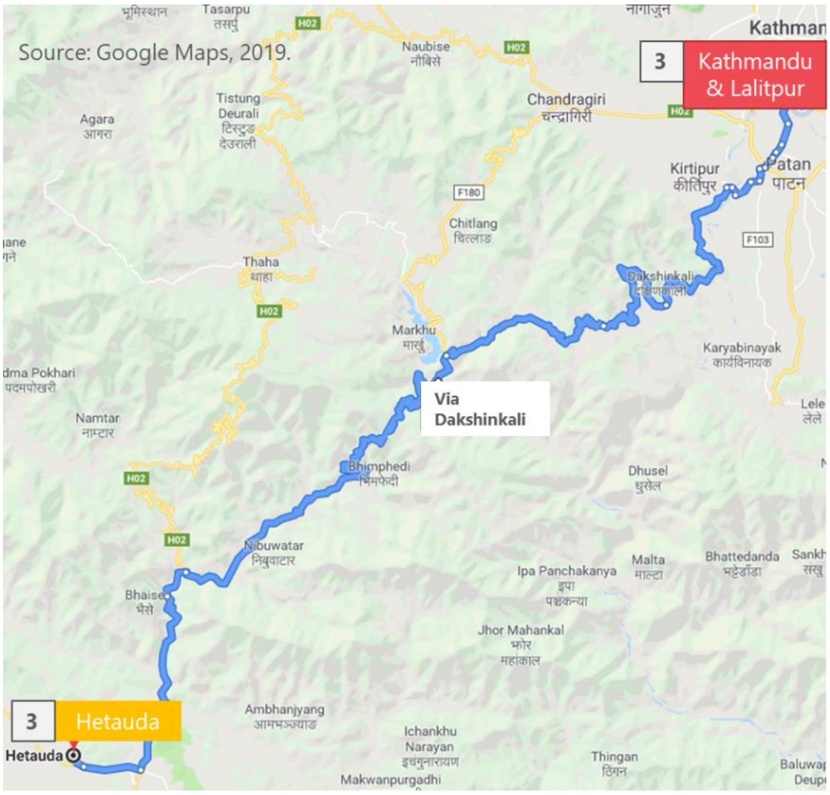
The total travel distance between Kathmandu Valley (Lagankhel Bus Park) and Hetauda via Kulekhani-Bhimphedi is around 82 km. The estimated total one way travel time for PR 2, including time spent by buses to pick up passengers, is estimated to be around 4 hours 30 mins to 5 hours. Besides Kathmandu Valley and HSMC, the major cities and municipalities serviced by buses operating on this route are listed in Table B2.5.

Like PR1, PR2 also offers viable extension services. Rather than serving nearby tourist attractions, PR2's primary service extensions would cater to travelers looking to reach Birgunj, and thereby India. These are outlined in Table B2.6 below.

Table B2.5: Major Transit Municipalities on PR2

Major Transit Municipalities	Population
Dakshinkali Municipality	24,297
Bhimphedi Rural Municipality	23,344
Thaha Municipality	41,623
Indrasarowar Municipality	17,780
Total	**107,044**

Figure B2.5: Kathmandu Valley to Hetauda Sub-Metropolitan City Provincial Route (PR2)

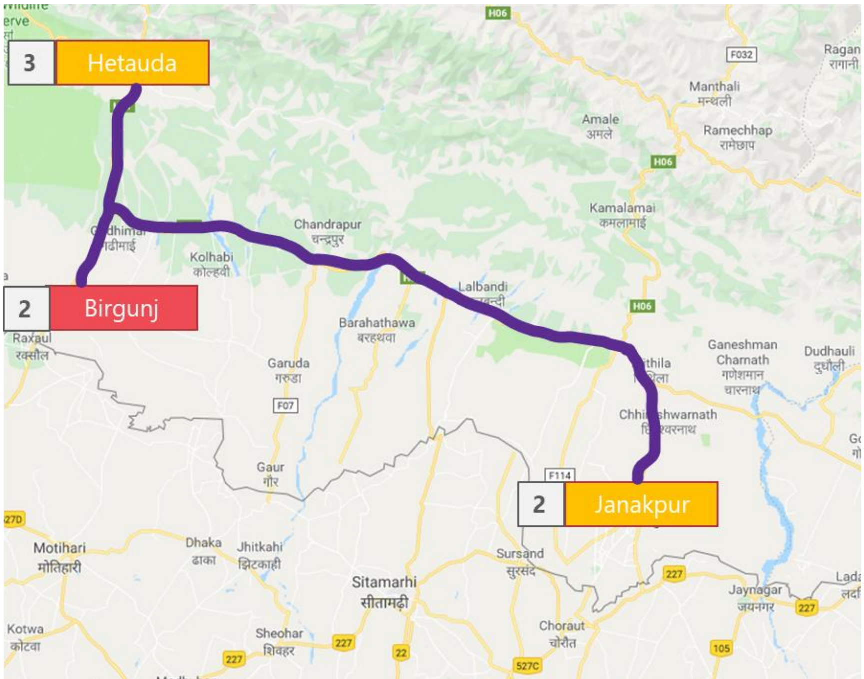


44 IDM. (2014). Hetauda Industrial District. Industrial District Management Limited. Retrieved from https://www.idm.org.np/index.php/2014-12-30-08-23-17/hetauda

Table B2.6: Possible Extension from Hetauda Sub-Metropolitan City

Destination	Distance	Travel Time	Population	Comments
Birgunj	56 km	2h 10m	Birgunj: 240,922	Major commercial and industrial city. It is the principal transit point for trade between Nepal and India. Also, Simara Special Economic Zone will be established with an aim of developing the garment manufacturing sector.[45]
Janakpur	167 km	4h	Janakpur: 162,172	Janakpur is the interim capital of Province 2. It is a major city for cultural and religious tourism.

Figure B2.6: Possible Extension from Hetauda Sub-Metropolitan City



Source: Google Maps, 2019.

3. Intra-City (Kathmandu) Routes

In the case of metropolitan routes, a pre-feasibility study of electric bus deployment in Kathmandu Valley carried out by GGGI in January 2018 identified Lagankhel to Budhanilkantha (denoted by MR 1) to be a highly viable route. MR 1 runs centrally across the Kathmandu Valley in the north-south direction.

Based on GGGI's internal review and series of discussions held with Sajha Yatayat as well as key representatives of the Government of Province 3, three more routes were identified within Kathmandu Valley which had the possibility of running e-buses. Another similar central route which runs in an east-west direction across the valley was identified to be the Swayambhu to Suryabinayak Route (denoted by MR 2). An eight-lane ring road (denoted by MR 3) encircling the cities of Kathmandu and Lalitpur was also considered for the analysis. A

[45] The Himalayan Times. 2016. Government to set up GPZ within Simara SEZ. Retrieved from https://thehimalayantimes.com/business/govt-to-set-up-gpz-within-simara-sez/

relatively shorter route (denoted by MR 4), connecting Lagankhel to the densely populated city of Kirtipur completes the metropolitan route options.

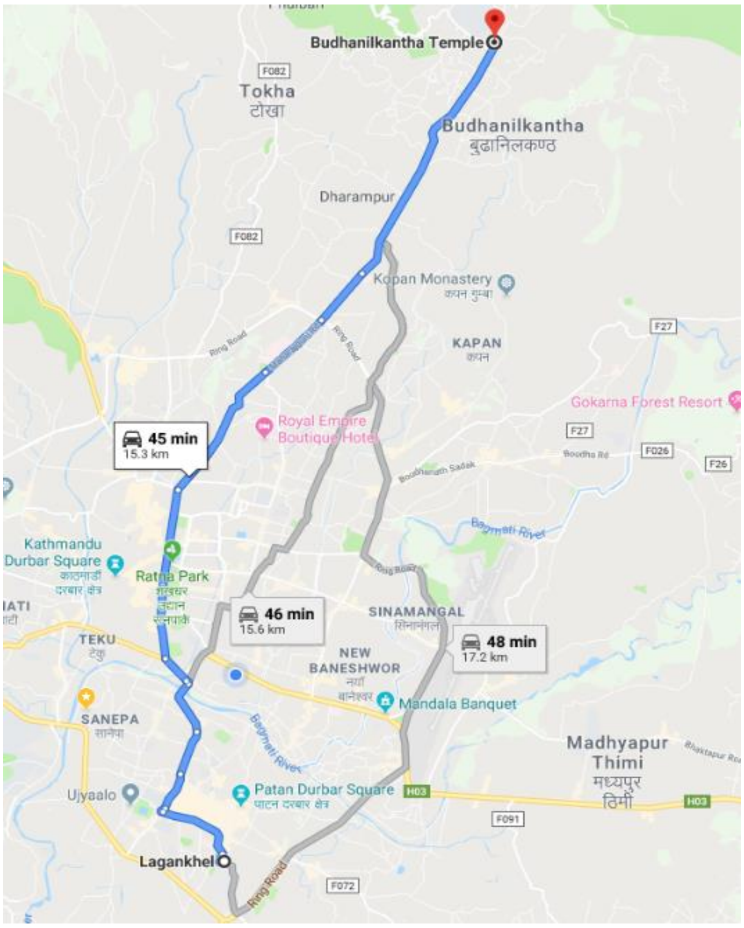
Route MR1. Lagankhel to Budhanilkantha

Taking into account a range of operational factors, including route length, terrain, and strategic long-term considerations, Sajha Yatayat and GGGI's previous assessment had identified MR 1 to be highly viable for the deployment of electric buses. MR 1 falls along the main trunk of the city and passes along bus stops with largest passenger exchange volumes in the valley. According to Sajha Yatayat which has been providing service along this route, the average number of daily commuters is highest (3,585 in 2017/18) along this route when compared to other routes it services.

Table B2.7: Key Route Stats (Lagankhel-Budhanilkantha)

Route Type/Code	Metropolitan / MR 1
Route Length	17 km
Estimated Travel Time	1 h 7 m
Key Stops	Lagankhel, Jawlakhel, Teku, Sahid Gate, Jamal, Lazimpat, Narayan Gopal Chowk, Hattigauda , Budhanilkantha.

Figure B2.7: Lagankhel to Budhanilkantha Metropolitan Route (MR1)



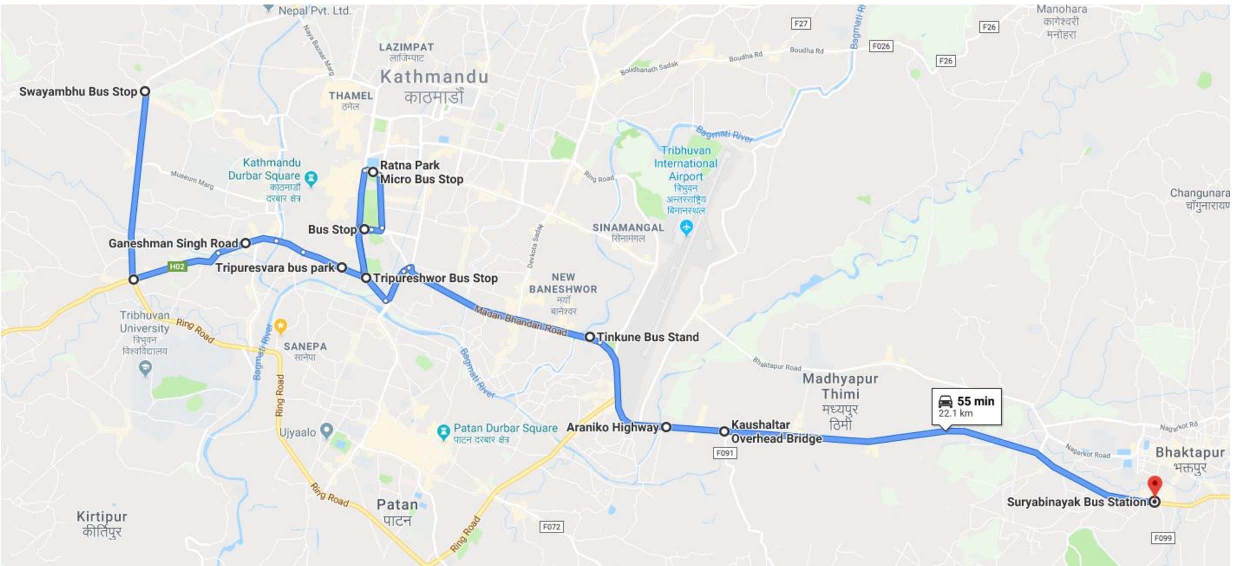
Route MR2. Swayambhu-Suryabinayak

The MR 2 route also runs centrally through the Kathmandu Valley in an east-west direction, passing through several key bus stops with the highest passenger exchanges, such as Kalanki, Ratnapark, Sahidgate, and Koteshwor. The average daily commuter rates, using Sajha Yatayat's existing service on this route stands at around 3,363 - slightly lower than that in MR 1.

Table B2.8: Key Route Stats (Swayambhu-Suryabinayak)

Route Type/Code	Metropolitan / MR 2
Route Length	27km
Estimated Travel Time	1 h 20 m
Key Stops	Swayambhu, Kalanki, Teku, Kalimati, Ratnapark, Purano Bus park, Sahidgate, Tripureshwor, Maitighar, New Baneshwor, Teenkune, Koteshowr, Jadibuti, Lokanthali, Kaushaltar, Suryavinayak.

Figure B2.8: Swayambhu to Suryabinayak Metropolitan Route (MR2)



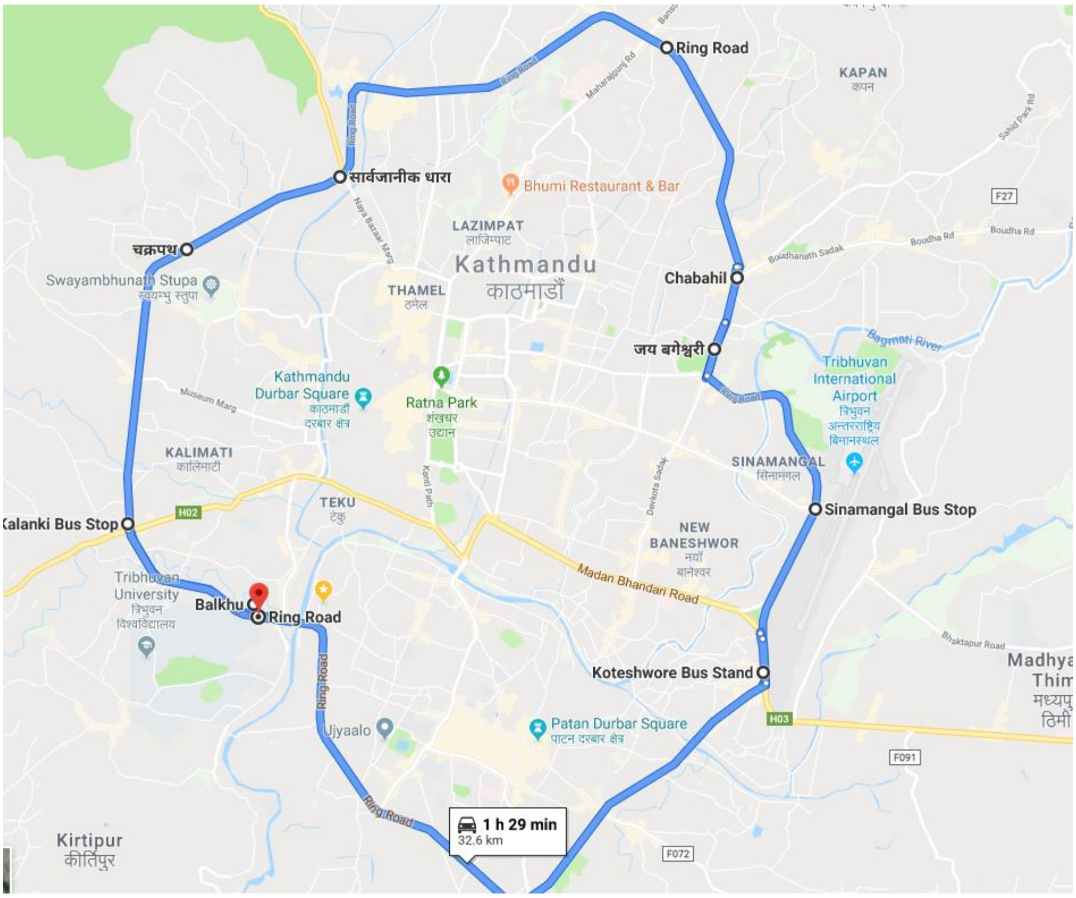
Route MR3. Ring Road

Table B2.9: Key Route Stats (Ring Road)

Route Type/Code	Metropolitan / MR 3
Route Length	32.6 km
Estimated Travel Time	2 hrs
Key Stops	Swayambhu, Chakrapath, Chabhil, Gaushala, Tribhuvan International Airport, Koteshwor, Satdobato, Balkhu, Kalanki.

The ring road is another major road of Kathmandu Valley which encircles the majority of key cities in the valley. This route also passes through key bus stops, some such as Kalanki, Koteshwor, and Balkhu have high passenger volumes and represent major bus stops for out-of-valley routes. MR 3 also passes though the country's only international airport: Tribhuwan International Airport.

Figure B2.9: Ring Road (MR3)



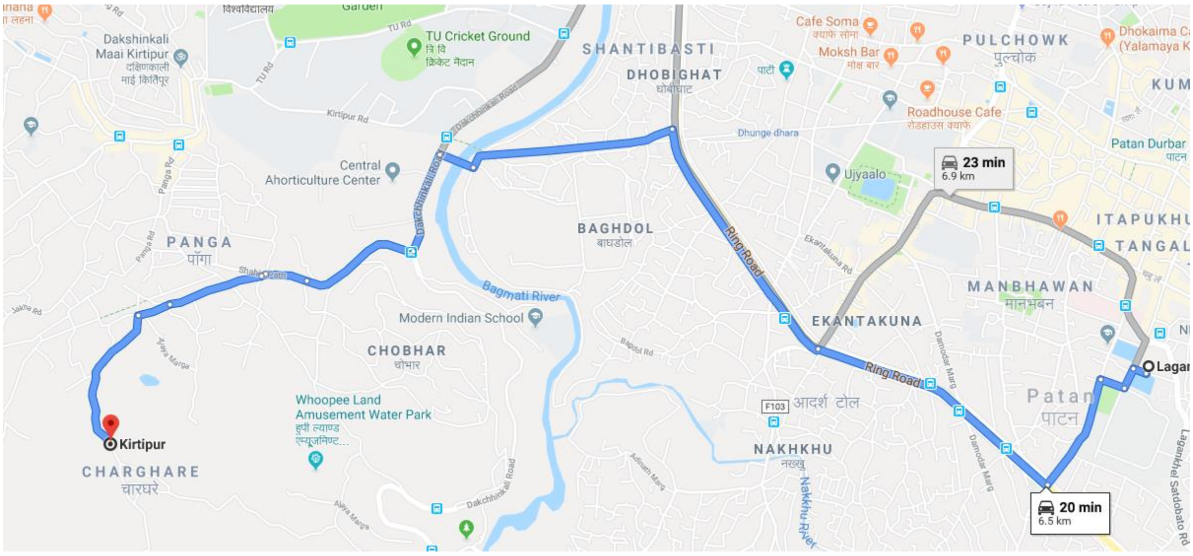
Route MR4. Lagankhel-Kirtipur

Table B2.10: Key Route Stats (Lagankhel-Kirtipur)

Route Type/Code	Metropolitan / MR 4
Route Length	6.5 km
Estimated Travel Time	50 mins
Key Stops	Lagankhel, Baghdole, Sanepa, Balkhu, Tribhhuvan University, Kirtipur.

MR 4 is a very short route which passes through a section of the ring road and connects two major urban centers - Lagankhel and Kirtipur. Lagankhel is a major bus park located in the southern part of the valley and Kirtipur Municipality is a densely-populated ancient city located in the south-west part of the country. MR4 also passes through Tribhuvan University, which is the oldest university in Nepal, located in Kirtipur.

Figure B2.10: Lagankhel-Kirtipur (MR4)



4. Route Prioritization

The two provincial routes and four metropolitan routes were presented to clients and stakeholders on April 22[46] and May 17[47] for discussion and consideration. Criteria based on a range of operational and environmental factors for deploying electric buses are identified. Provincial and metropolitan routes are then compared against each criterion to assess the viability of electric buses along the routes. The criteria include:

- **Maximum gradient:** gradient refers to the steepness of a road section. The higher the gradient, the steeper will be the section. Higher gradient also means higher energy consumption by e-buses and more torque requirement. E-buses come with a maximum allowable gradient in their specification, which generally ranges between 15% to 20%. In the "Nepal Road Standards 2070," the maximum allowable gradient is 12% for design speed below 20 km/hr.[48] It can therefore be assumed that all identified routes were designed as meeting the standard, with maximum gradients of 12%.
- **Travel distance appropriateness:** electric vehicles have a fixed travel range unless they are charged en-route. On longer routes, such as provincial routes, an electric bus would only complete a single one way trip per day (terminal A to terminal B). For shorter routes such as metropolitan routes, the electric bus may complete several round trips (terminal A to terminal B, and then back to terminal A). With this in mind, routes were considered for the total travel distance the buses were expected to cover per day.
- **Extent of passenger demand:** major trunk routes across Kathmandu have high demand. Routes which include key bus stops such as Ratna Park, Lagankhel, Sahid Gate, Balkhu etc. also have higher passenger demand. Deploying buses through such routes would also increase financial performance.
- **Extent of service supply:** some routes are already over-supplied with bus operators, particularly the ring road, which seems to have an oversupply, relative to demand. Deploying electric buses where competition between suppliers is not very high would be desirable.
- **Visibility potential:** major trunk routes across the city are highly visible and passing through the city's primary business and residential neighborhood as well as major thoroughfares. This means that electric

[46] Consultation 1: Technical Consultation on Electric Bus Investment Options; refer to Part A for more details.

[47] Consultation 2: Consultation with stakeholders from Provincial government; refer to Part A for more details.

[48] MOPIT. 2013. Nepal Roads Standards 2070. Ministry of Physical Infrastructure and Transport. Government of Nepal.

buses on these routes will be highly visible, something which can be utilized for branding and marketing of buses.

- **Road quality:** electric buses have clearance limitations. It is therefore desirable to run the buses on smooth black-topped roads.

Table B2.11: Route Performance Against Selected Criteria

Criteria		PR 1	PR 2	MR 1	MR 2	MR 3	MR 4
Maximum gradient		2	2	3	3	3	3
Travel distance appropriateness		1	1	3	3	3	3
Extent of passenger demand		2	2	3	3	2	3
Extent of service supply		2	2	3	3	1	1
Visibility potential		3	1	3	3	3	2
Road quality		3	1	3	3	2	3
Total		**13**	**9**	**18**	**18**	**14**	**15**

Table B2.11 presents the results of this review of the six routes against the above criteria. Each route is scored against these criteria. The scoring is based on a simple 1-2-3 attribution, where 1 = sub-optimal, 2 = neutral and 3 = optimal.

From the table above, it is evident that the Lagankhel-Budhanilkantha and Swayambhu-Suryabinayak routes are optimum for electric bus operations. MR3 and MR4 have very high supply and thus would not be suitable. The PR routes are recommended for the second phase of electric bus deployment.

5. Conclusion

The six identified routes were presented to stakeholders from Sajha Yatayat as well as representatives from the Province 3 Government. Suggestion and feedback were analyzed, and conclusions were drawn on the feasibility of these routes, based on key operational and environmental aspects, political mileage, and financial opportunities.

Considering the novelty of commercial electric bus operations in Nepal, deploying e-buses along provincial routes comes with operational risks due to long travel distances. Furthermore, there may also be a financial risk due to insufficient passenger volumes. Providing electric bus services along metropolitan route would eliminate range-related operational risks, and passenger volumes in these routes have also been recorded to be higher. In addition, deploying buses along metropolitan routes would increase bus visibility and showcase political achievement in promoting higher environmental benefits. Therefore, provincial routes have been discarded for the deployment of electric buses at this stage.

For metropolitan routes, based on feedback by Sajha Yatayat, route permits given to other service providers for MR 3 and MR 4 are on the higher end. On MR 1 and MR 2, on the other hand, Sajha Yatayat has been operating its buses for several years and these routes contribute to the majority of its revenue. Considering the high degree of competition among service providers for MR 3 and MR 4, the routes might not be financially feasible and have therefore been discarded for further analysis. For the remaining analysis, based on route performance scores, MR 1 (Lagankhel-Budhanilkantha) and MR 2 (Swayambhu-Suryabinayak) are taken into consideration.

Chapter B3. Charging Regime Comparative Analysis

1. Introduction

The objectives of this chapter are:

- to identify charging regimes of buses which could be adopted by Sajha Yatayat;
- to find capital and operational expenditures of the charging regimes;
- to find the operational aspects of the charging regimes; and
- to determine the most appropriate charging regime on selected routes.

Due to limitations in energy storage capacity, buses either need to have a sufficiently large amount of energy storage on board or the storage must be recharged during operation. Traditionally, EVs were fitted with sufficiently large battery banks with enough capacity to cover the expected range of travel. Therefore long, mostly overnight, charging was required. However, advancement in EV charging and lithium-ion battery technologies have resulted in the provision of recharging buses even during operational hours.

Various charging regimes have been adopted around the world, including:

- **Overnight charging regimes:** these regimes involve charging buses overnight while they are parked. Generally, buses are fully charged overnight and the battery pack is big enough to travel the estimated mileage for the next day. There are no en-route charging facilities. If any recharging is required, the buses must return to the depot.
- **Terminal station charging regimes**: these regimes consist of moderate to fast chargers at the terminal stations of routes. There are two possible variations for these regimes. If the terminal station chargers are not supported by overnight chargers, then the terminal station chargers must be of very high charging capacity. However, if a combination of overnight chargers and terminal station chargers are used, the capacity of terminal station charger will be low. The major advantage of these regimes come in the form of reduced battery sizes and consequently reduction in the cost of buses.
- **Opportunistic charging regimes:** this involves the charging of buses at intermediate stops along the route, using fast chargers. These regimes require very fast chargers (generally above 400kW), however the battery bank is relatively smaller than overnight schemes.[49]

[49] Lajunen, A. (2017). Lifecycle costs and charging requirements of electric buses with different charging methods. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2017.10.066

In terms of operational aspects, considering the cost and technical sophistication of chargers required for running e-buses, opportunistic charging regime is neglected and only overnight (Scenario A) and terminal station charging regimes (Scenario B with depot chargers) are considered for further analysis.

The operational and financial aspects of these regimes were assessed in detail. During the technical consultation held on April 2019, the stakeholders were also in broad agreement with the proposed charging regimes. They expressed certain challenges in relation to opportunistic charging regime, especially due to the current transport and electrical infrastructure.

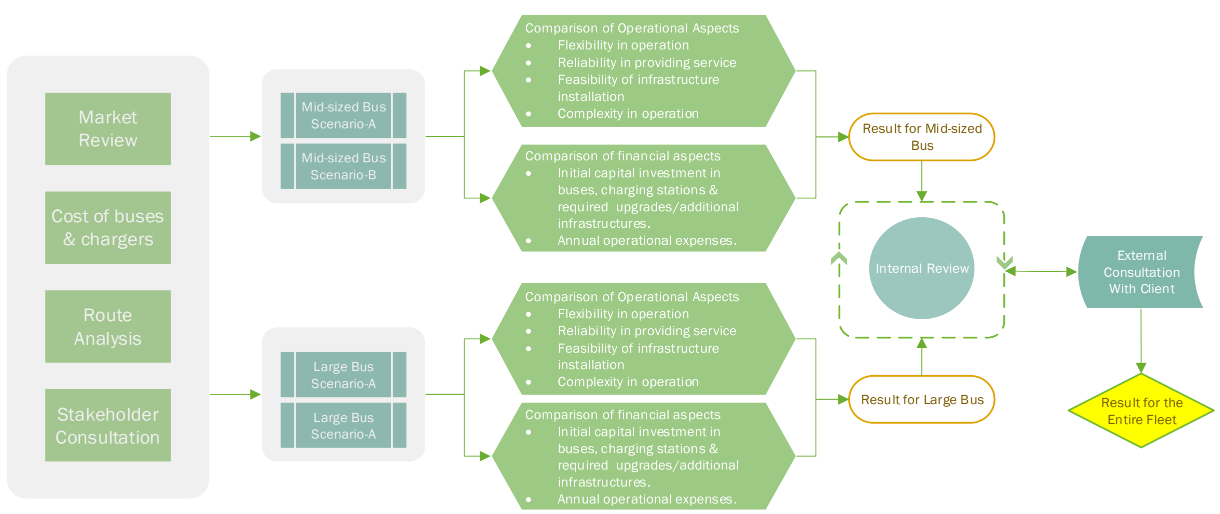
2. Methodology for Finding a Suitable Charging Regime

A market review of electric buses available in the region (discussed in Chapter B4) was conducted in order to find key elements such as size, battery bank capacity, seating capacity, and cost. A similar study was also carried out for chargers. Findings of the review were then discussed with stakeholders for their approval and feedback. These finalized parameters were then used to construct two scenarios (A and B) for comparison, which are delineated in next section. Essentially, these two scenarios were created for two different bus sizes: a mid-sized bus (8.5 to 9 m) and a large-sized bus (11 to 12 m).

For both bus sizes, a separate comparison of operational and financial performance for Scenario A and Scenario B was carried out. While comparing operational aspects, key parameters such as flexibility, reliability, feasibility of infrastructure installation, and degree of complexity for both scenarios were identified. Comparing the financial performance between the scenarios involved estimating the required total capital and operational expenditure, and then comparing the difference between both scenarios.

Results from the comparison between the two regimes from a financial and operational point of view were then presented to stakeholders in order to obtain their feedback. Finally, with stakeholders' inputs, results were drawn on which scenario would be appropriate for Sajha Yatayat. Figure B3.1 describes the overall charging regime comparison methodology.

Figure B3.1: Choice of Appropriate Charging Regime – Selection Methodology



3. Two Charging Regime Scenarios

Two scenarios which are found to be viable are described as follows:

- **Scenario A - a larger battery bank without terminal chargers**: in this charging regime, buses are charged overnight at the Sajha Yatayat depot and moderate capacity chargers are used. The buses have bigger battery banks and thus are heavier and more expensive. The buses operate during the day with full dependence on the energy stored in the battery banks.
- **Scenario B – a smaller battery bank with fast terminal chargers:** in this charging regime, a combination of terminal station and depot chargers is considered. As a result of the introduction of fast chargers at terminal stations, the size (and cost) of battery required is reduced. The buses are charged overnight at the depot (with chargers having the same capacity as that of Scenario A) and are then supported by brief but fast charging at terminal stations during operational hours.

  Since a large portion of the cost of an electric bus is due to the battery bank, reducing the size of the battery bank may significantly reduce the cost of the bus. The cost reduction will be even more significant for the entire fleet. However, reducing the battery size comes at a cost of additional charging infrastructure. To maintain the energy requirement of the bus, besides the moderate capacity charger at the depot, fast chargers will have to be installed at the terminal stations of the routes. Figure B3.2 describes the relation between size of terminal station chargers, battery bank and cost of the bus. The higher the capacity of terminal station chargers, the lower will be battery size and consequently cost of the bus, and vice versa.

Figure B3.2: Relationship Between Terminal Station Charger Power, Battery Size & Cost of Bus

Table B3.1: Summary of Parameters in Scenario A & Scenario B

Parameter	Scenario A	Scenario B
Terminal Station Chargers	No terminal Station Chargers	Terminal station chargers are present
Depot Chargers	Depot chargers are present and are of same capacity for both scenarios.	
Battery Bank Size	As required to last full day of operation	50% of that of Scenario A

The battery bank size for Scenario B was determined through consultations with key stakeholders. Here, 50% is the lowest capacity that was agreed on during the technical consultation. A minimum of 50% battery capacity would still be able to cover the required drive range.

4. Comparison of Operational Aspects

As mentioned in the previous sections, it is imperative to consider both environmental and operational parameters when deploying electric buses. Therefore, several criteria have been identified as essential for successful operation of electric bus fleets, as follows:

- Flexibility of bus fleet operations
- Reliability of bus fleet operations
- Feasibility of infrastructure installation (charging stations, local distribution grid etc.)
- Complexity of operation

As a result, despite possible cost reductions highlighted in Scenario B when compared to Scenario A, Scenario B nevertheless presents considerable operational complexity and additional expenditure in infrastructure. Scenario B also reveals reliability issues, especially in cities like Kathmandu with frequent traffic congestion and unscheduled power cuts. Scenario A presents a higher degree of flexibility and reliability at the cost of larger battery bank. Table B3.2 discusses the advantages and disadvantages of Scenarios A and B.

Table B3.2: Scenario A and Scenario B. A Comparison

	Scenario A	Scenario B
ADVANTAGES	• **Flexibility and reliability:** if the distance to be covered by the bus is within the range of installed batteries, it is a very flexible and reliable system. It can easily replace current ICE buses without route modification. • Impact on the timetable is minimal. No additional time needs to be allocated during operational hours. • **Infrastructure cost**: overnight chargers have 6 to 8 hours for charging, therefore moderate capacity chargers may be sufficient which are relatively cheaper and do not require significant upgrades in the local electricity distribution grid. • **Land acquisition:** infrastructure required for this regime is relatively less. Additional costs and "hassles" (such as acquiring lands and electricity access points) to construct terminal stations is not needed.	• **Battery cost**: reduction in battery size can significantly reduce the cost and even weight of the bus. • **Infrastructure revenue**: terminal station chargers may even be an additional source of revenue generation. If the stations are not occupied by Sajha Yatayat owned buses, it could charge other compatible EVs and generate additional revenue.

	Scenario A	Scenario B
DISADVANTAGES	• **Complexity and reliability**: Heavy traffic congestion and long idle time during the day may cause depletion of batteries, which will disrupt service. In this case, the bus will need to return to the depot for charging, which may not be possible with a low charge. • **Energy Supply**: Although electricity supply has become more reliable, frequent unscheduled power cuts at night may delay charging of buses, potentially affecting operational schedules during the day. • With larger battery banks, the weight of the bus increases. This may limit the possible payload of the buses. As revenue directly depends on the number of passengers, buses with larger battery banks may have less revenue. Also, energy consumption of the bus may also be on the higher end as a result of increased total weight.	• **Complexity and reliability:** for cities such as Kathmandu where traffic is not properly managed, congestion and traffic jams may alter charging schedules, especially during rush hours. If buses are not able to follow strict charging routines, batteries may become depleted before the bus reaches the terminal. In this case, this scenario will be more costly. • **Energy Supply:** although electricity supply has become more reliable, frequent unscheduled power cuts may disrupt charging at terminal stations during the day when buses are in operation. This has implications on reliability and operation of the fleet. In some cases, capacity of the local electricity distribution grid may also prevent installation of high power chargers. • **Infrastructure cost and land acquisition:** operational costs of this regime are also higher as several additional charging stations besides the depot chargers have to be installed. Operating terminal station chargers involves the extra cost and hassle of additional land acquisition within the city as well as manpower-related costs. In some cases, it may be hard to find space for charging stations close to the route. Also, high capacity terminal chargers are required, which cost significantly more than slow or moderate chargers. • **Flexibility:** buses need to stick to assigned charging routines at terminal stations to maintain their service. Major disruption could occur if buses are diverted during an emergency, thereby limiting access to terminal charging stations. Thus, flexibility of operation is limited.

5. Financial Analysis of Two Scenarios

A. Overview

As discussed earlier, it is clear that the Scenario B regime requires more infrastructure than Scenario A in the form of terminal station charging facility, while the fleet cost will be lower for Scenario B as a result of a reduced battery bank. The aim of this section here is to identify the difference in:

- the initial capital investment between the two regimes for both bus sizes; and
- annual operational expenses between the two regimes for both bus sizes.

Overall, this section identifies the most feasible scenario, from a financial perspective.

B. Key Assumptions and Datapoints

Analysis is carried out separately for mid-sized and large-sized buses, one at a time, following the same method. It is assumed that 16 units of mid-sized buses or 16 large-sized buses will be procured by Sajha Yatayat, and for simplicity, only the Lagankhel to Budhanilkantha route is considered for analysis. Details of the route along, with other operational assumptions, are presented in Table B3.3.

Table B3.3: Financial Performance Comparison of Scenarios A and B – Operational Assumptions

Criteria	Assumptions
Name of route	Lagankhel-Budhanilkantha
Length of the route	17 km
Total time [On-road + passenger pick up]	65 mins
Lunch break	60 mins
Break at terminal station	15 mins
Possible number of trips per day	8 trips
Number of extra trips (safety factor)	1 trip

Table B3.4: Estimated Available Charging time for Both Scenarios

	Scenario A	Scenario B
Available overnight charging time in a single day	480 mins	480 mins
Lunch hour charging time in a single day	0 mins	60 mins
Terminal station charging time in a single day	0 mins	90 mins

Table B3.5: Breakdown of CAPEX Components for Scenario A & Scenario B.

Parameter	Scenario A	Scenario B
CAPEX components	▪ Cost of 16 buses ▪ Cost of depot chargers (16 units) ▪ Cost of upgrading charging infrastructure at the depot	▪ Cost of 16 buses ▪ Cost of depot chargers (16 units) ▪ Cost of upgrading charging infrastructure at the depot ▪ Cost of 2 additional fast chargers at the terminal stations ▪ Other infrastructure cost of erecting 2 terminal station chargers (Transformers, electricity network, perimeter fencing *et cetera*)

Depot chargers of the same capacity are placed in the Sajha Yatayat depot for both scenarios. Scenario A will not have terminal station charging provisions, while for Scenario B it is assumed that terminal station chargers are located at Lagankhel and Budhanilkantha terminal stations respectively. Table B3.4 presents the assumed available charging time for both scenarios in a particular operating day.

Capital expenditure (CAPEX) consists of the initial investment cost of the entire fleet of 16 buses and 16 separate depot chargers for each bus.[50] It also includes the cost of upgrading electrical and civil infrastructure at the Sajha Yatayat depot to accommodate all 16 units' depot chargers. As highlighted in previous sections, the fundamental difference between both scenarios is the additional infrastructure cost for Scenario B in exchange for the lower cost of buses. Table B3.5 lists the CAPEX-related components for both scenarios.

Regarding the annual operational expenses (OPEX), Scenario B is assumed to bear additional expenditure in the form of yearly O&M of two additional terminal station chargers. Generally, annual land lease cost must also be factored in while estimating OPEX. However, it is assumed that Sajha Yatayat will be able to negotiate with the Government to provide land free of any costs.

The cost of upgrading the charging infrastructure at the Sajha Yatayat depot for operating the fleet of all large buses is outlined in Chapter B5.2, while the cost of upgrading the charging infrastructure all mid-sized bus fleets is outlined in Annex IV. Similarly, CAPEX and OPEX in relation to terminal station chargers are provided in Annex V.

i. Energy consumption

An estimation of energy consumption by buses according to size is another important component of the analysis. Based on this estimation, other key elements such as battery bank size, annual energy expenditure, capacity of depot, and number of terminal station chargers are taken into account.

When comparing terrain and route length between the Lagankhel-Budhanilkantha route and a route in downtown Macau (for a summary of findings related to the Macau study, please refer to Chapter B1), the specific energy consumption of buses were taken from real-life case study of Macao[51] for mid-size as well as large buses, which has already been discussed in detail in the literature review chapter.

Based on this study, the range of specific energy consumption of mid-sized and large-sized bus are assumed. Values from test condition scenario - with a fully-loaded (FL) bus and AC switched 'ON' - is taken as the maximum value of the range. For minimum value, specific energy consumption of a bus with fully-loaded capacity, but without AC in operation, is taken.

[50] A fleet with a minimum of 20 buses is considered. The size of the fleet may change, depending on the envelope budget being provided by Province 3, KMC and LMC.

[51] Zhou, B., Wu, Y., Zhou, B., Wang, R., Ke, W., & Zhang, S. (2016). Real-world performance of battery electric buses and their life-cycle bene fi ts with respect to energy consumption and carbon dioxide emissions, *96*(2016). https://doi.org/10.1016/j.energy.2015.12.041

Figure B3.3: Breakdown of Total Energy Consumption by Electric Bus.

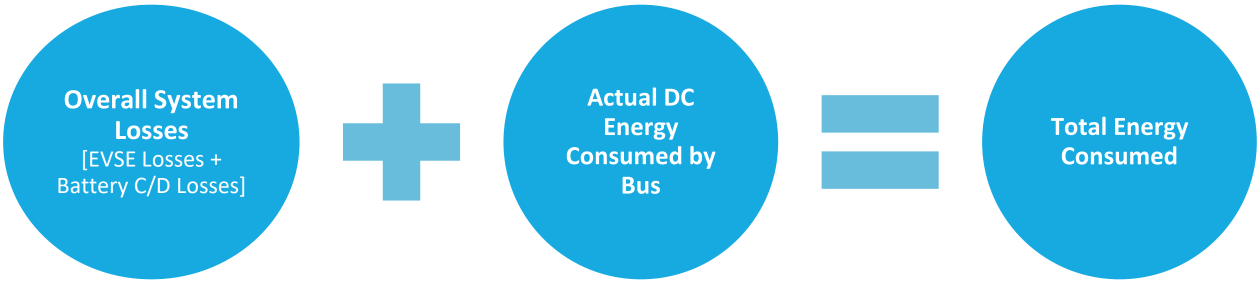


Table B3.7: Derivation of Actual Specific DC Energy Consumption by E-Bus Motor

Total Energy Consumption (kWh/km)	Efficiency	Actual Energy Consumption (kWh/km)
Large bus		
Min [FL, AC OFF] :1.91	69%	1.32
Max [FL, AC ON]: 2.11	69%	1.46
Mid-sized bus		
Min [FL, AC OFF]: 0.80	84%	0.67
Max [FL, AC ON]: 1.00	84%	0.84

Adapted from: Zhou et al (2016)

This total energy consumption also includes overall system losses in the form of the electric vehicle supply equipment's[52] (EVSE) losses, as well as losses while charging and discharging the battery. To determine the actual DC energy consumption (by motor) - which in turn is used to estimate battery bank size – the overall system loss must be removed to arrive at the actual level of DC energy consumed per bus. Removing the loss component gives us the actual DC energy consumption specified in Table B3.7.

Therefore, the actual DC-specific energy consumed by the motor from a battery bank for a mid-sized bus is in the range of 0.67 to 0.84 kWh/km and for large-sized bus it is between 1.32 to 1.46 kWh/km respectively. Taking a conservative approach and for further analysis, where size of battery bank is calculated, maximum values of actual energy consumption of 0.84 for a mid-sized bus and 1.46 for a large-sized bus are considered respectively.

ii. Electricity tariff

The latest electricity consumer categorization by the Nepal Electricity Authority (NEA) consists of two categories of transport: trolley bus and Safa Tempo (electric three wheelers).[53,54] Electricity and demand charges for the trolley bus category is lower than Safa Tempos. For this study, applicable electricity charges are based on consumer category tariffs "Trolley Bus" for 11kV connection. The tariff for this category is preferential and it is

[52] Accounts for losses by electric vehicle supply equipment such as chargers, line losses, charging conditions.

[53] Safa Tempo is electric three-wheeler which can accommodate up to 12 people, including the driver.

[54] NEA. (2017). *A year in review 2016/17*. Retrieved from https://wrds-web.wharton.upenn.edu/wrds/query_forms/variable_documentation.cfm?vendorCode=COMP&libraryCode=compm&fileCode=funda&id=fyear

assumed that Sajha Yatayat will also be eligible under this category, considering Nepal's ambition to promote electric vehicles.

Table B3.8: Weighted Average Electricity Tariff for Scenarios A and B and Peak Demand Charge

	Rate	Unit
Demand Charge for Scenario A & Scenario B	315	NPR/kVA
Annual Weighted Average Tariff for Scenario A	5.16	NPR/kWh
Annual Weighted Average Tariff for Scenario B	5.48	NPR/kWh

NEA has a two-part tariff, consisting of demand charges (per kVA) and energy charges (per kWh). In addition, the energy charges vary between "Dry" and "Wet Season". Based on these factors, demand and energy charges are considered for this study (see Table B3.8 for weighted average tariff rates and Annex I for more details on the calculation).

Electricity expenditure of a bus is then a function of electricity tariffs, demand charges, specific energy consumption (including EVSE losses), and distance traveled. The annual weighted average tariff for Scenario B accounts for variations in tariff during the day, whereas only the nighttime tariff is considered for Scenario A.

iii. Bus size, battery bank size, and cost of bus

Battery bank size for Scenario A is calculated using actual specific DC energy consumption as explained in earlier sections and the expected distance traveled in a single day (see Chapter B6). For Scenario B, the size of the bank is assumed to be around half of Scenario A.

Based on the regional market review (discussed later) of electric buses, the cost of buses matching Scenario A and Scenario B were assumed. If the battery bank size of a bus found from the review did not meet the required calculated size, the global weighted average cost of a lithium-ion battery pack was used to estimate the cost. For example, if the size of the bank of a bus from the market review is 'X' kWh smaller than the required bank size, the new assumed cost is given as follows:

*'Assumed cost of bus with required battery bank size' = 'Cost of battery with smaller bank from market review' + 'X' * 'Global weighted average cost of lithium-ion battery pack (per kWh)'*

Table B3.9 presents the final assumed cost of bus, the required battery bank size for both bus sizes, and other relevant assumptions.

Table B3.9: Battery Bank Requirement for Large and Mid-Sized Bus

	Large Bus		Mid-sized Bus	
Scenario	Scenario A	Scenario B	Scenario A	Scenario B
Length (m)	11 to 12		8 to 9.5	
Battery bank size (kWh)	280	140*	170	90*
Cost of bus ('000 USD)	151	130	139	127
Global weighted average cost of Lithium-ion battery pack	176[55] USD/kWh			

*Note: The values have been rounded up to the nearest multiple of 10 as a safety measure.

55 https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

iv. Capacity and cost of chargers

Table B3.10 presents the cost of DC chargers which are also based on the market review of regional EV manufacturers. The cost of chargers range from USD 6238 for 20 kW to USD 37,686 for 60 kW.

Table B3.10: Cost of DC Chargers by Charging Capacity

Capacity of chargers (kW)	20	40	60	80
Cost of chargers (USD)	6,000	17,000	22,000	38,000

C. Results of comparison of financial analysis

Calculations based on the mentioned assumptions result in savings on the initial capital investment for Scenario B. When compared with Scenario A, the capital investment is 6.96% lower for Scenario B in the case of mid-sized bus. The difference is even bigger for a large bus, by 11.61%.

On the other hand, the annual operating expenditure is higher for Scenario B for both bus sizes, primarily due to additional operating expenses while maintaining terminal stations along the route. Annual electricity charges are also slightly higher for Scenario B. Differences in CAPEX and OPEX for mid-sized as well as large-sized buses are depicted in the table below. For a complete breakdown of results, please refer to Annex II.

Table B3.11: Financial Comparison - Scenarios A & B ('000 NPR)

	Mid-sized Bus	Large Bus
Capital Expenditure		
Total CAPEX: Scenario A	2,465	2,871
Total CAPEX: Scenario B	2,308	2,555
Difference [A-B]	157	316
% Difference	6.38%	11.02%
Operational Expenditure		
Total OPEX: Scenario A	60	101
Total OPEX" Scenario B	70	114
Difference [A-B]	(11)	(13)
% Difference	-18.14%	-12.39%

6. Conclusion

Battery costs account for a large portion of the cost of electric buses. Purchasing buses with a reduced battery bank size could be a profitable decision for Sajha Yatayat. The initial capital investment can be reduced by around 6% to 11% if the charging regime is based on a combination of terminal station and depot charging with reduced on-board battery.

However, these financial savings must then be considered and weighed against any operational risks associated with Scenario B. Primarily, Scenario B presents higher operational risks related to the potential unavailability or high acquisition cost of land for terminal charging stations and traffic congestion,[56] thereby leading to a disruption in terminal charging schedules. In addition, interruption in electricity supply at the terminal raising

[56] Traffic congestion presents a risk to Scenario B, especially during the evenings. This risk needs to be considered when calculating total battery capacity in Scenario A. Thus, the drive range considered includes a 15% safety margin, which accounts for all disruptions caused due to traffic congestion. Please see Chapter B6 for a calculation of the proposed maximum drive range.

questions on reliability of bus service. These operational risks present a significant challenge to the cost effectiveness of Scenario B.
Through rounds of discussion with Sajha Yatayat, the perceived operational risk for this regime is considered to be more than the estimated financial savings. Cost benefit of Scenario B is at most 11 %, which is appreciable but not significant. While the operational risks presented above have not been monetized, they may be effectively considered to exceed the 11% saving. As such, Scenario A is considered a superior option.

Market review (in section B4) of bus manufactures based in India and China also favor Scenario A regime. Most of the models come with bigger battery sizes which are required for Scenario A. Only a few models are manufactured with smaller battery banks. Several manufacturers from China were also asked if they could manufacture the same models with reduced battery bank. All of the manufacturers responded negatively. It is recommended to go with overnight charger-based charging regime with required battery bank size.

Chapter B4. Market Review

1. Introduction

This chapter aims to:

- understand the market situation and the availability of electric buses in the region, along with their specifications;
- locate buses matching the required specifications for Scenario A and Scenario B; and
- identify chargers applicable in Scenario A and Scenario B.

In this chapter, a range of electric buses and chargers available in the market are identified and reviewed. Geographically, Nepal is sandwiched between two huge economies, India and China. It is most important to note that these two neighboring countries are leading the way in terms of transport electrification in the global arena. China's growth in electrifying its fleet and establishing electric vehicle manufacturing plants has been remarkable. A recent report indicates that out of the total electric buses running globally, 99.05 % are based in China.[57] To electrify its bus fleet, one of the major strategies adopted by China was subsidizing the cost of EVs to encourage bus manufacturers to produce electric buses.[58] Consequently, China's electric vehicle manufacturing sector has expanded rapidly and several household names such as BYD, CRRC, FOTON, Dongfeng, Kinglong, and Yutong have emerged.

Recently, Indian manufacturers have also started to catch up. Prominent vehicle manufacturers such as TATA, Ashok Leyland, and Mahindra & Mahindra have started manufacturing electric buses. Chinese manufacturers have also joined hands with Indian manufacturers to make electric buses in India. One such example is Olectra-BYD, which has supplied buses to several cities in India. Moreover, most of the buses currently operating in Nepal are imported either from China or India. So, for the review of electric bus market, only manufacturers from China and India are considered.

The market review focused on two bus sizes, in line with the analysis and discussions in the preceding chapters – namely, 8 to 9.5 meter buses and 11 to 12 meter buses. This is mainly because Indian standards recommend these sizes and both China and India produce buses of these sizes. Chinese manufacturers also produce buses that are 10.5 meters and smaller, but these have not been reviewed in this study. In addition, other specifications, such as length, battery type, size and warranty, seating capacity, air conditioning, and braking mechanism are also identified. Based on the size of battery, models suitable for Scenario A or Scenario B operation are then identified.

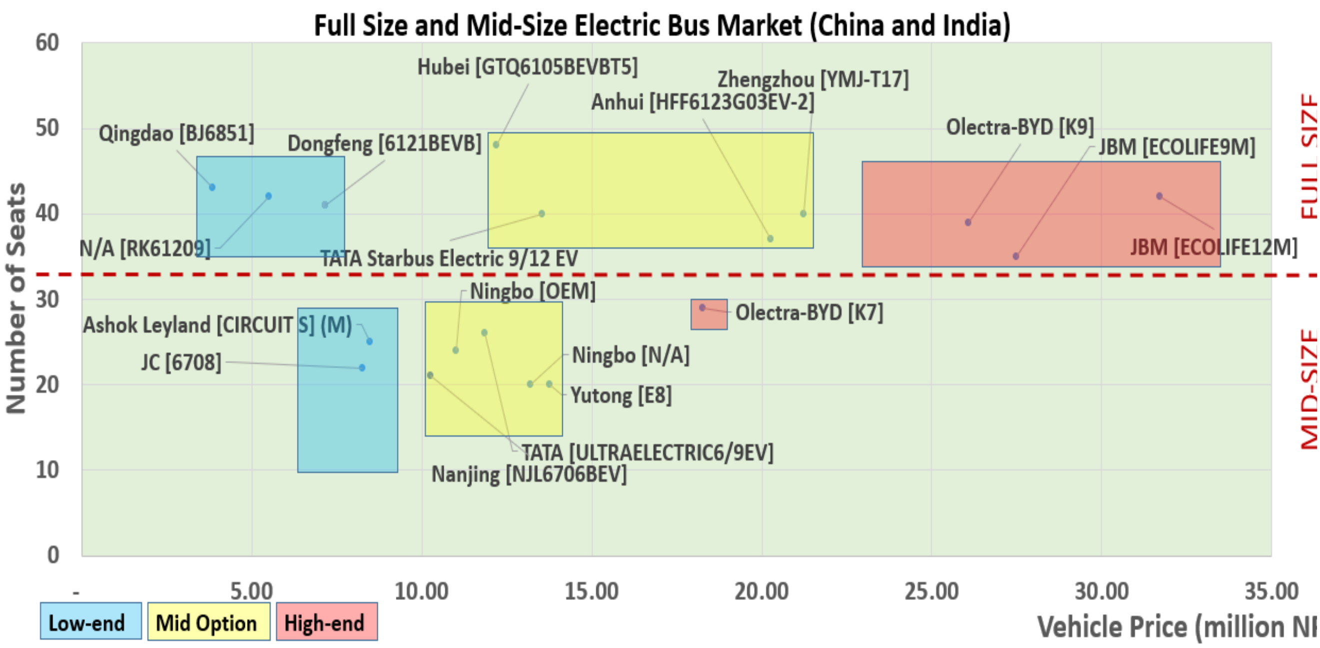
[57] Bloomberg. (2019). The U.S. Has a Fleet of 300 Electric Buses. China Has 421,000. Retrieved from https://www.bloomberg.com/news/articles/2019-05-15/in-shift-to-electric-bus-it-s-china-ahead-of-u-s-421-000-to-300

[58] Quartz. (2019). Beijing gave its biggest electric-vehicle maker $1 billion in help toward a single year of sales. Retrieved from https://qz.com/1579568/how-much-financial-help-does-china-give-ev-maker-byd/

Altogether, around 35 models from 15 manufacturers were reviewed for this study. These manufacturers range from global leaders such as BYD to economical range producers such as JC Automobile. Some were established players like TATA and others are newly formed companies like JBM. Reviews were based on an online market survey followed by direct enquiries in the case of a few manufacturers. The objective of this review is to draw the reader's attention to the diversity of the electric bus market in the region. Besides the models and manufactures mentioned here, there are many other manufacturers and models available in the market.

The market can be broadly segmented into low-end, mid-market, and high-end products. Figure B4.1 shows the Indian manufacturer JBM is at the higher end of the spectrum. Many Chinese manufacturers such as Dongfeng and Qingdao are producing large buses, ranging from NPR 3 million to 10 million. There are also cheaper large-sized buses available in the market, when compared to mid-sized buses, because they have achieved certain economies of scale. Since fewer mid-sized buses are produced, they tend to be more expensive. The price of Ashok Leyland buses are in the lower range because of the battery swap programs they are adopting with lower battery size. The price of Olectra-BYD buses is on the higher side, when compared to most Chinese manufactured buses.

Figure B4.1: Prices of Mid-Sized & Large-Sized Buses from China & India



*Note: The above prices are estimates for FOB and do not include transportation costs, import duty, and insurance, that are required to ship the vehicle to Nepal. Actual prices may vary in line with changes in vehicle specifications.

2. Market Sample of Buses

The tables below illustrate numerous models of mid-sized buses from India and China. Almost all the buses reviewed come with full-sized battery bank (close to 280 kWh for large buses and 140 kWh for mid-sized buses) which are suitable for Scenario A. Based on the market review, only one bus (Yutong [E8]) was found which comes with a much smaller battery bank (63 kWh), suitable for Scenario B.

Table B4.1: Sample of Mid-Size Buses From Chinese Manufacturers

Dongfeng (EQ6850CBEVT1)[59]		
	**Bus make**	Dongfeng
	Bus model	EQ6850CBEVT1
	Length	8.4 m
	Battery size	150 kWh
	Battery type	Lithium-ion based
	Battery warranty	Not stated
	Seating	31 seats
	Air conditioning	Optional
	Regenerative breaking	No

King Long (XMQ6850G)		
	**Bus make**	King Long
	Bus model	XMQ6850G[60]
	Length	8.5 m
	Battery size	Customizable
	Battery type	Lithium-ion based
	Battery warranty	Not stated
	Seating	30 seats
	Air conditioning	Optional
	Regenerative breaking	Not given
Sunda New Energy (CDK6810CBEV)		
	**Bus make**	Sunda New Energy
	Bus model	CDK6810CBEV[61]
	Length	8.1 m
	Battery size	141 kWh
	Battery type	Lithium-iron Phosphate
	Battery warranty	Not stated
	Seating	61 passengers in total
	Air conditioning	Optional
	Regenerative breaking	No

[59] http://www.dongfeng-bus.com/index.php/product/product_show/artid/60.html

[60] http://kinglong-bus.com/5-3-4-8m-electric-bus/

[61] http://m.sundaev.com/electric-vehicle/electric-bus/8-meters-pure-electric-city-buses.html

Yutong (E8)		
	**Bus make**	Yutong
	Bus model	E8[62]
	Length	8 m
	Battery size	63 kWh
	Battery type	Lithium-ion based
	Battery warranty	Not stated
	Seating	20 seats
	Air conditioning	Optional
	Regenerative breaking	No

Table B4.2: Sample of Mid-Sized Buses from Indian Manufacturers

Olectra-BYD (K7)		
	**Bus make**	Olectra-BYD
	Bus model	K7[63]
	Length	8.6 m
	Battery size	
	Battery type	Li-iron Phosphate
	Battery warranty	8 years
	Seating	29 seats
	Air conditioning	Yes
	Regenerative breaking	Yes

TATA (Starbus Ultraelectric 6/9EV)		
	**Bus make**	TATA
	Bus model	STARBUS ULTRAELECTRIC6/9EV[64]
	Length	9 m
	Battery size	Customizable
	Battery type	Lithium-ion based
	Battery warranty	
	Seating	26 seats
	Air conditioning	Optional
	Regenerative breaking	No

JBM (ECOLIFE9M)		
	**Bus make**	JBM
	Bus model	ECOLIFE9M[65]
	Length	9.4 m
	Battery size	Customizable
	Battery type	Customizable
	Battery warranty	Depends on battery type
	Seating	35 seats
	Air conditioning	Optional
	Regenerative breaking	Yes

[62] https://www.alibaba.com/product-detail/Yutong-E8-Pure-Electric-Bus-electric_60390382375.html

[63] https://olectra.com/k7/

[64] https://www.buses.tatamotors.com/products/brands/starbus-ultra/starbus-ultra-electric-6-9-ev/

[65] http://jbmbuses.com/JBM-Eco-Life-Brochure.pdf

Ashok Leyland (Circuit S)	
Bus make	Ashok Leyland
Bus model	Circuit S (Swappable)[66]
Length	9 m
Battery size	
Battery type	Lithium-ion based
Battery warranty	
Seating	25 seats
Air conditioning	Optional
Regenerative breaking	Yes

The tables below summarize the review of markets for large buses in India and China. As with mid-sized buses, most of the buses come with a larger battery bank which is suitable for Scenario A. For a Scenario B application, the Golden Dragon [12m e-bus] with 120 kWh bank is suitable.

Table B4.3: Sample of Large-Sized Buses from Chinese Manufacturers

Yutong (E12)	
Bus make	Yutong
Bus model	E12[67]
Length	12 m
Battery size	295 kWh
Battery type	Lithium-Iron Phosphate
Battery warranty	Not stated
Seating	39 seats
Air conditioning	Optional
Regenerative breaking	Yes

Dongfeng (EQ6120CBEVT)	
Bus make	Dongfeng
Bus model	EQ6120CBEVT[68]
Length	12 m
Battery size	228 kWh
Battery type	Lithium-ion based
Battery warranty	Not stated
Seating	42 seats
Air conditioning	Optional
Regenerative breaking	No

[66] https://www.team-bhp.com/forum/commercial-vehicles/195366-ashok-leyland-circuit-s-bus-auto-expo-2018-a.html

[67] https://en.yutong.com/z/newenergybus/

[68] http://www.dongfeng-bus.com/index.php/product/product_show/artid/58.html

Anhui Ankai (HFF6123G03EV-2)	
Bus make	Anhui Ankai
Bus model	HFF6123G03EV-2[69]
Length	12 m
Battery size	320 kWh
Battery type	Lithium-ion based
Battery warranty	Not stated
Seating	37 seats
Air conditioning	Optional
Regenerative breaking	No

King Long (XMQ6127GEV)	
Bus make	King Long
Bus model	XMQ6127GEV[70]
Length	11.9 m
Battery size	Customizable
Battery type	Lithium-iron Phosphate
Battery warranty	Not stated
Seating	45 seats
Air conditioning	Optional
Regenerative breaking	Not given

Golden Dragon	
Bus make	Golden Dragon
Bus model	12 meters e-bus[71]
Length	12 m
Battery size	120 kWh
Battery type	Ultra-capacitor+Lithium-ion
Battery warranty	Not stated
Seating	24 seats
Air conditioning	Optional
Regenerative breaking	Not given

Table B4.3: Sample of large size buses from Indian manufacturers

Olectra-BYD (K9)	
Bus make	Olectra-BYD
Bus model	K9[72]
Length	12 m
Battery size	324 kWh
Battery type	Lithium-iron Phosphate
Battery warranty	8 years
Seating	39 seats
Air conditioning	Yes
Regenerative breaking	Yes

69 http://english.ankai.com/HFF6123G03EV-2/index.htm

70 http://kinglong-bus.com/5-5-3-12m-electric-bus/

71 http://www.goldendragonbus.com/car/view/11153.html

72 http://goldstoneebus.com/k9/

JBM (ECOLIFE12M)		
	**Bus make**	JBM
	Bus model	ECOLIFE12M[73]
	Length	12 m
	Battery size	Customizable
	Battery type	Customizable
	Battery warranty	Not stated
	Seating	42 seats
	Air conditioning	Optional
	Regenerative breaking	Yes

TATA (STARBUS ULTRA ELECTRIC 9/12 EV)		
	**Bus make**	TATA
	Bus model	STARBUS ULTRA ELECTRIC 9/12EV[74]
	Length	12 m
	Battery size	Not stated
	Battery type	Lithium-ion based
	Battery warranty	Not stated
	Seating	40 seats
	Air conditioning	Optional
	Regenerative breaking	Yes

Ashok Leyland (Circuit S)		
	**Bus make**	Ashok Leyland
	Bus model	Circuit S (Swappable)
	Length	12 m
	Battery size	Customizable
	Battery type	Lithium-ion based
	Battery warranty	Not stated
	Seating	35 seats
	Air conditioning	Optional
	Regenerative breaking	Not stated

3. Market Sample of Charging Stations

Charging types can be divided into two categories: alternating current (AC) charging and direct current (DC) charging. Batteries can only be charged with DC current. Rectifiers are required for converting any AC current source (such as utility grid) into DC current. In the case of plugs for DC chargers, rectifiers are present within the external chargers and the vehicle itself does not contain any rectifier. There is therefore no constraint on the size of external charger. However, for AC plug-based vehicles, rectifiers are pre-installed within the vehicle itself which can limit the amount of charging power. Most importantly, the selection of AC or DC charger completely depends on the bus type. Manufacturers like BYD adopt AC charging and manufacture their own chargers while the majority of other bus manufacturers are found to have external DC charger-based charging ports.

[73] http://jbmbuses.com/JBM-Eco-Life-Brochure.pdf
[74] https://www.buses.tatamotors.com/tata-buses-brands/tata-starbus/

Globally, charging plugs and communication protocols (to link batteries and chargers) vary from country to county and manufacturers. In case of DC chargers, depending on charging plug standard[75], several standards are found globally, such as:

- CHAdeMO plug
- Combined Charging System (CCS)
- Tesla Super-charger
- GB/T

CCS plugs are backed by the European Union, Tesla Super-chargers are exclusive to Tesla vehicles, and CHAdeMo plugs are developed by Japanese manufacturers such as Mitsubishi and Nissan. The GB/T plug standard is backed and widely used by China, currently the world's largest EV market. India's latest guideline on EV charging infrastructure mandates the use of either CCS or CHAdeMO standards for fast DC charging in public charging stations in future.[76]

Based on this analysis, in the case of Scenario A, charging a mid-sized bus by overnight charger requires the charger capacity to be at least 20 kW, and as for large bus the capacity should be at least 40 kW. In Scenario B, the capacity of terminal station charger is 40 kW for mid-sized bus and 60 kW for a large-sized bus bus[77] (see Annex III for a calculation of terminal station chargers).

For these capacities, a large number of charger manufacturers exist. A few manufacturers identified from our review are: TONHE Technologies, Schneider Electric, SETEC Power, SENKU Machinery, ABB, Dongha, Siemens, and E Bus Bar Sc-tech. Besides these manufacturers, there are many more globally players. Table B4.4 presents a few manufacturers identified from China.

Table B4.4: Sample of DC Chargers from China

TONHE Technologies		
	**Charger make**	TONHE Technologies
	Capacity	20-120 kW
	Plug type	GB/T
	Efficiency	≥95%
	Power Factor	≥0.99
	Output Voltage	300-750VDC (200-500VDC optional)
	Input Voltage	3Ø-380Vac (50Hz±10%)

[75] Standards include communication protocol between charger and batteries and plug type.

[76] MoP. (2019). Charging infrastructure for electric vehicles-Guidelines and Standards. Ministry of Power, Government of India. Retrieved from https://powermin.nic.in/sites/default/files/webform/notices/scan0016 %281%29.pdf

[77] Rated capacity of terminal station chargers = % of required battery bank size * total energy required per vehicle.

SETEC Power		
	**Charger make**	SETEC Power
	Capacity	20-200kW
	Plug type	CCS and CHAdeMO
	Efficiency	≥95%
	Power Factor	≥0.99
	Output Voltage	400/700
	Input Voltage	3Ø-380Vac (50Hz±10%)

SENKU Machinery		
	**Charger make**	SENKU Machinery
	Capacity	60 kW
	Plug type	CCS1, CCS2 and CHAdeMO
	Efficiency	≥94%
	Power Factor	≥0.99
	Output Voltage	150-500VDC (150V-750V / 150V-1000V for Option)
	Input Voltage	3Ø-380Vac (50Hz±10%)

4. Conclusion

Our market review heavily favors scenario A. Apart from a few models, the majority of mid-sized and large-sized buses are manufactured with larger battery banks in order to maximize their range. Also, several manufacturers from China were asked if they could manufacture some of their models with a reduced battery bank. Although most manufacturers responded negatively to this request, some manufacturers (like JBM and Kinglong) claim to offer a customizable battery bank, depending on requirements.

Almost all the reviewed manufacturers have the option of installation an air conditioning system in the bus. Considering the milder weather patterns of Kathmandu valley and the fact that most buses running in Kathmandu Valley operate without air conditioning, the cost of the bus may be lowered by removing the air conditioning option altogether.

The selection of plug and type of charger (AC or DC) and charging standard is completely dependent on the bus to be operated. There are many manufacturers to choose from. In the case of plugs, there is an ongoing global competition among different standards to increase their market share.[78] Choosing buses and charger plug with a 'dominant' standard will there have benefits in the form of an established global supply chain and extensive network, as well as the prospect of ongoing research and developments to further the standard. If buses with a less dominant standard are procured, then additional costs may occur in the future in the form of charging port and interface mechanism replacements so that they are to be compatible with a more dominant standard.

[78] Steitz, C. (2018, January 24). Plug wars: the battle for electric car supremacy. *Reuters*. Retrieved from https://www.reuters.com/article/us-autos-electricity-charging/plug-wars-the-battle-for-electric-car-supremacy-idUSKBN1FD0QM

Chapter B5. Charging Station Installation at Sajha Yatayat Depot

1. Introduction

This chapter aims to assess:

1. maximum peak electricity demand of Sajha Yatayat depot;
2. capacity of the existing local electricity distribution network to supply power to Sajha Yatayat depot after the addition of electric buses;
3. existing the internal electrical distribution network of the depot and upgrade costs: and
4. parking space availability at the depot.

Since the number of mid- and large-sized buses in the blended model is yet to be determined, this study takes a conservative approach and assesses the feasibility of installing charging stations for maximum peak electricity demand at the depot. The maximum demand occurs when all 16 buses are large buses and 16 separate 40 kW capacity chargers are installed to charge the buses at the same time. Therefore, to gain an idea of the maximum capacity, large buses are assessed in this chapter.

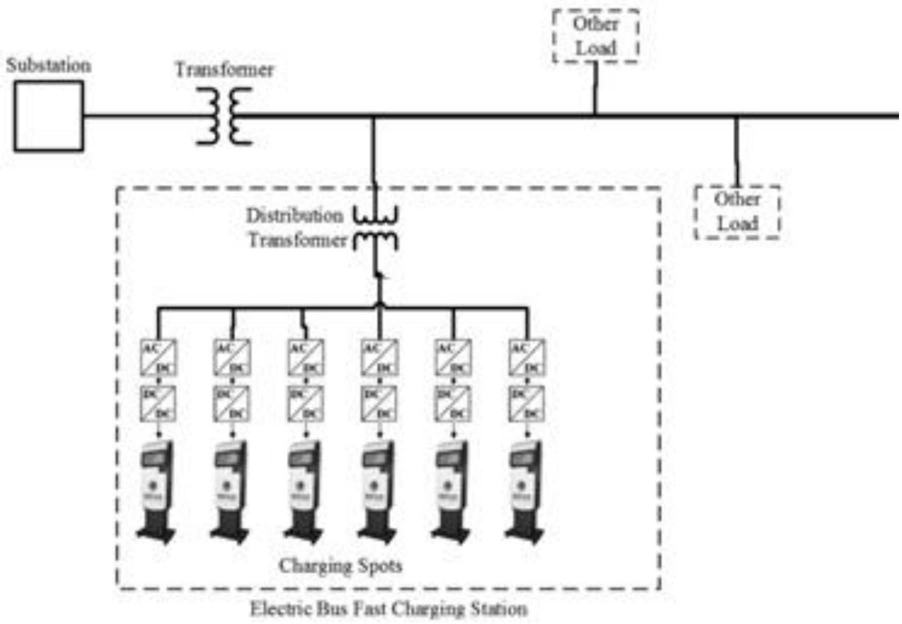
2. Technical Assessment

A. Assessment of Substation Capacity

In most cases, installation of bus chargers, especially those of higher capacity, is limited by the residual capacity of the distribution network as well as investment budget.[79] Typically, the capacities of each substation, feeders, and distribution transformers are set according to the peak load of the specific service area by each utility company. Since the charging station shares capacity of the distribution network with other consumers in that area, additional power demands from the station may potentially overload the network. In such a case, augmentation of the network may be required.

[79] Ding, H., Hu, Z., & Song, Y. (2015). Value of the energy storage system in an electric bus fast charging station. *Applied Energy*, *157*, 630–639. https://doi.org/10.1016/j.apenergy.2015.01.058

Figure B5.1: Typical Layout of Distribution Network Providing Power to Bus Charging Station



Source: (Ding et al., 2015)[79]

Table B5.1: Maximum Power Demand by Sajha Yatayat Depot

Criteria	Capacity	Unit
Expected total active power loading from 20 chargers	640	kW
Expected total demand including auxiliary services and extra margin	736	kW
Power factor	0.85	
Current peak electricity demand of the depot	20.0	kVA
Expected total apparent power loading from chargers	886	kVA
Size of transformer available in the market	1,200	kVA

Table B5.2: Details of Substation Supplying Power to Sajha Yatayat Depot

Specifications	
Location	Sajha Depot, Pulchowk.
Expected maximum demand at the depot (kVA)	886 kVA
Nearest substation supplying power (Voltage Rating)	New Patan Substation (66/11kV)
Nominal capacity of the substation (kVA)	54,000
Maximum demand on the substation up to February 2019 (kVA)	51,090

The Nepal Electricity Authority (NEA) owns and manages almost all the electricity distribution networks in the country. If any augmentation is needed, it is handled by NEA. Sajha Yatayat's role is limited to formally requesting NEA for a connection upgrade. A typical electricity distribution network supplying power to a bus charging station is illustrated in Figure B5.1.

To calculate a depot's maximum power demand, it is assumed that Sajha Yatayat would purchase 16 units of large buses and then charge them overnight with 16 units of 40 kW chargers. The charging sequence of all 16 buses would overlap and the peak power demand of the depot would be the sum of all power demand by the combined 16 individual chargers. Table B5.1 presents the calculations.

For the purposes of assessing a substation's capacity, the closest substation supplying power to the depot is found. Based on the rating of the substations and the maximum demand it currently meets, the substation's available capacity is found and then compared with the depot's peak demand. Should the available capacity exceed the depot's demand, then major augmentation is not required in the substation. Table B5.2 shows the calculation.

Available maximum supplying capacity (kVA)	2,910
% of supplying capacity available	5%

Source: Field survey

B. Assessment of Distribution Line (Feeder) Capacity from Sub-station to Charging Stations

Following a similar approach, existing maximum power demand on a distribution feeder as well as the feeder's maximum power supplying capacity are found. Available capacity is then calculated as the difference between maximum supply capacity and maximum existing demand load on the feeder. Should the available capacity exceed the charging station's demand, then augmentation of distribution line is not required.

Multiple 11 kV feeders are currently running in the vicinity of the Sajha Yatyat depot. As part of demand-side management, frequent switching between feeders to supply power is generally practiced by NEA. It is therefore not necessary that a particular feeder always serve the same load center. Site surveys identified two of the feeders running near the depot: the Patan-II feeder and the Pulchowk feeder. Table B5.3 depicts the maximum available supply capacity of these feeders. The 11 kV Pulchowk Feeder with a 2,476 kVA supply capacity will be able to comfortably charge 16 large-sized electric buses with a total demand of 886 kVA. However, the Patan-II Feeder will need to be upgraded in order to charge the 16 buses along that route. For a consumer demanding supply greater than 2,000-3,000 kVA, a dedicated feeder from the nearest substation to the load center is required. NCell, NTC, and Radio Nepal are a few examples of consumers which have a dedicated feeder from the New Patan substation. In the case of the Sajha Yatayat depot, maximum expected load is not more than 886 kVA and therefore no such dedicated feeders are necessary.

Table B5.3: Details of Feeders Supplying Power to the Sajha Yatayat Depot, Pulchowk

Specifications		
Location	Sajha Yatayat Depot, Pulchowk.	
Nearest substation	New Patan Substation (66/11kV)	New Patan Substation (66/11kV)
Name of feeder (voltage level)	Patan-II Feeder (11kV)	Pulchowk Feeder (11kV)
Expected maximum demand at depot (kVA)	886	886
Nominal capacity of the Feeder (kVA)	5,715	5,715
Maximum demand on the feeder (kVA)	5,144	3,239
Available maximum supplying capacity (kVA)	571	2,476
% of supplying capacity available	10%	43%

C. Assessment of Power Transformer and Existing Electric Power Network

Currently, a newly-installed 200 kVA transformer is supplying electricity at the Sajha Yatayat Depot. The transformer is owned and managed by NEA and is also supplying power to the adjoining Nepal Telecom Customer Care building.

However, according to NEA directives, if the demand load is above 50 kVA, consumers must have a dedicated private transformer installed. Also, for loads above 25 kVA, a separate Time of Day (TOD) meter must be installed. Since Sajha Yatayat's load is expected to increase to 886 kVA, both a dedicated transformer and a TOD meter are required at the Sajha Yatayat depot.

A quick survey of existing internal electrical distribution networks indicated the need for significant upgrades, in addition to the installation of dedicated transformer and TOD meters within the depot. The depot needs to be upgraded in areas such as:

- major low voltage distribution networks with appropriately sized wires and distribution panels;
- appropriate grounding and protection units;
- lighting fixtures and other covering shades for chargers.

Tentative upgrade costs, along with expected materials, devices, and workmanship are provided in table B5.4 below. The installation of transformers represents the majority of total required cost outlay, followed by electrical control room costs.

Figure B5.2: A 200 kVA Transformer Supplying Sajha Yatayat Depot and NTC Building

Table B5.4: Estimated Cost of Upgrading the Depot's Internal Electrical Power Network

S. N	Item	Unit	Qty	Rate ('000 NPR)	Total ('000 NPR)	Total (USD)
Transformer						
1	1200 kVA Delta/Y Transformer	pcs	1	3,071	3,071	27,921
2	Accessories required for transformer installation	set	1	460	460	4,188
New Electrical Control Room						
1	Civil works (3X3 m)	LS	1	300	300	2,727
2	Main distribution panel	pcs	1	15	15	136
3	MCCB 4P, 3 kA	pcs	1	720	720	6,549
4	TOD Meter	pcs	1	318	318	2,891
5	Surge protection device	pcs	1	25	25	227
6	Earthing system	LS	1	150	150	1,364
Distribution						
1	250 Sq.mm 4-core copper AC wire	m	125	5	687	6,250
2	750 mm cable tray and mounting accessories	m	125	3	375	3,409
Charging Ports						
1	Rain and sun protective covering set	set	20	10	200	1,818
2	MCCB 4P, 125A	pcs	20	5	110	1,000
3	Metal control box	pcs	20	3	70	636
Lighting Fixtures						
1	Wall-mounted IP65 20W flood light	pcs	10	3	30	273
	Sub-Total (NPR)				**6,532**	**59,390**
Technician and transportation charges						
1	Consultancy fee	LS	1	195	195	1,782
2	Installation fee	LS	1	75	75	682
3	Transportation and other charges	LS	1	50	50	455
	Grand Total (NPR)				**6,853**	**62,308**

E. Assessment of Space Requirements

Figure B5.3 provides the general layout of the Sajha Yatayat depot at Pulchowk, Lalitpur. The total estimated parking area available at the depot is indicated by the yellow box, which is around 2,685 square meters. Currently, 45 large-sized-buses are parked overnight at the depot. Through consultations with Sajha Yatayat, it has been determined that only a further 10 buses can be added at the depot. Sajha Yatayat is considering submitting a request to the Government for the provision of additional land on a lease basis to accommodate the additional buses.

Figure B5.3: Layout of the Sajha Yatayat Depot, Pulchowk

3. Conclusion

Available capacity at the substation supplying the Sajha Yatayat depot is 2,910 kVA, while Sajha Yatayat's peak demand is around 886 KVA. Substation capacity is therefore considered sufficient and no upgrade is required.

In terms of distribution feeders, although the maximum available supplying capacity of the Patan-II feeder (571 kVA) is insufficient to supply peak demand of 886 KVA, any excess demand can be met by the Pulchowk feeder with available capacity above 2,000 kVA, if managed properly. Therefore, NEA's existing distribution network can supply power to the depot during peak hours. Although there's no need for a new dedicated feeder line, a bigger capacity transformer in the range of 1,200 kVA must be installed, owned, operated, and maintained by Sajha Yatayat.

In terms of space availability at the depot, since 45 buses are currently being parked at the Sajha Yatayat depot, only a further 10 additional buses can be accommodated. Sajha Yatayat is keen on leasing land to park additional buses that will be purchased in the future.

Chapter B6. Proposed Vehicle Specifications

1. Required General Features of the Bus and Preferred Features

This chapter discusses proposed specifications of electric buses that will be viable along the Lagankhel-Budhanilkantha and Swayambhu-Suryabinayak routes. These specifications have been suggested based on extensive consultations with Sajha Yatayat, manufacturers, and relevant stakeholders (see Part A) to understand their specific requirements as well as to complement the analyses presented in preceding chapters. Most proposed specifications have been adapted from suggestions received from manufacturers and suppliers of the relevant electric buses. However, Sajha Yatayat has formed a procurement committee consisting of representatives from Sajha Yatayat, the Ministry of Physical Infrastructure and Transport, the Department of Transport Management, and the Kathmandu Metropolitan City and Nepal Electricity Authorities. The specifications suggested here may slightly differ from the suggestions presented by the committee. The specifications on vehicle body and chassis would be as per Sajha Yatayat's requirement as well as those specified by manufacturers.

A. Proposed Bus Specifications

i. Vehicle Dimensions

Mid-and large-sized buses have been proposed for both the Lagankhel-Budhanilkantha and Swayambhu-Suryabinayak routes.

Table B6.1: Proposed General Specifications of the Vehicle

Specification Description	Mid-sized Bus	Large-sized Bus
Length (mm)	8,500 +/-0.5	11,5000 +/-0.5
Width (mm)	2100-2600	2500-2600
Height (mm)	Max: 3600	Max: 3600
Floor height (mm)	Semi-low Floor or Standard High Floor (max 900 mm; 650 mm or lower preferred)	Semi-low Floor or Standard High Floor (max 900 mm; 650 mm or lower preferred)
Ground clearance (mm)	Minimum ground clearance 150 mm acceptable if bus is to be operated in well paved roads	Minimum ground clearance 150 mm acceptable if bus is to be operated in well paved roads
Wheelbase (mm)	4200-5000 mm	5200-5600 mm
Seating capacity (including driver)	At least 25+1	At least 32+1

Pay load (kg)	3,750 kg	6,000 kg
Gross vehicle weight (kg)-(including AC)	Min: 10,000 kg*	Min: 13,000 kg*

The length proposed for the mid-and large-sized buses range from 8-9.5m and 11-12m respectively. In addition, a minimum of 26 seats for mid-sized and 33 seats for large-sized buses have been proposed. Since the road condition of Kathmandu is not suitable for low-floored buses, semi-low floored step buses, with a height lower than 650 mm is preferred. The payload for a mid-sized bus is based on the estimate of 50 passengers (at an average of 75 kg per person), including luggage can be accommodated on the bus at any one time. Similarly, for a large-sized bus, the passenger load has been estimated at 80 persons.

ii. Energy Consumption and Battery Bank

Energy consumption of an electric bus is mainly dependent on the type and size of battery packs being installed, in addition to availability of air conditioners. It has been proposed that the manufacturer determine the minimum battery bank size required to cover this drive range. In addition, lithium-based batteries with a minimum guaranteed life of eight years, and battery management and battery cooling systems should be included in the vehicles. This ensures the type of battery being used will provide at least a 202 km drive range at the end of its guaranteed life for the specified gross vehicle weight during the life of the battery and an integrated AC component.

$$Drive\ range = [(a * b) + c] * 1.15$$

whereby:

a = total distance traveled by the bus between terminals;
b = maximum number of one way trips per day; and
c = round trip distance between the depot and the closer terminal in the route.

The Swayambhu-Suryabinayak route has been considered for this estimation because the total daily distance traveled by a bus is highest along this route. A 15% safety margin is added to account for any disruption due to traffic congestion and diversions.

Table B6.2: Routes and Respective Drive Ranges

Route	a (km)	b (trips)	c (km)
Lagankhel-Budhanilkantha	17	8	6
Swayambhu-Suryabinayak	27	6	13

Table B6.3: Proposed Specifications Related to Energy Consumption and Battery Bank Size

Specification Description	Mid-sized Bus	Large-sized Bus
Minimum battery bank size (kWh)	To be specified by manufacturer	To be specified by manufacturer
Drive range per single full charge	At least 202 km in a single full charge for specified GVW with AC (cooling) on during battery lifetime (warranty period)	At least 202 km in a single full charge for specified GVW with AC (cooling) on during battery lifetime (warranty period)
Battery cell type	Lithium-based battery	Lithium-based battery
Minimum battery life	At least 8 years of guarantee	At least 8 years of guarantee
Battery management system	An advanced BMS should be an integral part of the battery pack to monitor the following parameters of battery for safety and optimal performance: i. Overcharge or discharge protection;	

	ii. Over current protection; iii. High and low voltage protection; iv. High and low temperature protection; and v. State of charge and battery health	
Battery cooling system	Liquid cooling	Liquid cooling

iii. Chassis and Other features

It has been proposed that most of the chassis specifications be recommended by the manufacturer, except specifications related to the transmission system, front and rear brakes, steering system, suspension system (front and rear), and shock absorber (front and rear). Regenerative braking and anti-lock braking systems are required for Kathmandu's terrain. Therefore, these specifications have been recommended. In addition, air suspension, hydraulic telescopic type shock absorber and assisted power steering are also components that have been proposed as required in the vehicle.

Table B6.4: Proposed Specifications of Chassis and Other Features

Specification Description	Mid-sized Bus	Large-sized Bus
Chassis		
Transmission system	Automatic transmission system	Automatic transmission system
Front brake system	Drum brakes	Drum brakes
Rear brake system	Drum brakes	Drum brakes
Anti-lock braking system [ABS]	Required	Required
Regenerative braking system	Required	Required
Steering system	Assisted power steering	Assisted power steering
Suspension system: front	Air suspension	Air suspension
Shock absorber: front	Hydraulic telescopic type	Hydraulic telescopic type
Suspension system: rear	Air suspension	Air suspension
Shock absorber: rear	Hydraulic telescopic type	Hydraulic telescopic type
Other features		
Cooling/heating system	Air conditioner	Air conditioner
Minimum speed	At least 60 km/h	At least 60 km/h
Minimum gradient climbing ability (%)	At least 15%	At least 15%
Extendable ramp	Preferable	Preferable
Public announcement system	Preferable	Preferable

It has been proposed that vehicles have air conditioning units installed, rendering rides more comfortable for passengers. However, this will also have direct implications on battery capacity. The addition of air conditioners will only slightly increase bus costs, but their operation will increase the energy consumption by up to 30%.[80]

The terrain of Kathmandu is such that a minimum gradient climbing ability of 15% and a minimum speed of 60 km/hr are required specifications for the vehicle. An extendable ramp for wheelchair-bound and elderly passengers is a preferred feature. In addition, it is recommended that a public announcement system be included in the bus.

[80] Hongwen, H., Yan, M., Sun, C., Peng, J., 2017. Predictive air-conditioner control for electric buses with passenger amount variation forecast. Applied Energy.

iv. Vehicle Body System

All vehicles in Nepal are right-hand drive, thus buses should comply with this local standard. Additional handrails and hanging rings are also components that are required in the bus to ease the journey for passengers who are standing.

To provide additional comfort to passengers, it has been proposed that buses have a reserved area for wheelchairs, front and central doors, and city bus type passenger seats. Moreover, priority seats for elderly and pregnant women should be clearly labeled.

Table B6.5: Proposed Specifications Related to Vehicle Body System

Specification Description	Mid-sized Bus	Large-sized Bus
Steering position	RHD	RHD
Wheelchair area	Reserved area for wheelchair	Reserved area for wheelchair
Door arrangement	Front and central door	Front and central door
Passenger seat type	City bus type	City bus type
Handrail	Required	Required
Hanging ring	Required	Required

v. Safety and Preferred Features

Passenger safety is of utmost priority, therefore safety hammers, fire extinguishers, passenger exit doors, and CCTV surveillance systems have been proposed as "non-negotiable" features for the bus. In addition, buses should be energy efficient and have clearly-labeled priority seats allocated clearly for elderly passengers, pregnant women, and wheelchair-bound passengers.

Table B6.6: Proposed Onboard Safety Features

Safety Features	Mid-sized Bus	Large-sized Bus
Safety hammer	Required	Required
Fire extinguisher	Required	Required
Passenger exit door bell	Required	Required
CCTV surveillance system	Required	Required

B. General Design and Preferred Bus Features

1. Buses should be energy efficient and the design should be environmentally and commuter friendly.
2. Buses should be designed, and where required, modified to suit the operational and climatic environment of Kathmandu Valley. The existing infrastructure and condition of the road should also be taken into consideration while doing so.
3. Buses should have adequate structural strength and meet key requirements related to stability, deflection, and vibration for at least the following main loads:
    - Dynamic loads
    - Single wheel bump loads
    - Double wheel bump (diagonally opposite) loads
    - Braking and acceleration loads

    - Front impact loads
    - Roll over loads
    - Speed breaker induced loads.
4. Materials used in the buses should be of internationally acceptable standards.
5. Passenger seating and standing arrangements should provide maximum passenger comfort. In addition, buses should have aesthetically-designed interiors and exteriors.
6. Buses should be energy efficient.
7. In order to foster gender equality and social inclusion (GESI), semi-low floor features are required for the comfort of wheelchair-bound passengers and the elderly. In addition, labeled priority seats for pregnant women and the elderly will be required, along with reserved seats for differently-abled passengers as part of the act relating to the "Rights of Persons with Disabilities, 2017."
8. Considering the growing trend of installing fast electric vehicle chargers, battery packs capable of safely handling high charging power (generally above 100 kW) are preferred.

2. Conclusion

The proposed bus specifications were finalized through several rounds of discussions with Sajha Yatayat to understand their requirements. These specifications complement the assessments made in previous chapters. The suggested specifications, specifically those related to bus dimensions, the vehicle's energy consumption as well as the battery bank, are critical for smooth bus operation. For electric buses, it is important to have a strong understanding of the drive range required, as well as the implications of adding air conditioners, and the Gross Vehicle Weight (GVW) to be able to determine the capacity of the battery banks needed and their efficiency. It is therefore up to the manufacturer to specify viable battery bank options for a bus with AC to cover the 202 km drive range for the Swayambhu-Suryabinayak route specified above.

In addition, features such as right-hand-drive, a minimum ground clearance of 170 mm, a minimum gradient climbing ability of 15%, the availability of an air suspension system and shock absorbers, and a minimum speed of 60 km/h are based on general driving requirements of the country and local road conditions. Without these specifications, vehicles will incur very high maintenance costs and may not be viable for the Lagankhel-Budhanilkantha and Swayambhu-Suryabinayak routes.

Finally, it is very important to specify the general safety features required in the bus in the event of a fire breaking out, as well as additional features such as labeled seats and wheelchair access areas that encourage gender equality and social inclusion.

PART C. FINANCIAL ANALYSIS

Chapter C1. Financial Analysis of Electric Bus Fleet

1. Introduction

In this section, the results of the financial analysis detailing the economics of electric buses on the two selected metropolitan routes - MR1 (Lagankhel to Budhanilkantha) and MR2 (Swayambhu-Suryabinayak) are presented.

The Government of Nepal is a shareholder of Sajha Yatayat, having invested in the company to cover the purchase cost of the electric bus fleet, charging stations, and other associated costs related to upgrading the depot infrastructure. As a result of the government's investment, Sajha Yatayat's financial goals for the deployment of electric buses are not the typical metrics of investment evaluation such as IRR, NPV, Payback. etc. Instead, it wishes to ensure that over the company's operating life, passenger fare revenues are adequate to cover the operating costs of the electric bus fleet.

The objectives of the financial analysis include:

- cash flow projections arising from operations of the electric bus fleet;
- an assessment of the adequacy of passenger revenue to meet annual operational expenses; and
- and estimate of the Total Cost of Ownership (TCO) in deploying the electric bus fleet.

2. Methodology

Sajha Yatayat provided GGGI with the information required to establish a reference base case. For some of the electric bus technical parameters, results of relevant electric buses evaluations conducted by the public transport authorities in other cities and GGGI's experience with electric buses for public transportation were relied upon in order to build a reliable cost forecasting model, reflective of Sajha Yatayat's particular operating characteristics.

Costs of Ownership for Public Buses

The total cost of ownership for a vehicle is an important indicator for public transport operators when considering new bus technologies. The total cost of ownership generally includes changes in capital expenses (vehicle purchase, infrastructure, and facility upgrades) as well as operational expenses (energy charges, repairs, and maintenance). Additional considerations that could impact the costs of adopting electric buses include the effects of route structure, planning for infrastructure investment, and decisions about technical configurations (i.e. on-route vs. optimized depot charging vs. convenience charging only).

A key focus of this study is characterizing how changes to key parameter assumptions contribute to the total costs of public bus ownership. Uncertainty in lifetime costs stems from variability in key costs, as well as uncertainty that may arise from a lack of knowledge about likely parameter values. The latter is especially important when considering future costs, since costs for emerging technologies are not well established and are subject to considerable future change. To assess the effects of these variations on total cost, a probabilistic parameter assumptions methodology is employed to estimate the value of lifetime vehicle costs.

3. Assumptions

The assumptions for the base case scenario are detailed below.

A. General and Macroeconomic Parameters

The key general and macroeconomic parameters are detailed in the table C1.1 below. Note all US dollar values (USD) in this analysis is based on a starting exchange rate of USD 1 = NPR 110 and the NPR is assumed to depreciate every subsequent year by the difference in the annual inflation rate of 4.0% between Nepal and the USA.

Table C1.1: Key Parameters

Particulars	Value
Operating life of e-bus fleet	15 years
Operating days in a year	350 days
Average annual inflation rate in Nepal	6.0%
Average annual inflation rate in the USA	2.0%
Average Forex Rate: NPR – USD (2019)*	110

B. Routes

Routes MR1 (Lagankhel) and MR2 (Swayambhu), located within the metropolitan area of Kathmandu, are those routes selected for the deployment of the electric bus fleet. Please refer to part B2 of the report for the analysis regarding the selection of the appropriate routes for the electric bus fleet. Currently, a total of 16 diesel buses are deployed, of which 10 buses are designated for route MR1 and 6 buses for route MR2. Sajha Yatavat proposes to replace the existing diesel bus fleet with electric buses.

The number of passengers on the respective routes was estimated by GGGI, based on the information provided by Sajha Yatayat. For route MR1, passenger demand was estimated based on the revenue generated per route and average passenger fare of NPR 14.8. For route MR2, neither the revenue for the entire year nor the passenger data for the entire year is available. As a result, monthly data provided by Sajha Yatayat was used to forecast annual passenger demand. During FY 2018-19, annual passenger demand on route MR1 is estimated to be 1,400,000 passengers and on route MR2 it is estimated to be 700,000 passengers. Although the route distance of MR2 is higher than that of MR1, the estimated passenger numbers are higher in MR1 because more buses are deployed on the MR1 route than on the MR2 route.

Table C1.2 details the characteristics of the selected routes – MR1 (Lagankhel) and MR2 (Swayambhu).

Table C1.2: Route Characteristics

Route	MR1 (Lagankhel)	MR2 (Swayambhu)
Length of route– one way (km)	17	27
No. of diesel buses currently deployed	10	6
No. of one way trips per day	8	6
Depot to starting point & return (km)	6	13
Distance covered per bus per day (km)	142	175
Annual passengers	1,400,000	700,000

C. Capital Costs

Electric Bus

The electric buses considered for the fleet include two types – mid-size (8-9 meter) and large size (11-12 meter) buses. The base case scenario is based on swapping the current fleet of 16 diesel bus with the same number of electric buses, comprising 11 mid-sized and 5 large-sized buses. The prices for buses used in the financial analysis were based on the purchase price estimate of the electric bus manufacturers detailed in Annex VI. Specification and purchase price of recommended bus types are shown in the Table C1.3.

Table C1.3: Electric Bus Specification

<table>
<tr><th colspan="2">Bus Type</th><th>Mid-Size</th><th>Large Size</th></tr>
<tr><td colspan="2">Length (m)</td><td>8.5 +/- 0.5m</td><td>11.5 +/- 0.5 m</td></tr>
<tr><td colspan="2">Passenger capacity (Seated + Standing)</td><td>50</td><td>75</td></tr>
<tr><td colspan="2">Battery type</td><td>Lithium-Ion</td><td>Lithium-Ion</td></tr>
<tr><td colspan="2">Battery size (kWh)</td><td>170</td><td>300</td></tr>
<tr><td colspan="2">Energy consumption (kWh / km)</td><td>0.84</td><td>1.46</td></tr>
<tr><td colspan="2">Range between charging intervals (km) (with 20% charge remaining)</td><td>202 km</td><td>202 km</td></tr>
<tr><td rowspan="2">Purchase Price per bus</td><td>USD</td><td>145,000</td><td>162,000</td></tr>
<tr><td>NPR *</td><td>15,950,000</td><td>17,820,000</td></tr>
</table>

** NPR – USD exchange rate; USD 1 = NPR 110*

Charging Infrastructure

The charging infrastructure comprises of an overnight charging outlet station for each electric bus in the fleet and the associated depot upgrade cost. The estimated cost of the 20-kW charging station for a mid-sized bus is approximately NPR 690,000 (USD 6,250) and the cost of the 40-kW charging station for a large-sized bus is approximately NPR 1,870,000 (USD 17,000). The associated electrical infrastructure of the depot also needs to be upgraded to accommodate the electric bus fleet and is estimated to cost approximately NPR 7,000,000 (USD 64,000), as detailed in Table B5.4

Capital Cost Incurred by Sajha Yatavat

Table C1.4 details the total capital cost for deploying the 16 electric buses on routes MR1 and MR2. Note that the entire cost is covered by the Government of Nepal in the form of a grant to Sajha Yatayat. As a result, no upfront capital cost is incurred by Sajha Yatavat.

Table C1.4: Total Capital Cost

	Amount (NPR)	Amount (USD)*
Purchase price of e-bus fleet (11 Mid-sized bus + 5 large-sized bus)	264,550,000	2,405,000
Cost of charging infrastructure (11 nos. of 20 kVA + 5 nos. of 40-KVA)	23,912,500	217,500
Vehicle registration fee for e-bus fleet (NPR 18,000 per bus)	288,000	2,600
Total	**288,750,500**	**2,625,100**

** NPR – USD exchange rate; USD 1 = NPR 110*

D. Revenue Parameters

Passenger Fare

Table C1.5 shows the current passenger fare tariff rate approved by the government.

From the FY 2018-19 revenue data provided by Sajha Yatayat, the average fare paid by passengers has been assessed to be NPR 14.80. This implies that each passenger travels an average distance of around 4 km. Based on historical data, the passenger fare is assumed to increase by 3% once every five years.

Table C1.5: Approved Passenger Fare

Distance	Passenger Fare (NPR)	Passenger Fare (USD)*
Up to 4 km	14	0.13
Up to 5 km	16	0.15
Up to 6 km	17	0.15
Up to 8 km	18	0.16
Up to 10 km	21	0.19
Up to 13 km	23	0.21
Up to 16 km	25	0.24
Up to 19 km	26	0.25
More than 19 km	27	0.13

** NPR – USD exchange rate; USD 1 = NPR 110*

Passenger Demand

During FY 2018-19, the annual passenger demand on route MR1 is estimated to be 1,400,000 passengers and on route MR2 it is estimated to be 700,000 passengers. Based on historical data, an annual passenger growth of 2.0% has been assumed.

Table C1.6 details the maximum capacity of the fleet for each route and the average passenger load.

Table C1.6: Passenger Demand

Parameter	Symbol / Formula	MR1 (Lagankhel)	MR2 (Swayambhu)
No. of mid-sized buses (Max passenger capacity per bus : 50)	A	8	3
No. of large-sized buses (Max passenger capacity per bus : 75)	B	2	3
No. of one way trips per bus per day	C	8	6
No. of operational days	D	350	350
Maximum annual passenger capacity	E = ((A*50) + (B*75)) * C *D	1,540,000	787,500
Annual passenger demand (First operational year)	F	1,400,000	700,000

E. Operational Expenses

The operational expenses assumed includes maintenance costs, electricity tariff, salaries, and annual renewal of bus registrations.

Maintenance Cost

Maintenance costs include three categories of costs: preventive maintenance, routine (or running) maintenance, and servicing of the buses daily. The cost of exceptional repairs (accidents, vandalism, etc.) is excluded from the financial analysis. The current maintenance cost of Sajha Yatayat diesel bus fleet is used as the basis for estimating the cost of the electric bus fleet.

The maintenance cost of the electric bus has been estimated using Sajha Yatayat's historical maintenance cost data for diesel buses. Due to the simplification of the propulsion system, the maintenance cost of an electric bus is conservatively estimated to be 30% lower than the annualized maintenance cost of a diesel bus. This includes the cost of tires, electric motor fault repair, cleaning and collision repair, etc. The first-year maintenance cost is annualized at NPR 330,000 (USD 3,000) per bus, or NPR 6.0 (USD 0.055) per km, and is forecast to increase at the annual inflation rate of 6%.

Electricity Cost

The electricity cost has two components, the demand charge and the usage charge. The demand charge is a fixed monthly charge based on the peak energy demand of the charging infrastructure, whereas the usage charge is based on the electricity consumed for charging the e-bus fleet.

The following table C1.7 details the assumptions involved in estimating the electricity cost.

Table C1.7: Electricity Charges

Electricity Demand Charges		
Electricity demand charges	NPR/kVA/month	315
	USD/kVA/month	2.86
Peak demand from 16 charging stations (11 nos. 20-kW + 5 nos. of 40-kW stations)	kW	420
Power factor	-	0.85
Annual demand charges (first year)	NPR	1,868,000
	USD	17,000
Electricity Consumption Charges		
Annual distance traveled by the e-bus fleet		
• **11 mid-size buses**	km	535,500
• **5 large size buses**	km	394,800
Energy consumption		
• **Mid-sized bus**	kWh/km	0.84
• **Large sized bus**	kWh/km	1.46
Annual fleet energy consumption	kWh	970,242
Electricity consumption charges (first year)	NPR / kWh	5.16
	USD / kWh	0.047
Electricity consumption charges (first year)	NPR	5,000,000
	USD	45,500

In total, the estimated electricity cost including the demand charge for the first year is approx. NPR 6,868,000 (USD 62,500). Based on historical trend data, the electricity tariff is assumed to increase by 1% annually.

Salary Expenses

Sajha Yatayat currently has a staff of two per diesel bus and the same ratio has been assumed for the electric bus fleet. As per the information provided by Sajha Yatayat, an average annual salary of NPR 195,000 per staff member is assumed in the analysis. The total annual salary expenses is estimated at NPR 6,240,000 (USD 56,700) for the first year. The salary is assumed to increase with an inflation rate of 6% annually.

Battery Replacement Expenses

GGGI has conservatively estimated that the lithium-ion battery pack in the electric bus would be replaced at the end of eight years of operation. The cost of the replacement battery pack is based on the Bloomberg New Energy Finance (BNEF) forecast for the cost of a lithium-ion battery. In 2018, the cost of a lithium-ion battery ranged between USD 175 to 200 per kWh and by 2028, the price is expected to drop to approximately USD 75 per kWh by 2028 (real 2018).

Figure C1.8 : Lithium-ion Battery Price Forecast

Source: Bloomberg New Energy Finance

At the time of the first battery replacement in 2028, in nominal terms, the battery pack replacement cost for a mid-sized bus is forecasted to cost NPR 2,400,000 (USD 15,250) and for a large-sized bus is forecasted to cost NPR 4,300,000 (USD 27,500).

Registration Renewal Expenses

Vehicle registration renewal expenses is currently NPR 11,000 (USD 100) per bus per year and is assumed to increase with an annual inflation rate of 6%.

4. Key Findings

A. Financial Projections

Using GGGI's proprietary financial analysis model, the financial projections from operating a fleet of 16 electric buses on the metropolitan routes MR1 (Lagankhel to Budhanilkantha) and MR2 (Swayambhu-Suryabinayak) are presented. Figure C1.9 shows the financial projection in NPR (revenue, operating expenses, and battery replacement cost), as well as the cash balance at the end of each operational year. Similarly, figure C1.10 shows the financial projection in USD.

Figure C1.9 : Financial Projections (NPR)

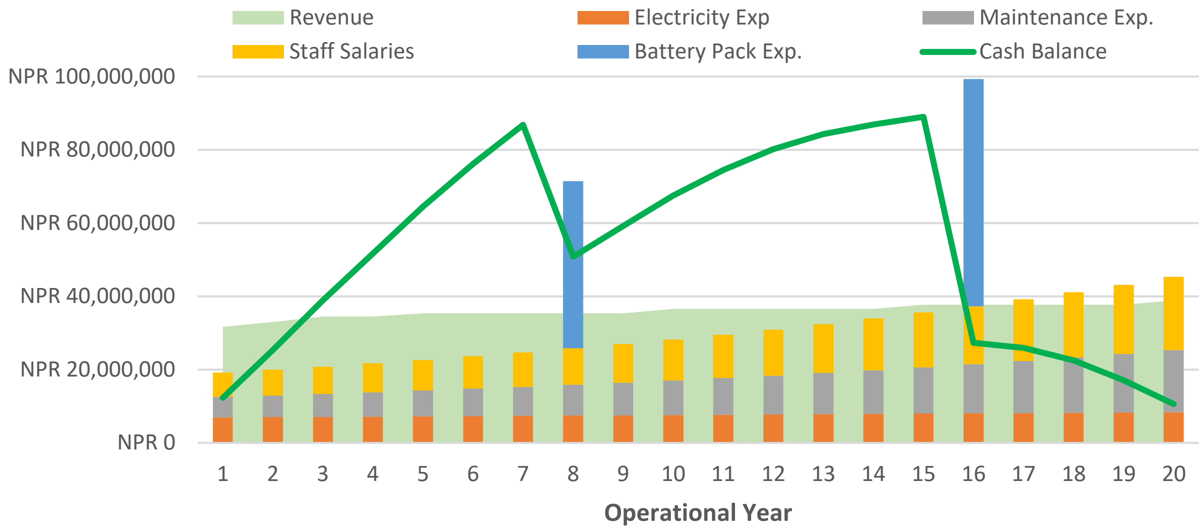
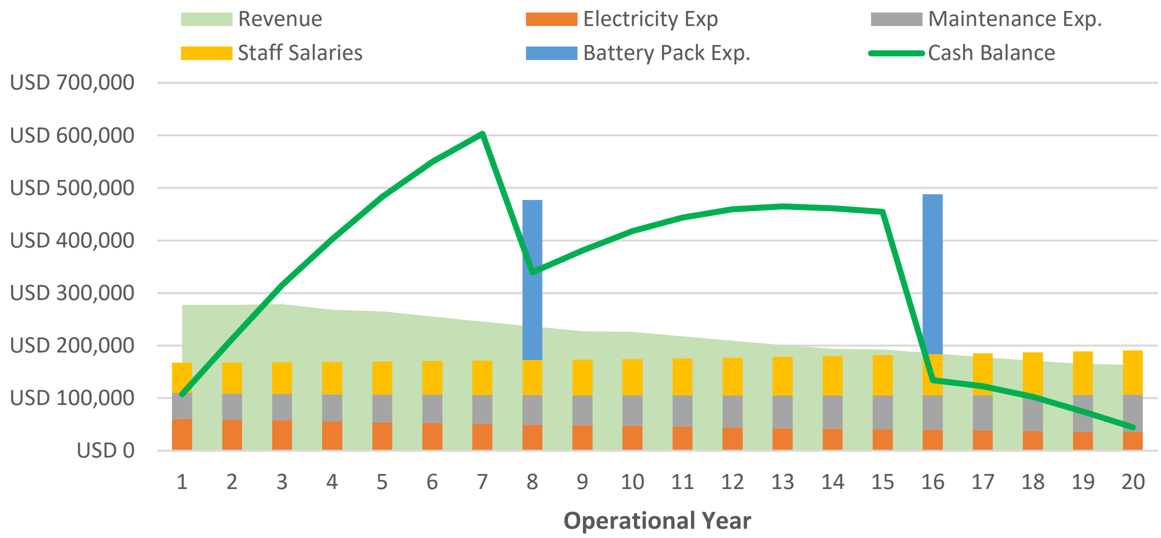


Figure C1.10 : Financial Projections (USD)



Key observations from the financial projection is summarized below:

- Over the normal operating life of 15 years, the revenue from the operations is significantly higher than operating costs. As a result, the average cash balance at the end of each operating year is NPR 63,200,000 (USD 406,000). This implies that the operations are financially sustainable.
- During operational year 8, a large expense outlay is forecast to accommodate replacing the battery packs of the e-bus fleet. To ensure reliable operations, it is recommended that approx. NPR 6,000,000 (USD 38,000) per year is reserved towards major maintenance activities.

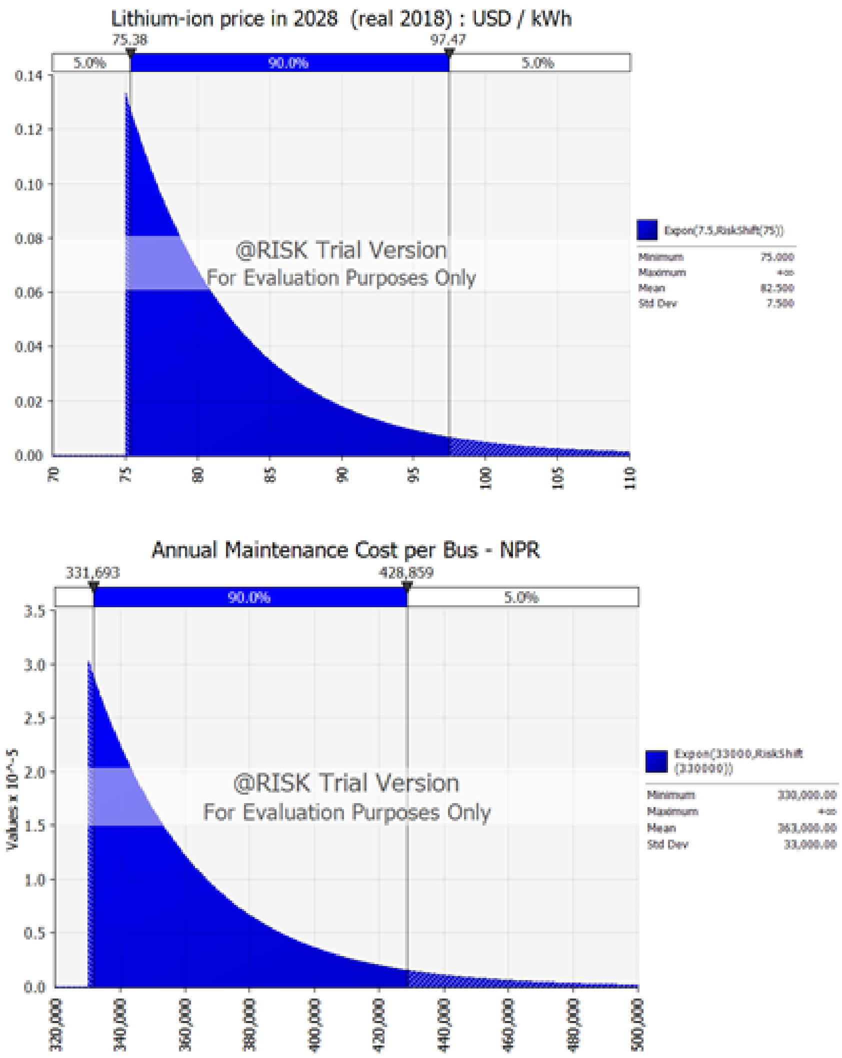
- Despite robust passenger growth, the revenue is mostly flat (in NPR terms) as maximum passenger load factor is achieved after the first three years of operations. Considering the strong free cash flow from operations, there is a strong commercial case to increase the fleet size on the selected routes.
- At the end of normal operational life of 15 years, the projected cash balance is adequate to extend the operational life for another five years. The year 15 cash balance of NPR 89,000,000 (USD 454,000) is adequate to cover the second battery replacement expense as well as the shortfall in passenger fare revenue over operational years 16 to 20.

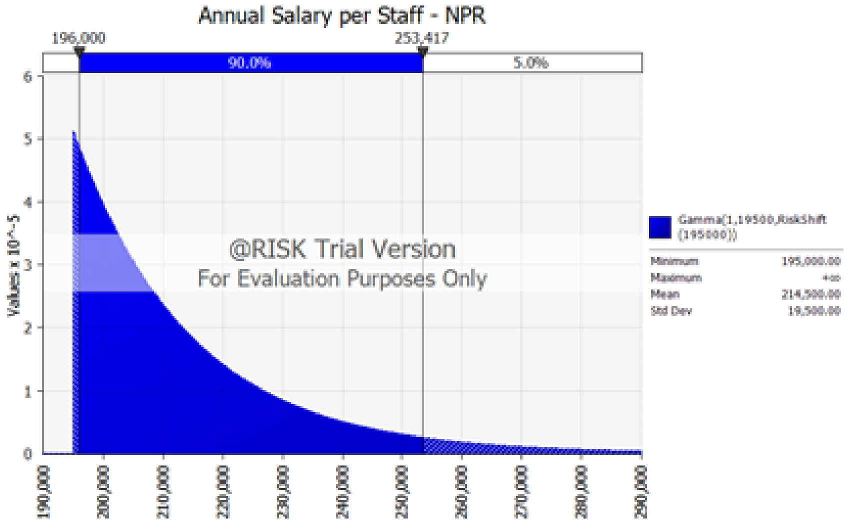
B. Adequacy of Passenger Fare Revenue

To assess the adequacy of passenger fare revenue, a Monte Carlo simulation has been conducted to quantify the likelihood of a scenario whereby passenger revenue is less than the operating expenses over the electric bus operating life of 15 years.

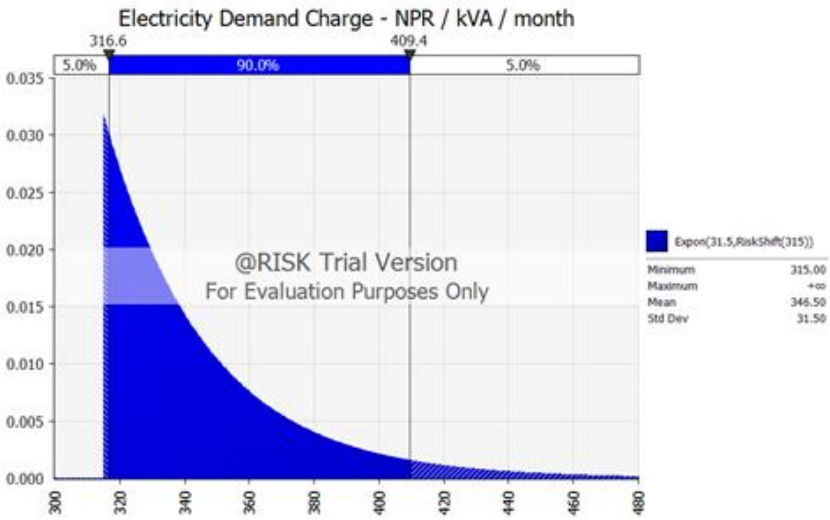
Each of the cost drivers are modeled using an exponential distribution function, with the minimum value of the distribution function being the base case value and the standard deviation being 10% of the base case value. The statistical distribution function for the key cost parameters are shown in the figure C1.11 below.

Figure C1.11 : Key Cost Parameters

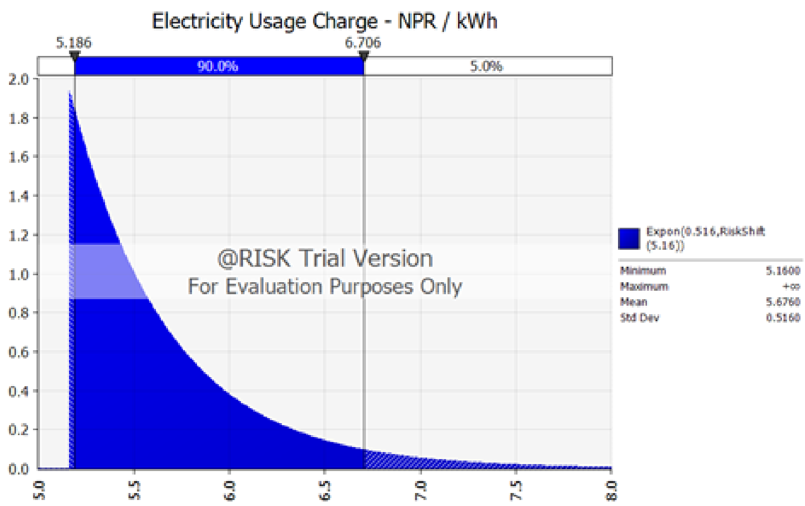




Annual Salary per Staff - NPR
196,000
253,417
90.0%
5.0%
Values x 10^-5
@RISK Trial Version
For Evaluation Purposes Only
Gamma(1,19500,RiskShift(195000))
Minimum 195,000.00
Maximum +∞
Mean 214,500.00
Std Dev 19,500.00

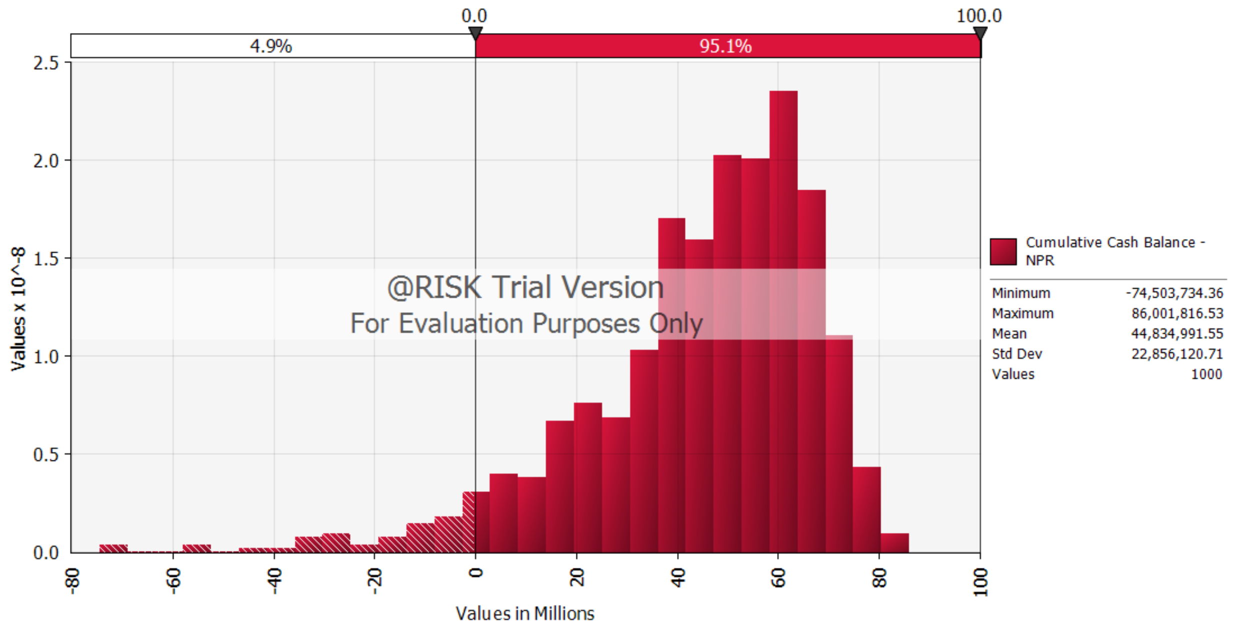


Electricity Demand Charge - NPR / kVA / month
316.6
409.4
5.0%
90.0%
5.0%
@RISK Trial Version
For Evaluation Purposes Only
Expon(31.5,RiskShift(315))
Minimum 315.00
Maximum +∞
Mean 346.50
Std Dev 31.50



Electricity Usage Charge - NPR / kWh
5.186
6.706
90.0%
5.0%
@RISK Trial Version
For Evaluation Purposes Only
Expon(0.516,RiskShift(5.16))
Minimum 5.1600
Maximum +∞
Mean 5.6760
Std Dev 0.5160

Figure C1.12 : Results of Monte Carlo Simulation



A simulation of about 1,000 scenarios was performed using cost parameters that were randomly generated from the respective distribution function. For each of the scenarios, the financial sustainability of operating the electric bus fleet is assessed by comparing the passenger fare revenue and the operating costs over the operating period of 15 years. A positive value indicates that the cumulative revenue is greater than the cumulative costs, whereas a negative value indicates the cumulative revenue is lower than the cumulative costs. Figure C1.12 shows the results of the Monte Carlo simulation

The results of the simulation show that risk of costs exceeding the passenger revenue is less than 5% and that there is greater than a 95% probability that the electric bus fleet will result in profitable operations.

C. Total Cost of Ownership (TCO)

Total Cost of Ownership ("TCO") is a methodology that analyzes the cost of a solution over its entire lifecycle. It is considered a major factor in determining value for money in purchase decisions. In the context of the procurement of the electric bus fleet, TCO is an important concept because it enables the comparison of diverse solutions within a standardized framework.

The calculation of TCO includes the accumulated costs of acquiring, operating, and maintaining the electric bus fleet, less any residual value upon disposal. There is no one-size-fits-all approach and the TCO calculation will vary on a case-by-case basis. When calculating TCO, the time value of money must be considered to determine the current worth of the money when payment is required in the future.

Total Cost of Ownership formula applied in the case of the electric bus fleet is shown below.

$$TCO = \frac{\sum_{n=1}^{n=15} PV(MEn, DR) + PV(EEn, DR) + PV(SGAn, DR) + PV(BRn, DR) + PV(REGn, DR)}{\sum_{n=1}^{n=15} ADn}$$

Where n is the year of operation, PV is the Present Value, DR is the Discount Rate used to estimate the present value, ME is Maintenance Expenses, EE is Electricity Expenses, SGA is Salaries and General Expenses, BR is Battery Replacement Expenses, REG is Vehicle registration expenses, AD is the Annual Distance traveled by the E-Bus Fleet.

Since the upfront capital cost for deploying the electric bus fleet is provided by the Government of Nepal, the capital cost has been excluded from the TCO analysis. A Discount Rate (DR) of 10% is assumed in the TCO calculation, which is a long-term fixed deposit rate offered by the banks in Nepal. Table C1.13 summarizes the TCO for the base case scenario.

Observations from the Total Cost of Ownership is summarized below:

- TCO from operating the electric bus fleet is NPR 13.98 per km, where the present value of the passenger fare revenue is NPR 16.10 per km. Since publicly-owned bus systems in most cities generally recover only about 70 to 90 percent of operating costs, a strong commercial case exists that supports the transition from diesel to electric buses.
- Staff-related expenses is the largest component of the Total Cost of Ownership. In this scenario, salaries account for 33% of the total costs over the operating life of the electric bus fleet. The adoption of smart payment technologies could help in moderating the high staff-related expenses in the future.
- Due to rapid decreases in the price forecasted for Li-ion battery packs, the periodic battery replacement cost accounts for only 13% of the TCO.
- Unlike diesel prices which are volatile, EV buses are poised to take advantage of low renewable electricity prices which are substantially lower than today's electricity prices. There is a high probability that the electricity expenses which is forecasted to account for 24% of the TCO is significantly lower in the future.

Table C1.13: Total Cost of Ownership (TCO) of Electric Bus

Component	Unit	Value	% Total
Present value of maintenance expenses (ME)	NPR USD	73,217,302 476,824	28%
Present value of electricity expenses (EE)	NPR USD	63,146,577 434,203	24%
Present value of salary expenses (SGA)	NPR USD	86,529,539 563,519	33%
Present value of battery replacement expenses (BR)	NPR USD	34,773,750 208,490	13%
Present value of registration expenses (VR)	NPR USD	2,440,577 15,894	1%
Total	**NPR** **USD**	**260,107,745** **1,698,929**	**100%**
Cumulative distance traveled by e-bus fleet	km	18,606,000	-
Total cost of ownership (TCO)	**NPR per km**	**13.98**	
	USD per km	**0.09**	

5. Conclusion

Based on the information available, GGGI assesses that electric buses can perform as reliably as the rest of the fleet of diesel buses, but will require thorough planning, training, and resources to ensure that Sajha Yatavat derives the full benefits of their use.

Electric buses offer a range of environmental and potential economic benefits. Environmental benefits will increase over time, as the source of energy used to charge buses gets cleaner. It is also expected that the economic benefits of using e-buses will improve over time as the cost of diesel increases, relative to the cost of electricity, which will decrease with improvements in generation and transmission.

Given the analysis above, the following key financial observations should be noted:

- Cashflow from the bus fleet will be positive across the entire 15-year operating life, with adequate cover to extend operating life to 20 years.
- Adequacy of passenger fare revenues to cover operating costs over the 15-year operating life has been evaluated using a robust probability-based method. The likelihood of sustainable financial operations is estimated to be greater than 95%.
- Unlike the diesel bus fleet, passenger fares collected over the 15-year operating life exceed the Total Cost of Ownership (TCO) of the electric bus fleet.

As a result, GGGI concludes that it is financially feasible to introduce e-buses in the Sajha Yatayat bus fleet.

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ANNEXES

Annex I

Calculation of Weighted Average Electricity Tariff for Scenario A and Scenario B.

1. Wet Season Tariff for 11kV connection				
	Number of Months	8		
	Wet Season Weightage	67%		
	Demand Charge (kVA/month)	**Peak (17.00-23.00)**	**Off-peak (23.00-5.00)**	**Normal time (5.00-17.00)**
Charging hours: Scenario A		1	6	1
% of total charging time		13%	75%	13%
Charging hours: Scenario B		2	6	2.5
% of total charging time		19%	57%	24%
Trolley buses	230	7.15	4.20	5.60
2. **Dry Season Tariff for 11kV connection**				
	Number of Months	4		
	Dry Season Weightage	33%		

	Demand Charge (kVA/month)	Peak (17.00-23.00)	Off-peak (23.00-5.00)
Charging hours: Scenario A		2	6
% of total charging time		25%	75%
Charging hours: Scenario B		4.5	6
% of total charging time		43%	57%
Trolley buses	230	7.15	5.60
Weighted average annual tariff for Scenario A	5.16		
Weighted average annual tariff for Scenario B	5.48		

Annex II

Complete Results of Financial Comparison Between Scenario A and Scenario B.

Description	Mid-sized Bus		Large-sized Bus		Unit
	Scenario-A	Scenario-B	Scenario-A	Scenario-B	
Bus					
Number of buses in fleet	20	20	20	20	Units
Size of bus	8 to 9.5		11 to 12		m
Unit cost	144.8	130.7	158.4	133.8	'000 USD
	15.9	14.4	17.4	14.7	million NPR
Fleet cost	2.9	2.6	3.2	2.7	'000 USD
	318.5	287.6	348.5	294.3	million NPR
Energy Requirement & Battery Sizing					
Required battery bank size	170	90	280	140	kWh
Energy required by bus per day (including 1 extra trip for reliability)	129	129	223	223	kWh
Percentage of total required energy supplied by terminal station chargers	0%	50%	0%	50%	
Depot Chargers					
Required charging capacity	20	20	40	40	kW
Unit cost	6,238	6,238	17,153	17,153	USD/
	0.7	0.7	1.9	1.9	million NPR
Units	20	20	20	20	
Total cost	124.8	124.8	343.1	343.1	'000 USD
	13.7	13.7	37.7	37.7	million NPR
Terminal Station Chargers					
Required charging capacity	-	40	-	60	kW
Unit cost	-	17,153	-	22,092	USD/
Units	-	2	-	2	
Total cost	-	34.4	-	44.1	'000 USD
		3.7		4.8	million NPR
Infrastructure Upgrade Expenditure					
Depot upgrade	48.8	48.8	62.3	62.8	'000 USD
	5.4	5.4	6.9	6.9	million NPR
Terminal station chargers	-	33.6	-	33.6	'000 USD
		3.7		3.7	million NPR
Annual Electricity Expenditure					
Annual energy charge for entire fleet	50.9	54.1	107.5	114.3	'000 USD
	5.6	5.9	11.8	12.6	million NPR
Annual demand charge for entire fleet	11.2	11.2	19.3	19.3	'000 USD
	1.2	1.2	2.1	2.1	million NPR
Total (energy+demand) for entire fleet	62.1	65.3	126.8	133.6	'000 USD
	6.8	7.2	13.9	14.7	million NPR
Annual electricity expenditure per bus	3,105	3,266	6,341	6,681	USD/bus
	0.3	0.4	0.7	0.7	million NPR

Annex III

Daily deficit energy to be supplied by terminal chargers = % of required battery bank size * total energy required per vehicle.

Rated capacity of terminal chargers = accepted coefficient for overnight charging * (daily deficit energy to be supplied by terminal chargers/available charging time per day).

Selected Scenario	Scenario A	Scenario B	Units
Selected Route	Lagankhel-Budhanilkantha	Lagankhel-Budhanilkantha	
Capacity of Terminal Stations Chargers for Large-Sized Buses			
Required size of TS chargers (Max)	-	52.4	kW
Select TS charger	**40kW**	**60kW**	
Rated capacity of selected TS charger	0	60	kW
Cost selected TS chargers	-	22,092	USD
		2.4	million NPR
Total number of TS chargers	**2**	**2**	units
Total cost of TS chargers	-	44,183	USD
		4.9	million NPR
Capacity of Terminal Stations Chargers for Mid-Sized Buses			
Required size of TS chargers (Max)	-	30.2	kW
Select TS charger	**10kW**	**40kW**	
Rated capacity of selected TS charger	0	40	kW
Cost of selected TS chargers	-	17,153	USD
		1.9	million NPR
Total number of TS chargers	**2**	**2**	units
Total cost of TS ch1.9argers	-	34,307	USD
		3.8	million NPR

Annex IV

Estimated Electrical & Related Infrastructure Cost for Sajha Yatayat Depot Upgrade for 20 mid-sized bus units.

S. N	Item	Unit	Qty	Rate ('000 NPR)	Amount (million NPR)	Amount (USD)
	Transformer					
1	630 kVA Delta/Y transformer	pcs	1	1,819	1.82	16,539
2	Accessories required for transformer installation	set	1	273	0.27	2,481
	New Electrical Control Room					-
1	Civil works (3X3 m)	LS	1	300	0.30	2,727
2	Main distribution panel	pcs	1	15	0.02	136
3	MCCB 4P, 3 kA	pcs	1	720	0.72	6,549
4	TOD meter	pcs	1	318	0.32	2,891

5	Surge protection device	pcs	1	25	0.03	227
6	Earthing system	LS	1	150	0.15	1,364
						-
	Distribution					-
1	250 Sq.mm 4-core copper AC wire	m	12 5	6	0.69	6,250
2	750 mm cable tray and mounting accessories	m	12 5	3	0.38	3,409
						-
	Charging Ports					-
1	Rain and sun protective covering set	set	20	10	0.20	1,818
2	MCCB 4P, kA	pcs	20	6	0.11	1,000
3	Metal Control Box	pcs	20	4	0.07	636
						-
	Lighting Fixtures					-
1	Wall mounted IP65 20W Flood Light	pcs	10	3	0.03	273
	Sub-Total (NPR)				**5.09**	**46,301**
	Technician and transportation charges					-
1	Consultancy fee	LS	1	153	0.15	1,389
2	Installation fee	LS	1	75	0.08	682
3	Transportation and other charges	LS	1	50	0.05	455
						-
	Grand Total (NPR)				5,370,878	**48,826**

Annex V

Estimated Capital & Operational Cost of Single Terminal Station (For mid-sized as well as large-sized buses)

		Amount ('000 NPR)	Amount (USD)
	CAPEX		
1	Transformer-100kVA	622	5,650
2	Mounting pole set	93	848
3	T.O.D Meter	35	318
4	Distribution and protection unit	100	909
5	Perimeter fencing	1,000	9,091
	Total CAPEX	**1,849**	**16,816**
	OPEX		
1	Land rent		-
3	O&M	420	3,818
	Total Annual OPEX	**420**	**3,818**

Annex VI

Estimated Cost of Buses on the Lagankhel-Budhanilkantha and Swayambhu-Suryabinayak Routes

Lagankhel-Budhanilkantha Route

The reference model for the cost of a large bus is a TATA bus with 180 kWh battery, which is priced at USD 140,800 in a bid made in India, assuming the additional battery capacity can be purchased (or the surplus of battery capacity can be discounted) at the unit cost of USD 176 per kWh, the

- cost of a large bus = 140,800 + 60 x 176 = USD 151,400 (rounded up to the nearest hundred).
- cost of a mid-sized bus, the reference is a TATA bus with 120 kWh which is priced at USD 136,000 in a bid made in India. Thus,
- cost of a mid-sized bus = 136,000 + 20 x 176 = USD 139,600 (rounded up to the nearest hundred).

Swayambhu-Suryabinayak Route

Using the same reference models and assumption as above, the

- cost of a large bus = 140,800 + 120 x 176 = USD 162,000 (rounded up to the nearest hundred);
- cost of a mid-sized bus = 136,000 + 50 x 176 = USD 144,800.

GGGI