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Solar Powered Charging Station for Electric Vehicles in Kathmandu Valley-A Case Study of Sundar Yatayat

by

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A THESIS

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled "Solar Powered Charging Station for Electric Vehicles in Kathmandu Valley-A Case Study of Sundar Yatayat" submitted by Bikash Kumar Pal in partial fulfillment of the requirements for the degree of Master of Science in Engineering in Energy System Planning and Management.

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ABSTRACT

Nepal is shifting towards clean mobility with increasing reliance on electric vehicles. There will be huge pressure on NEA to meet the future electricity demand, so alternatives like renewable energy should be opted for charging. Using solar energy is viable in Nepal since the technology is already advanced and economically cheap. In this paper, a feasibility study is done about the techno-financial aspect of installing the solar PV system for charging electric vehicles. Public electric vehicles operated by company, Sundar Yatayat Pvt. Ltd. are taken into consideration for data collection and feasibility test. The company operates four vehicles currently, two buses of length 10.5m and 8.5m and two vans of length 6m which runs in ring-road of Kathmandu valley. A survey is conducted regarding the types of vehicles operated, charging pattern of the vehicles, number of units consumed to charge the vehicles, charging location, annual income as well as its operation and maintenance costs, internal rate of return (IRR) and payback period are used for the feasibility of the use of solar PV energy for charging the vehicles. There are four vehicles in operation at present, so the comparison is done between charging the vehicles through various percentage share of solar PV system to the current charging units i.e., 100%, 80% and 50% share of solar PV system. In all three cases, the Levelized Cost of electricity is calculated and the vehicle operating routes are studied inside Kathmandu valley. Finally, the optimal and feasible solution for solar-based charging and the optimal route for profit maximization is proposed in this paper. Best feasible solution is found if the vehicles are charged through 80% share of solar PV and other through grid with discounted payback period of 5.03 years and LCOE of Rs. 5.72 per kWh.

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LIST OF ABBREVIATIONS

A	Ampere
Ah	Ampere-Hour
DC	Direct Current
EV	Electric Vehicle
IPL	Intelligent Parking Lot
IRR	Internal Rate of return
km/h	Kilometer per Hour
kW	Kilo-Watt
kWh	Kilo-Watt Hour
LCOE	Levelized Cost of Electricity
LED	Light Emitting Diode
MG	Microgrid
mm	Millimeter
Nm	Newton-Meter
PSO	Particle Swarm Optimization
PV	Photo Voltaic
rpm	Revolutions per Minute
T	Tons
WACC	Weighted Average Cost of Capital
Wh	Watt-Hour

CHAPTER ONE: INTRODUCTION

1.1 Background

Environmental issues have become the point of major concern in the past few decades. The main reason for this environmental issue is the change in climatic conditions due to global warming. Nearly one-fourth of the total greenhouse emission is contributed by the transportation sector. Conventional transportation is majorly powered by internal combustion engines using fossil fuels. As we know the availability of fossil fuels is finite, renewable energy is only the best solution for this. Nepal has greater potential for solar energy but we are heavily dependent on imported fossil fuels. A major portion of the imported fossil fuel is utilized in the transportation sector.

The number of vehicles has been reportedly increasing by 14% annually since 1990 resulted in urbanization and improvement in the living standard of people. Road transport is dominant in Nepal and the major percent of the vehicles is private. The registered number of public vehicles has decreased to 3% from 11% within 25 years from 1990. This significant increase in vehicles is the major source for the emission of greenhouse gases. Recently, Kathmandu has topped the list of the major polluted city in South Asia. The pollution level recorded is much greater than the standard limit set by the World Health Organization. Since 1975 the stock had expanded by right around 70 folds. The period between 1987-1997 is viewed as the first run-through when there was more interest in Liquefied Petroleum Gas (LPG). It is because LPG was presented as another lamp fuel, power, and so forth in the metropolitan and semiurban region. Because of the weight of the high populace Nepal Oil Corporation (NOC) is being not able to supply appropriately. Even though it has a capacity limit of 70309 kiloliters (KL) it is experiencing the issue of deficiency. NOC keeps up an extremely low load of oil-based goods, uplifting dangers of lack whenever supply is upset. The current stock can't keep going for over three days of interest in the capital. Likewise, there is a requirement for a decrease in fossil fuel byproducts. Force electric vehicles utilizing housetop solar panels and charging stations are mainstream as of late. In Europe, gas vehicles will be prohibited in 2050. Many significant vehicle organizations have come out with electric vehicles as of late. Some new, more modest organizations have additionally evolved electric vehicles. The scope of electric vehicles is not as much as that of gas-fueled vehicles. Enhancement's ineffectiveness should be made to expand the reach.

The need for electric vehicles has been increasing for the past few decades due to their technical, economic, and most importantly environmental benefits. Also, the technology in electric vehicles is improving in the field of production as well as reducing per-unit cost for its operation. The electric vehicle consists of four parts traction source, energy storage system, battery management system, and charging system. The electric vehicle comes with various benefits. It includes a reduction in greenhouse gases emission, reduction in air and noise pollution, reduction in fossil fuel consumption, increment in road safety as well as creates employment opportunities. Like for example, electric buses generate lesser noise than diesel busses at low speeds i.e., the intensity of the noise produced gets reduced by almost 20% which will eventually improve the health. Due to the absence of mechanical traction parts in electric buses, the maintenance costs of electric vehicles cost half as much as that of diesel vehicles. In hilly terrain the speed is low but to sustain in such terrain higher torque is required, such a high amount of torque at lower speed is provided by electric vehicles as well as easy start at lower temperatures. These conditions of electric vehicles are adaptable in Nepal due to favorable operating conditions. Thus, adopting electric vehicles will be beneficial for the context of Nepal. These are all favorable given Nepal's context.

1.2 Objectives

The general objective of this study is to analyze the technical as well as financial feasibility of installing solar PV system for charging public electric vehicles operated by Sundar Yatayat Pvt. Ltd.

Specific objectives of this study include:

- To compare financial feasibility between charging system between all four vehicles through various percentage share of solar PV system.
- To propose optimal route for the vehicles inside the valley.

1.3 Problem Statement

There are many projects and studies carried out in the past few decades related to charging scheme of electric vehicles, performance improvement of vehicles, reduction in per unit cost of the vehicles, etc. also, many researches have been carried out for developing solar based charging station operated mostly during daytime. But in this paper a study on the technical and economic study of installing solar PV system in the parking area of electric vehicles is carried out. The vehicles run at the day time, so during the day time battery could be charged through solar panels and it can be utilized to charge the electric vehicles during night time. The cost of electricity per unit from the PV system as well as payback period of the installed system is the prime concern in these types of projects. Increase in number of vehicles with limited charging units creates problem to charge the vehicles evenly. So, a feasible charging pattern also needs to be determined for smooth operation.

1.4 Project Scope

Electric vehicles run by a private company; Sundar Yatayat are taken for the study in this paper. First data are collected about the vehicles in operation, per unit electricity consumed, total energy required in a day, average income, operation and maintenance cost of the vehicles, specification of charging port, total area of parking space, etc. Three approaches are taken in this study, in the first approach 100% share of solar PV system for charging vehicle is taken and estimated like the number of panels, battery and other accessories as well as its costs. Based on the investment and electric power load and demand calculation the payback period and levelized cost of electricity (LCOE) is determined. Same process is followed for another approach i.e., for vehicles charging system using 80% share and 50% share of solar PV system. For financial feasibility in both cases, payback period and LCOE is compared and the best feasible solution is proposed. Also, various routes starting from Gongabu Bus Station is taken the study to determine the optimal route for the two 6m electric vans.

CHAPTER TWO: LITERATURE REVIEW

This section contains the evaluation of those articles who have described the electric vehicles and optimization using various methods.

Title	Author	Features	Comments
Techno-Economic Feasibility Study of Solar Based Vehicle Charging at TIA	Sunil Poudel, Jagan Nath Shrestha, Mahesh Chandra Luintel	The paper presented the study of charging station for electric taxis with the feasible IRR of 15.03% and payback period of 7.74 years.	Other parking spaces were available at TIA which can be taken for future study.
The dc microgrid for EV Charging	Locment and Sechilariu, 2015	Generally, dc type of microgrid includes major part of grid, ESU and PV. In this report, a system was proposed in which PV system was directly coupled with DC link without involving Static converter for reducing the complexity of control. Furthermore, this report proposed the rule-based algorithm based on real time which	Removal of micro grid system from the network may cause instability in the system.

Title	Author	Features	Comments
		would help in managing power flow through grid, PV and battery. In this report, grid was represented as backup which was lastly prioritized for charging EV.	
Daytime EV charging using PSO	Zhang et al., 2014	The main objective mentioned in this project was to maximize the utilization of PV system as well as to reduce the charging of EVs along with the operator electricity cost. This project utilized the PSO algorithm for meeting its objective. Similarly, various strategies for charging EVs in daytime were presented in the project report.	The method proposed in this paper failed to manage the wastage of energy when the energy from the PV system exceeded the need of electric vehicles and grid.

Title	Author	Features	Comments
Fuzzy logic based smart charging	Ma and Mohammed, 2012	This project represented the concept of fuzzy logic that could be implemented for smart charging system for vehicles parked in parking lots. In the report real time management of energy was discussed through the usage of forecasting models. In order to generate accurate production, author referred to hourly data that has been collected over 15 years of time. Report further discusses about the charging priorities along with the charging rate. It gives detail explanation about the charging requirements of EV such as SOC and stay	The fuzzy logic controller proposed in the paper is able to solve not all but some problems due to nonlinearity in the system.

Title	Author	Features	Comments
		time	
EVLS based EV charging analysis with different charging modes	Fattori et al., 2014	The feasibility study of charging electric vehicles by grid connected solar PV system was studied by building an EVLS, Electric vehicle Learning Static model. Various charging scenarios like smart, uncontrolled and V2G were considered for the analysis. In the paper, the authors concluded that the PV system supplied small portion of the energy demand during the uncontrolled charging scheme.	The effects of electric vehicles were studied using a linear optimization model, EVLS.
MG based EV charging under IPL	Honarmand et al., 2014	For a micro-grid system consisting of an intelligent parking lot (IPL), wind and	Not only micro grid but the main grid also contributed on the operation of

Title	Author	Features	Comments
		micro turbine, PV system and fuel cell, an energy management system was proposed in this paper. The IPL helped in the prevention of unwanted power mismatch and acted as a facilitator between micro grid operators and owners of electric vehicles.	V2G and G2V of electric vehicles charging.
Stochastic type EV charging model under IPL	Honarmand et al., 2015	An intelligent parking lot, IPL acted as the bridge between the PV system and the distributed generators. Various charging and discharging models like stochastic scheduling were proposed in this paper to reduce the power mismatch between EV and	Micro turbines and electric vehicles were the two energy storage systems used.

Title	**Author**	**Features**	**Comments**
		distributed generators.	
Realistic controlled charging	Rautiainen, 2015	The charging service provider and the distribution service operator were considered separate entities in this paper which was simpler than other studies such that the charging of electric vehicles does not affect the distribution service operator. The control of the operation will be simpler because the network and charging of the electric vehicles are handled by charging service provider.	In comparison to other charging and controlling schemes, the charging cost was reduced but the losses were increased.
Technical Economic Analysis of Photovoltaic-Powered Electric Vehicle Charging	Phap Vu Minh, Sang Le Quang and Manh-Hai Pham	Optimal configuration of EV charging stations powered by PV system is studied and analyzed under technical and	The paper presented the study of hybrid system of solar PV and grid for charging the electric vehicles.

Title	Author	Features	Comments
Stations under Different Solar Irradiation Conditions in Vietnam		economical conditions. The study was conducted in Vietnam under varying solar irradiations.	

In the above literature survey various studies were reviewed like feasibility of solar based electric vehicle charging system, optimization of tariff rates by using PSO algorithm, minimizing losses in the charging system by implementation of solar PV system, stochastic charging and discharging of the electric vehicles in the intelligent parking lot. Also, various studies carried out on the implementation of renewable energy sources for charging EVs, comparison between PV based charging and grid-based charging with the reduced charging costs, various optimization techniques like PSO-based optimization, linear optimization, fuzzy logic-based optimization were reviewed in this literature. Above studies motivated towards the feasibility study of solar PV-based electric vehicle charging for the public electric vehicles operated by Sundar Yatayat Pvt. Ltd. operating in Kathmandu valley. The details of vehicles and charging system, overall costs, operation route, etc. were taken into account. For the financial feasibility IRR and payback period were taken into account following the literatures reviewed during this study. The IRR calculated was compared with the discount rate and financial comparison was done for charging two of the vehicles and all four vehicles. The obtained result was compared with the literature for validation. As an additional feature of the study, the operation routes for two public vans were optimized using linear optimization.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Methodology

The methodologies followed for this study is shown in the picture below. The first step is identification of problem i.e., studying the existing system where the vehicles are charged through conventional grid system. Various literatures are studied relating to implementation of PV system for vehicle charging. Then all the necessary data are collected regarding vehicles, charging systems, overall costs, operating routes, etc. and then sizing of the solar PV system with various percentage share for charging the vehicles along with their financial analysis. The sizing of the solar PV system is done for three approaches. First is 100% share through the solar PV system, second is hybrid system with 80% share of solar PV system and third is also hybrid system with share of 50% solar PV system. While sizing the solar PV system for charging electric vehicles, various technical factors like number of solar modules, battery bank, inverters, charge controllers and mounting system is calculated. Along with the technical calculations, investment for all the three approaches are determined. Then financial feasibility is analyzed for all the three approaches. If the study is found feasible based on the IRR and payback period, and then financial comparison is done between three approaches. If the study is not found feasible sizing of the charging system is done again until feasible result is obtained. And finally concluded by optimization of the vehicle routes are done using MS Excel with necessary recommendations.

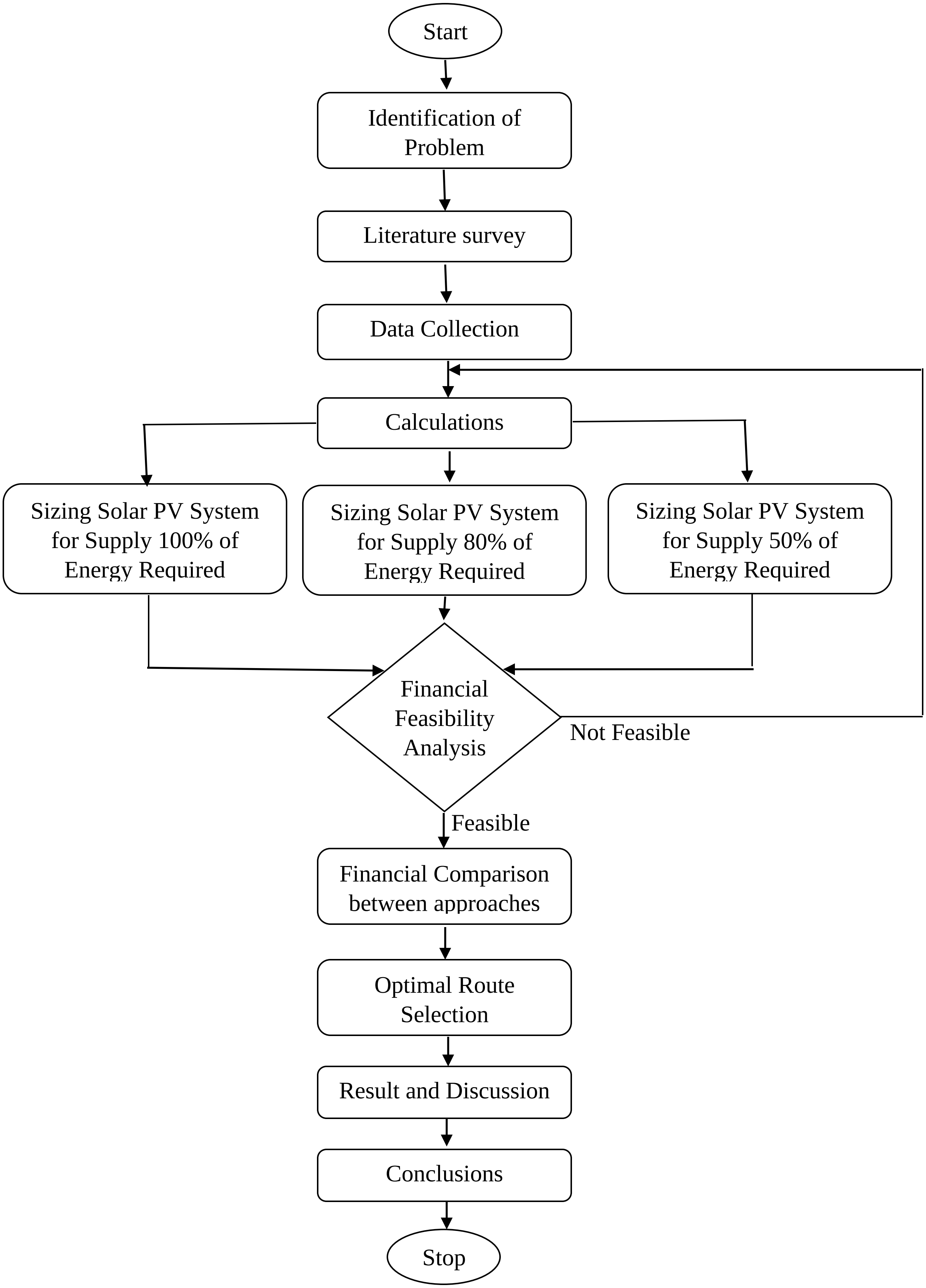

Figure 1: Methodology of study

3.2 Terminologies and Data Collection from Current Vehicles and Charging Station

3.2.1 Current Vehicles

Currently, there are only four vehicles in operation by the company. Two are city buses of length 10.5m and 8.5m and two electric vans of length 6m. The vehicles are manufactured by the Chinese company BYD. The specification of the vehicles is taken from the technical specification report of the company.

- **LSK6105GEV1 (Electric city bus 10.5 m)**

  This bus run in ring road of Kathmandu Valley starting from New Buspark. Daily it takes 6 trips of the ring road. Some of the specification of the 10.5m electric city bus is given in the table below. The specification is mostly focused on electrical part rather than mechanical part as per the requirement of the study. The specifications of the vehicle are listed in table 11.

Figure 2: Electric city bus of length 10.5m

- **LSK6850GEV1 (Electric city bus 8.5 m)**

This bus run in ring road of Kathmandu Valley starting from New Buspark. Daily it takes 6 trips of the ring road. Some of the specification of the 8.5m electric city bus is given in the table below. The specification is mostly focused on electrical part rather than mechanical part as per the requirement of the study. The specifications of the vehicle are listed in table 12.

Figure 3: Electric city bus of length 8.5m

- **JAX6660GBEV (Electric van 6m)**

This van was bought to operate on longer route from Kathmandu to Narayanghat. But due to lack of charging station in the route at present, it is run in ring road of Kathmandu valley. It is also run for 6 trips of the ring road same as the other electric buses. The specification of the electric van run by the company is presented in the table below. Since the paper deals with the electrical aspect of the vehicle so the specification is focused on the electric side rather than mechanical side of the vehicle. The specifications of the vehicle are listed in table 13.

Figure 4: Electric van of length 6m

3.2.2 Charging Location

Sundar Yatayat Pvt. Ltd. has been operating charging station for electric vehicles in its own charging location situated at Dhumbarahi-4, Kathmandu. As per the company, the total area of the current charging location is nearly 3.5 ropani which is around 1780 square meter. In total there are three charging units installed in the location, out of which two are currently in operation and one of them is under maintenance. The two charging units having a capacity of 30 kW each are in operation for both public as well as its own vehicles. About 8-10 public 15seater vans, 3-4 electric vans, private cars and buses has been charging per day. At present, 43.5 kVA power is used to operate two 30 kW charging units. The aerial view of the current charging location is shown in the picture below which is extracted from google earth.

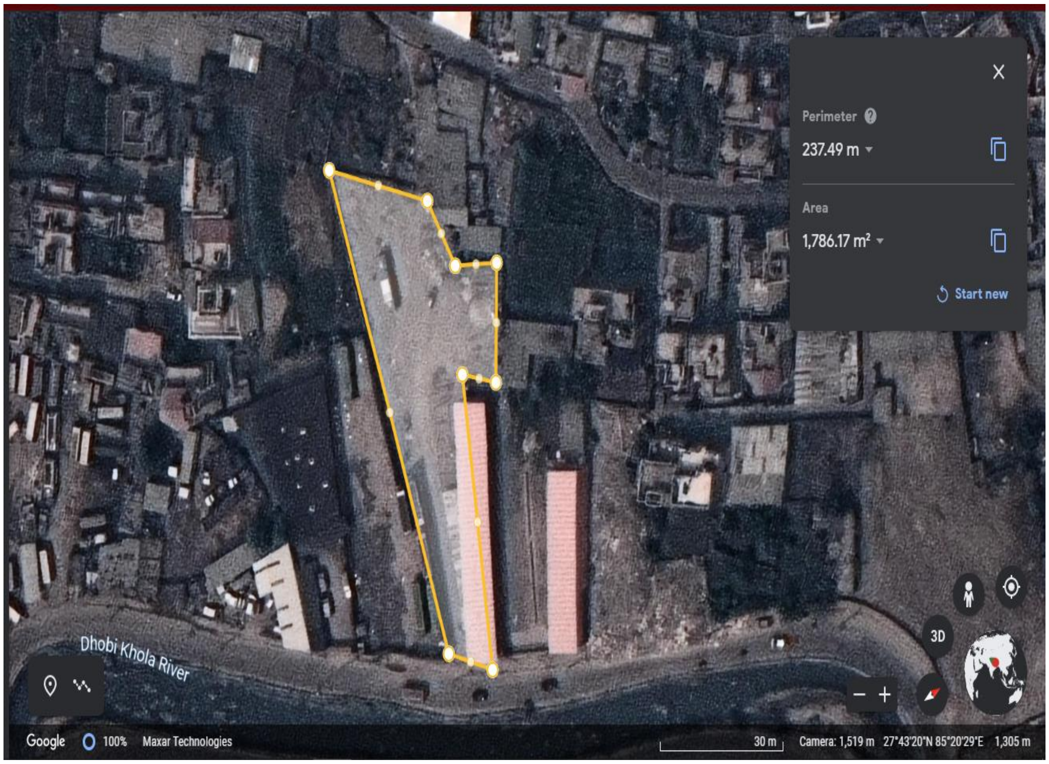

Figure 5: Aerial view of current charging location

3.2.3 Charging unit

The vehicles are currently charged currently by a DC charger of 30KW operated at rated input voltage of 380 V three phase AC and rated output voltage of 750V, DC. The charging units follows GB/T charging standard, which is a standard for AC and DC fast charging used in China. Normally, the charging system for electric vehicles are rated at 30, 60, 90, 120 and 180 kW based on the ratings of the vehicles. Higher the rating of charger, faster the vehicle charges. But the condition is that both the charging unit and vehicle should have same rate of charging current. Currently, the charging rate of the vehicles is 0.5C, which is not a fast charger. Each vehicle takes 5 hours for full charge from 20% to 100% daily. The specification of currently used 30 kW DC charger is listed in the table 14.

3.2.4 Income and Operation & Maintenance

After almost two and half year of operating electric buses in Kathmandu ring road many kinds of difficulty have occurred and many minor problems have faced. But comparing to cost expenditure of diesel vehicles, electric buses expenditure is found low. The per day income and expenditure of 10.5m, 8.5m electric buses and 6m electric van is presented in this section of the report.

- **Income**

For 10.5m bus

- Total distance travelled = 200 km
- Power unit consumed per km = 0.87
- According to government per unit cost is Rs.5.6
- Cost for per km = 0.87*5.6=Rs.4.87
- Cost of power consumed for 200 km= Rs.4.87*200 =Rs.974
- Average income for 140 km =Rs.8,500
- Average income per km = Rs.8,500/200=Rs.42.50
- Profit per km= Rs.42.50-4.87= Rs.37.63

For 8.5m bus

- Total distance travelled = 170 km
- Power unit consumed per km =0.74
- According to government per unit cost is Rs.5.6
- Cost for per unit= 0.74*5.6=Rs.4.14
- Cost of power consumed for 170 km= Rs.4.14*170 =Rs.703.80
- Average income for 170 km =Rs.7,500
- Average income per km = Rs.7,500/170=Rs.44.11
- Profit per km= Rs.44.11-4.14= Rs.39.97

For 6m electric van

- Total distance travelled = 200 km
- Power unit consumed per km = 0.43
- According to government per unit cost is Rs.5.6
- Cost for per km = 0.43*5.6=Rs.2.41
- Cost of power consumed for 200 km= Rs.2.41*200 =Rs.481.6
- Average income for 140 km =Rs.3,000

- Average income per km = Rs.3,000/200=Rs.15
- Profit per km= Rs.15-2.41= Rs.12.59

From the above data, we can determine the average cost of power consumed in a day and similarly in a day. Also, we can determine the average profit from the vehicles in a day and in a year.

- Average cost of total power consumed in a day= Rs.974+703.8+481.6 = Rs.2,160
- Average cost of total power consumed in a year=365*Rs.2160=Rs.7,88,400
- Average profit in a year=Rs.70,00,000

Also, daily five to six long routes vehicles get charged in the charging station on average. Each vehicle gets charged for nearly one hour and for this the company charges Rs. 500 on average for each vehicle. So, daily Rs.3,000 is earned from charging these vehicles which is Rs.10,80,000 annually.

- Average annual income = Rs.80,80,000

- **Operation & Maintenance cost**

The maintenance cost of electric vehicles is low as compared to that of diesel vehicles. Higher number of wear and tear in the diesel vehicles are seen due to complex driving components than that of electric vehicles. As per the report of the company, the electric buses costs around Rs. 50,000 each for the maintenance and the electric vans around Rs. 20,000 each year. The maintenance includes simple servicing of the parts of vehicle, lubrication of the traction system and also sometime change of damaged glasses.

3.3 Proposed Vehicles and Charging Stations

3.3.1 Proposed Vehicles

- BX9MRHDI (Electric Bus 9m)

Two BX9MRHDI buses of length 9m is proposed to be in operation for Kathmandu valley. The buses are manufactured by Causis which is an India based E-mobility private company. The process of bringing the buses to the valley for operation is still going on and is planned to operate in ring road same like other four vehicles currently in operation. Also, the charging location for these buses is planned to be in Dhumbarahi-4, Kathmandu. The technical specifications of the buses are listed in the table 16 below along with the picture of the bus.

Figure 6: Proposed electric bus of length 9m

3.3.2 Proposed charging location

Currently, there are three charging units, two 30 kW and one 60 kW installed at the charging station Dhumbarahi-4, Kathmandu. Only two 30 kW chargers are in operation but due to the increasing number of electric vehicles in Kathmandu, it is not possible to handle the charging demands with only two units. So, Sundar Yatayat Pvt. Ltd. is planning to install fast charging units having a capacity of 180 kW. For 180 kW charger to operate, NEA has already installed a transformer of 200 kVA. The company is constantly trying to expand the services all over Nepal in phase wise. In phase one, the company is planning to install charging station in Province-1 and Province-5. Each station will have one or two charging units as of now which is suitable for both small and heavy vehicles.

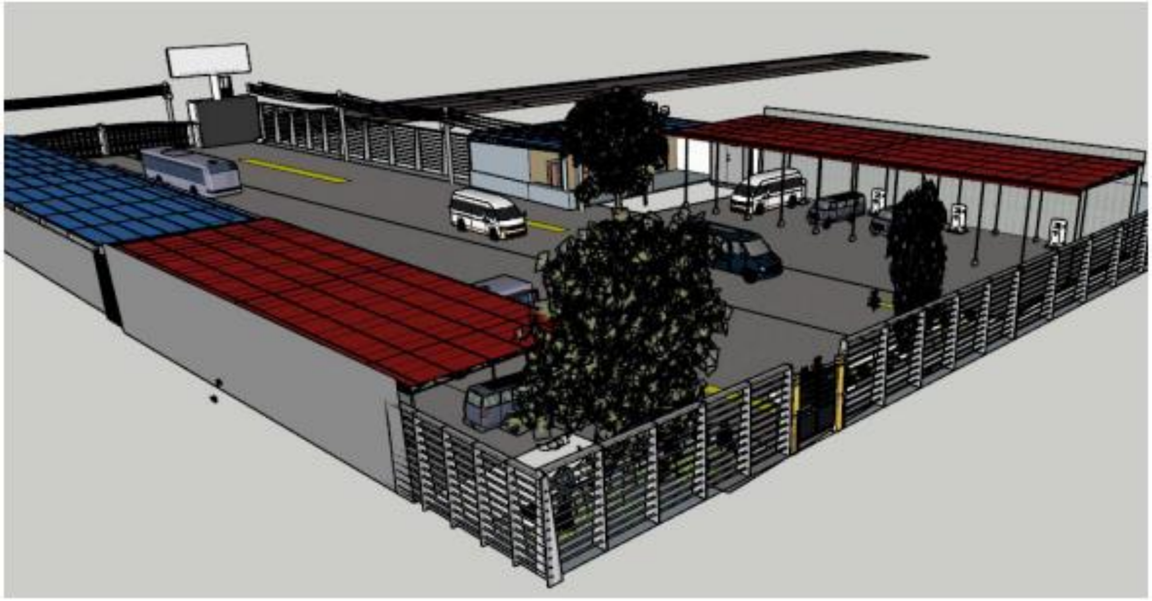

Figure 7: Proposed charging station model in Dhumbarahi-4, Kathmandu

- Province 1

In Province 1, after the survey of the road, Itahari is selected as the center point to install the charging unit so that most of the big cities of the province 1 would be benefitted. The distance from Itahari to the the major cities like Biratnagar, Dharan, Damak, Birtamode and Kakarvitta are 24.7 km, 16.8 km, 41.5 km, 75.8 km and 92.5 km. So, it is planned to install two 120 kW double gun DC charger in Itahari and one in Kakarvitta.

Table 1: Details of charging station in province 1

S.No.	Place	Charging Units	Quantity
1.	Itahari	120 kW/ 180 kW Double Gun (DC/GBT)	2
2.	Kakarvitta	120 kW/ 180 kW Double Gun (DC/GBT)	1

- Province 3

In this province, Mugling or Kurintar is taken as the center point to install the charging station. As per the study carried out by the company, for feasible operation of Kathmandu-Pokhara, Kathmandu-Narayanghat, Mugling or Kurintar is the best feasible location to install the charging station. But for Kathmandu-Butwal operation charging station needs to be installed at Narayanghat. And for vehicles operating in the eastern region from Kathmandu, charging station is planned to install in Sindhuli.

Table 2: Details of charging station in province 3

S.No.	Place	Charging Units	Quantity
1.	Mugling or Kurintar	120 kW/ 180 kW Double Gun (DC/GBT)	1
2.	Sindhuli or Khurkot	30 kW/ 60 kW Double Gun (DC/GBT)	1
3.	Narayanghat	120 kW/ 180 kW Double Gun (DC/GBT)	1

- Province-5

For this Province as per the study, two charging stations of 120 kW double gun DC charger is planned to be installed at Dumkibas and Butwal respectively. As Dumkibas is taken as the center point in this province for Kathmandu-Butwal operation.

Table 3: Details of charging station in province 5

S.No.	Place	Charging Units	Quantity
1.	Dumkibas	120 kW/ 180 kW Double Gun (DC/GBT)	1
2.	Butwal	120 kW/ 180 kW Double Gun (DC/GBT)	1

CHAPTER FOUR: DESIGN AND CALCULATIONS

4.1 Sizing of solar PV charging system

In this section of the report, sizing of the solar PV system is determined to charge the electric vehicles. The study location for the installation of solar panel is taken at the parking area of Sundar Yatayat, which is situated at Dhumbarahi-4, Kathmandu. Three approaches are taken for sizing the solar based vehicle charging system and the outcome is used to propose the best feasible approach. In the first approach, the solar based charging system is designed for supplying all the current energy required through solar PV system i.e., 100% solar size. Second approach is designing the solar based charging system to supply 80% of the energy required through solar PV and in third approach the solar based charging system is designed to supply 50% of energy required through solar PV.

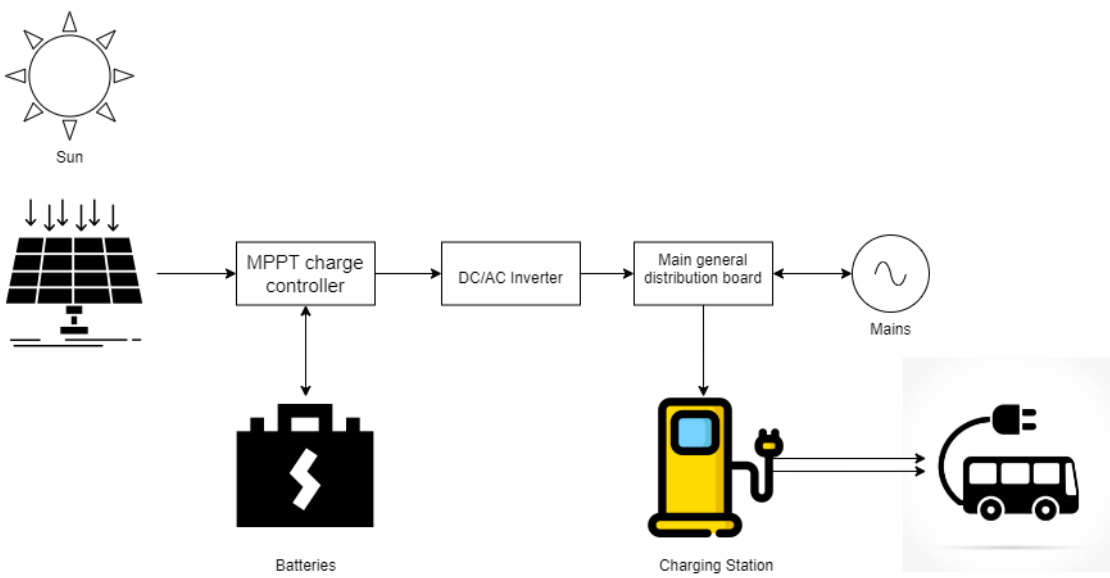

Figure 8: Solar based charging scheme

4.4.1 Module Selection

For the study, Himstar Topray Poly Crystalline solar panel is chosen because of its higher efficiency as compare to other modules available in Nepal. 300W poly crystalline modules are selected for the study. The current market price is Rs. 52 per Wp. So, the price of the 300 Wp solar module costs approximately Rs. 15600. The dimension of the module is 990*1956*40 mm. The electrical specifications of the module at standard test conditions (STC) i.e., air mass AM 1.5, irradiance 1000 W/m^2, cell temperature 25ºC is listed in the table 15:

4.4.2 Battery Selection

2V, 3000Ah AGM (Absorbed Glass Mat) battery is selected for the study. AGM battery is chosen for its advantage over the conventional lead acid battery in duty cycle of the battery as the AGM battery charges up to five times faster than the conventional lead acid battery. Also, the lifetime of AGM battery is higher than that of lead acid battery, is maintenance free, lighter in weight as well as provides good electrical reliability. At the same duty cycle, the AGM battery offers a depth of discharge (DOD) of 80% compared to that of the lead acid batteries which offers 50-60% depth of discharge. So, for this study AGM battery is used and the price of a single 2V, 3000Ah battery is around Rs.1,26,000.

4.4.3 Calculations for 100% energy from solar panel

In this part, the calculations for solar PV system are done for supplying all the energy required for electric vehicles charging through the solar modules. Currently, four vehicles are operated by Sundar Yatayat Pvt. Ltd. in Kathmandu valley which includes a 10.5 m, a 8.5 m bus and two 6 m electric vans. Each vehicle is operated in Ring Road of Kathmandu valley, which does six trips a day normally. The vehicles are charged from 20% until full for five hours a day. So, the average energy required will be 80% of the total energy required.

- Energy required to charge all four vehicles = (175.3+127.5+86+86) *0.8

  = 379.84 kWh

  ≅ 380 kWh

  = 380000 Wh

Where,

Energy required for the 10.5m bus = 175.3 kWh

Energy required for the 8.5m bus = 127.5 kWh

Energy required for the 6m van = 86 kWh

Taking minimum of 5 hours of sun-time in a day, we can calculate the number of modules required.

- Total watts required from the panel

$$= \frac{Energy\ Required\ in\ Watt-hours}{Average\ sun-hours\ per\ day*Temperature\ loss*Inverter\ Efficiency*Derating\ factor}$$

(Franklin, June 2019)

Where,

Energy required in watt-hours= 380000 Wh

Temperature loss= 0.88

Inverter efficiency= 0.96

Derating Factor= 0.722 (including losses due to shading, wiring, soiling, diodes and connections, etc.)

Average sun-hours per day= 5.549 hours (Anon., 2022)

For, determining the average sun-hours at the charging location, annual map Global Solar Atlas is followed. From the Global Solar Atlas the geographical coordinates of the charging location are found to be 27.721633°, 85.341362° (27°43'18", 085°20'29").

The annual solar map from data of the charging location from Global Solar Atlas is given in the table below:

Table 4: Solar Map data of current charging location

Specific photovoltaic power output	PVOUT_specific	1594.7	kWh/kWp
Direct normal irradiation	DNI	1540.8	kWh/m²
Global horizontal irradiation	GHI	1795.2	kWh/m²
Diffuse horizontal irradiation	DIF	790.3	kWh/m²
Global tilted irradiation at optimum angle	GTI_opta	1992.6	kWh/m²
Air temperature	TEMP	19.1	°C
Optimum tilt of PV modules	OPTA	29	°
Terrain elevation	ELE	1306	m

Table 5: Conversion factor (multiply top row by factor to obtain side column)
(A.Gueymard, March 2009)

	W/m^2	$kW\text{-}h(m^2.day)$	Sun hours/day	$kWh/(m^2.y)$	kWh/(kWp.y)
W/m^2	1	41.66666	41.66666	0.1140796	0.1521061
$kW\text{-}h(m^2.day)$	0.024	1	1	0.0027379	0.0036505
Sun hours/day	0.024	1	1	0.0027379	0.0036505
$kWh/(m^2.y)$	8.765813	365.2422	365.2422	1	1.333333
kWh/(kWp.y)	6.574360	273.9316	273.9316	0.75	1

The Global tilted irradiation at optimum angle is 1992.6 kWh/m^2 per year which is 5.549 kWh/m^2 per day. Using the above conversion factor, we can get average daily sun hours at the charging location i.e., 5.549 hours per day.

Then, Total watts required from the panel

$$= \frac{Energy\ Required\ in\ Watt-hours}{Average\ sun-hours\ per\ day*Temperature\ loss*Inverter\ Efficiency*Derating\ factor}$$

$$= \frac{380000}{5.549*0.88*0.96*0.722}$$

= 112273 W

The panels used for this study is 300 Wp, so the total number of solar panels required can be determined by dividing the above calculated size of PV system in watts by the watt of individual panel.

i.e., Total number of solar panels required = 112273/300

= 374.24

= 375 numbers

Since the panel has the voltage at Pmax of 36V, desired voltage level from the charging port is required 750V. MPPT charge controller works best if the input voltage level is nearly half than that required from the output voltage. So based on this, the array the panel is calculated.

Modules in series = $\frac{Nominal\ Operating\ Voltage}{Vmp}$ (Ministry of Energy, SEPTEMBER 2018)

= 750/36

= 20.83

Rounding up, we get, =21

Similarly,

Modules in parallel = $\frac{Number\ of\ Panels}{Modules\ in\ series}$

=375/21

= 17.85

Rounding up, we get = 18

So, total array of solar modules required = Modules in series * Modules in parallel

= 21*18

= 378 numbers

- Battery capacity = $\frac{\text{total watt−hours from the panels}}{\text{battery efficiency}*\text{DOD}*\text{nominal voltage of battery}} * \text{days of autonomy}$

Where,

Total watt-hours from the panels= 380000 Wh

Assuming,

Battery efficiency = 80%

Depth of Discharge = 60%

Nominal voltage of battery = 24 V

Days of autonomy = 1 day

$$= \frac{380000}{0.8*0.6*24} * 1$$

= 32986 Ah @ 24 V

Since 2V, 3000Ah battery is used, total number of batteries required = 11 numbers

Since the nominal voltage in the calculation is taken as 24 V, to 12 batteries should be connected in series to provide the nominal voltage of 24 V from a 2 V battery.

- Total number of batteries required = 12 numbers
- Size of MPPT charge controller = Current at Pmax * number of modules in parallel

  = 8.3*18

  = 149.4 A

  = 160 A @ 24 V (nearest greater value of MPPT charge controller)
- Inverter sizing = PV size in kW*inverter efficiency*power factor (Ministry of Energy, SEPTEMBER 2018)

Since, pf for a DC network is nearly equal to 0.8 and efficiency of the inverter is assumed to be around 90%. Therefore, the size of the inverter is nearly 90 kVA @ 24 V. Since the inverter is operated at 24 V, a 750 V/24 V buck converter is also required.

Then, the prices of the panels, batteries, inverter and the MPPT charge controller can be calculated.

- Average cost of the solar panels = Rs.52*378*300=Rs.58,96,800
- Average cost of batteries =Rs.1,26,000*12 =Rs.15,12,000
- Average cost of inverter= Rs.3,50,000
- Average cost of charge controller =Rs.56,000

4.4.4 Calculations for 80% energy from solar panel

In this part, the calculations for solar PV system are done for supplying 80% of all the energy required for electric vehicles charging through the solar modules. So, the average energy required will be 80% of the total energy required for charging the current operating four vehicles from 20% to 100%.

- Energy required = Energy required to charge all four vehicles*0.8

  = 380*0.8 kWh

  = 304 kWh

- Total watts required from the panel

$$= \frac{Energy\ Required\ in\ Watt-hours}{Average\ sun-hours\ per\ day * Temperature\ loss * Inverter\ Efficiency * Derating\ factor}$$

Where,

Energy required in watt-hours= 380000 Wh

Temperature loss= 0.88

Inverter efficiency= 0.96

Derating Factor= 0.722 (including losses due to shading, wiring, soiling, diodes and connections, etc.)

Average sun-hours per day= 5.549 hours

Then, Total watts required from the panel

$$= \frac{Energy\ Required\ in\ Watt-hours}{Average\ sun-hours\ per\ day * Temperature\ loss * Inverter\ Efficiency * Derating\ factor}$$

$$= \frac{304000}{5.549 * 0.88 * 0.96 * 0.722}$$

= 89819 W

The panels used for this study is 300 Wp, so the total number of solar panels required can be determined by dividing the above calculated size of PV system in watts by the watt of individual panel.

i.e., Number of solar panels required = 89819/300

= 299.4

Rounding up, we get

= 300 numbers

Since the panel has the voltage at Pmax of 36V, desired voltage level from the charging port is required 750V. MPPT charge controller works best if the input voltage level is nearly half than that required from the output voltage. So based on this, the array the panel is calculated.

Modules in series $= \frac{Nominal\ Operating\ Voltage}{Vmp}$

= 750/36

= 20.83

Rounding up, we get, =21

Similarly,

Modules in parallel $= \frac{Number\ of\ Panels}{Modules\ in\ series}$

=300/21

= 14.28

Rounding up, we get = 15

So, total array of solar modules required = Modules in series * Modules in parallel

= 21*15

= 315 numbers

- Battery capacity = $\frac{\text{total watt−hours from the panels}}{\text{battery efficiency}*\text{DOD}*\text{nominal voltage of battery}} * \text{days of autonomy}$

Where,

Total watt-hours from the panels= 304000 Wh

Assuming,

Battery efficiency = 80%

Depth of Discharge = 60%

Nominal voltage of battery = 24 V

Days of autonomy = 1 day

$= \frac{304000}{0.8*0.6*24} * 1$

= 26389 Ah @ 24 V

Since 2V, 3000Ah battery is used, total number of batteries required = 9 numbers

Since the nominal voltage in the calculation is taken as 24 V, to 12 batteries should be connected in series to provide the nominal voltage of 24 V from a 2 V battery.

- Total number of batteries required = 12 numbers
- Size of MPPT charge controller = Current at Pmax * number of modules in parallel

  = 8.3*15

  = 124.5 A

  = 160 A @ 24 V (nearest greater value of MPPT charge controller)
- Inverter sizing = PV size in kW*inverter efficiency*power factor

Since, pf for a DC network is nearly equal to 0.8 and efficiency of the inverter is assumed to be around 90%. Therefore, the size of the inverter is nearly 90 kVA @ 24 V. Since the inverter is operated at 24 V, a 750 V/24 V buck converter is also required.

Then, the prices of the panels, batteries, inverter and the MPPT charge controller can be calculated.

- Average cost of the solar panels = Rs.52*315*300=Rs.49,14,000
- Average cost of batteries =Rs.1,26,000*12 =Rs.15,12,000
- Average cost of inverter= Rs.3,50,000
- Average cost of charge controller =Rs.56,000

4.4.5 Calculations for 50% energy from solar panel

In this part, the calculations for solar PV system are done for supplying 50% of all the energy required for electric vehicles charging through the solar modules. So, the average energy required will be 80% of the total energy required for charging the current operating four vehicles from 20% to 100%.

- Energy required = Energy required to charge all four vehicles*0.5

  = 380*0.5 kWh

= 190 kWh

- Total watts required from the panel

$$= \frac{Energy\ Required\ in\ Watt-hours}{Average\ sun-hours\ per\ day * Temperature\ loss * Inverter\ Efficiency * Derating\ factor}$$

Where,

Energy required in watt-hours= 190000 Wh

Temperature loss= 0.88

Inverter efficiency= 0.96

Derating Factor= 0.722 (including losses due to shading, wiring, soiling, diodes and connections, etc.)

Average sun-hours per day= 5.549 hours

Then, Total watts required from the panel

$$= \frac{Energy\ Required\ in\ Watt-hours}{Average\ sun-hours\ per\ day * Temperature\ loss * Inverter\ Efficiency * Derating\ factor}$$

$$= \frac{190000}{5.549 * 0.88 * 0.96 * 0.722}$$

= 56137 W

The panels used for this study is 300 Wp, so the total number of solar panels required can be determined by dividing the above calculated size of PV system in watts by the watt of individual panel.

i.e., Number of solar panels required = 56137/300

= 187.12

Rounding up, we get

= 188 numbers

Since the panel has the voltage at Pmax of 36V, desired voltage level from the charging port is required 750V. MPPT charge controller works best if the input voltage level is nearly half than that required from the output voltage. So based on this, the array the panel is calculated.

Modules in series $= \frac{Nominal\ Operating\ Voltage}{Vmp}$

= 750/36

= 20.83

Rounding up, we get, =21

Similarly,

Modules in parallel $= \frac{Number\ of\ Panels}{Modules\ in\ series}$

=188/21

= 8.95

Rounding up, we get = 9

So, total array of solar modules required = Modules in series * Modules in parallel

= 21*9

= 189 numbers

- Battery capacity = $\frac{\text{total watt−hours from the panels}}{\text{battery efficiency}*\text{DOD}*\text{nominal voltage of battery}} * \text{days of autonomy}$

Where,

Total watt-hours from the panels= 190000 Wh

Assuming,

Battery efficiency = 80%

Depth of Discharge = 60%

Nominal voltage of battery = 12 V

Days of autonomy = 1 day

$= \frac{304000}{0.8*0.6*12} * 1$

= 32986 Ah @ 12 V

Since 2V, 3000Ah battery is used, total number of batteries required = 12 numbers

Since the nominal voltage in the calculation is taken as 12 V, to 6 batteries should be connected in series and 2 batteries should be connected in parallel to provide the nominal voltage of 12 V from a 2 V battery.

- Total number of batteries required = 12 numbers
- Size of MPPT charge controller = Current at Pmax * number of modules in parallel

  = 8.3*9

  = 74.7 A

  = 80 A @ 12 V (nearest greater value of MPPT charge controller)
- Inverter sizing = PV size in kW*inverter efficiency*power factor

Since, pf for a DC network is nearly equal to 0.8 and efficiency of the inverter is assumed to be around 90%. Therefore, the size of the inverter is nearly 45 kVA @ 12 V. Since the inverter is operated at 12 V, a 750 V/12 V buck converter is also required.

Then, the prices of the panels, batteries, inverter and the MPPT charge controller can be calculated.

- Average cost of the solar panels = Rs.52*189*300=Rs.29,48,400
- Average cost of batteries =Rs.1,26,000*12 =Rs.15,12,000
- Average cost of inverter= Rs.1,75,000
- Average cost of charge controller =Rs.35,000

CHAPTER FIVE: RESULTS AND DISCUSSION

5.1 Financial Analysis

In this section, a financial analysis for the installation of a solar-based electric vehicle charging system is done. For this, the internal rate of return and payback period of the investment is calculated. Finally, the Levelized Cost of electricity is calculated. These calculations are performed for all three approaches and the best feasible approach is proposed. For this, the annual expenses of the company are assumed due to copyright issues. In the expenses, salaries of employees, rents, loan interest, and other miscellaneous expenses are assumed to be 80% of the total annual income.

5.1.1 Financial analysis for charging vehicles from 100% solar PV

- Average cost of the solar panels = Rs.52*378*300 =Rs.58,96,800
- Average cost of batteries =Rs.1,26,000*12 =Rs. 15,12,000
- Average cost of charge controller =Rs.70,000
- Average cost of three phase inverter = Rs. 3,50,000
- Average cost of civil structure and labor charge = Rs.35,00,000
- Average cost of wiring and earthing = Rs.4,00,000
- Average cost of DC-DC buck converter =Rs.3,00,000

  (Above price are taken on average following the installation manuals and its costs)

- Total investment = Rs.1,20,00,000
- Annual Operation & Maintenance cost per year =Rs.50,000+20,000+10,000+50,000+20,000

  = Rs.1,50,000

(Rs.10,000 is the average maintenance and cleaning cost of the solar panels)

- Average income per year= Rs.80,80,000

  Assuming,

- Equity = 20% = Rs. 16,16,000
- Debt = 80% = Rs. 64,64,000
- Equity cost of capital = 15%

- Interest rate on debt = 12%
- Tax rate= 25%
- Annual escalation rate = 8%

This gives, WACC = 10.2% (Pandey, 2005)

Taking a study period of 25 years including battery replacement in 5 years and inverter replacement in 10 years and based on the above data, the internal rate of return is calculated using the net present value equation. The IRR of the investment is found to be 41.76%, which is greater than the discount rate.

Using this rate, payback period of the investment is calculated as follows: (Pandey, 2005)

Table 6: Payback period calculation for charging vehicles from 100% solar PV system

Year	Cash Flow	Discount Factor	Annuity Factor	Present Value
0	-12000000	1	0	-12000000
1	1466000	0.705438	1	1034172.458
2	3049280	0.497643	2.08	1517453.178
3	4759222.4	0.351056	3.2464	1670755.854
4	6605960.192	0.247649	4.506112	1635957.213
5	-269863.6442	0.174701	5.866601	-47145.40451
6	10754471.97	0.123241	7.335929	1325388.124
7	13080829.73	0.086939	8.922803	1137229.907
8	15593296.1	0.06133	10.63663	956334.6755
9	18306759.79	0.043264	12.48756	792031.5056
10	-5736678.737	0.03052	14.48656	-175085.629
11	24402284.62	0.02153	16.64549	525387.1626
12	27820467.39	0.015188	18.97713	422544.4364
13	31512104.78	0.010714	21.4953	337632.6013
14	35499073.16	0.007558	24.21492	268313.778
15	-1248997.241	0.005332	27.15211	-6659.573801
16	44455398.94	0.003761	30.32428	167212.3946
17	49477830.85	0.002653	33.75023	131284.5449

Year	Cash Flow	Discount Factor	Annuity Factor	Present Value
18	54902057.32	0.001872	37.45024	102766.2638
19	60760221.91	0.00132	41.44626	80230.64749
20	-18121737.86	0.000931	45.76196	-16880.28547
21	73920002.83	0.000657	50.42292	48573.66966
22	81299603.06	0.000464	55.45676	37686.54831
23	89269571.31	0.000327	60.8933	29191.76698
24	97877137.01	0.000231	66.76476	22578.60932
25	-3362873.238	0.000163	73.10594	-547.2495659

Therefore, the discounted payback period is 5.03 years, which is very good from the investment point of view.

Now, the Levelized cost of electricity for charging two vehicles is calculated using the following formula.

$$LCOE = \frac{Capex + \sum_{i=1}^{n} \frac{Opex}{(1+r)^i}}{\sum_{i=1}^{n} \frac{ei}{(1+r)^i}}$$ (Lai, 2019)

where,

Capex= capital cost (expenditure) in Nrs. = Rs.1,20,00,000

Opex= annual O&M cost (expenditure) in Nrs. = Rs.10,000

r= discount rate = 10.2%

ei= electricity generated in a year i (kWh) = 229678 kWh

n= service life in years = 25 years

$$LCOE = \frac{12000000 + \sum_{i=1}^{25} \frac{10000}{(1+0.102)^i}}{\sum_{i=1}^{25} \frac{229678}{(1+0.102)^i}} = Rs.5.88/kWh$$

5.1.2 Financial analysis for charging vehicles from 80% solar PV

- Average cost of the solar panels = Rs.52*315*300 =Rs.49,14,000
- Average cost of batteries =Rs.1,26,000*12 =Rs. 15,12,000
- Average cost of charge controller =Rs.56,000

- Average cost of three phase inverter = Rs. 3,50,000
- Average cost of civil structure and labor charge = Rs.28,00,000
- Average cost of wiring and earthing = Rs.3,20,000
- Average cost of DC-DC buck converter =Rs.3,00,000

  (Above price are taken on average following the installation manuals and its costs)

- Total investment = Rs.97,50,000
- Annual Operation & Maintenance cost per year =Rs.50,000+20,000+10,000+50,000+20,000

  = Rs.1,50,000

(Rs.10,000 is the average maintenance and cleaning cost of the solar panels)

- Average income per year= Rs.80,80,000

  Assuming,

- Equity = 20% = Rs. 16,16,000
- Debt = 80% = Rs. 64,64,000
- Equity cost of capital = 15%
- Interest rate on debt = 12%
- Tax rate= 25%
- Annual escalation rate = 8%

  This gives, WACC = 10.2% (Pandey, 2005)

Taking a study period of 25 years including battery replacement in 5 years and inverter replacement in 10 years and based on the above data, the internal rate of return is calculated using the net present value equation. The IRR of the investment is found to be 46.87%, which is greater than the discount rate.

Using this rate, payback period of the investment is calculated as follows: (Pandey, 2005)

Table 7: Payback period calculation for charging vehicles from 80% solar PV system

Year	Cash Flow	Discount Factor	Annuity Factor	Present Value
0	-9750000	1	0	-9750000
1	1466000	0.680895	1	998192.6559
2	3049280	0.463619	2.08	1413702.758
3	4759222.4	0.315676	3.2464	1502371.028
4	6605960.192	0.214942	4.506112	1419899.323
5	-269863.6442	0.146353	5.866601	-39495.38762
6	10754471.97	0.099651	7.335929	1071695.709
7	13080829.73	0.067852	8.922803	887560.7578
8	15593296.1	0.0462	10.63663	720412.3108
9	18306759.79	0.031457	12.48756	575884.0933
10	-5736678.737	0.021419	14.48656	-122875.2824
11	24402284.62	0.014584	16.64549	355889.2649
12	27820467.39	0.00993	18.97713	276267.1336
13	31512104.78	0.006762	21.4953	213070.15
14	35499073.16	0.004604	24.21492	163434.0767
15	-1248997.241	0.003135	27.15211	-3915.321945
16	44455398.94	0.002134	30.32428	94887.91668
17	49477830.85	0.001453	33.75023	71908.03998
18	54902057.32	0.00099	37.45024	54329.5138
19	60760221.91	0.000674	41.44626	40939.91634
20	-18121737.86	0.000459	45.76196	-8313.958329
21	73920002.83	0.000312	50.42292	23091.40585
22	81299603.06	0.000213	55.45676	17292.47772
23	89269571.31	0.000145	60.8933	12928.63423
24	97877137.01	9.86E-05	66.76476	9651.856511
25	-3362873.238	6.71E-05	73.10594	-225.7982109

Therefore, the payback period is 5.03 years, which is very good from the investment point of view.

Now, the Levelized cost of electricity for charging two vehicles is calculated using the following formula.

$$LCOE = \frac{Capex + \sum_{i=1}^{n} \frac{Opex}{(1+r)^i}}{\sum_{i=1}^{n} \frac{ei}{(1+r)^i}}$$ (Lai, 2019)

where,

Capex= capital cost (expenditure) in Nrs. = Rs.97,50,000

Opex= annual O&M cost (expenditure) in Nrs. = Rs.10,000

r= discount rate = 10.2%

ei= electricity generated in a year i (kWh) = 191399 kWh

n= service life in years = 25 years

$$LCOE = \frac{9750000 + \sum_{i=1}^{25} \frac{10000}{(1+0.102)^i}}{\sum_{i=1}^{25} \frac{191399}{(1+0.102)^i}}$$ = Rs.5.75/kWh

Final LCOE= Rs.5.75*80%+Rs.5.6*20%

Where, Rs.5.6/kWh is the price per kWh from the conventional grid charging.

Therefore, Final LCOE = Rs. 5.72/kWh

5.1.3 Financial analysis for charging vehicles from 50% solar PV

- Average cost of the solar panels = Rs.52*189*300 =Rs.29,50,000
- Average cost of batteries =Rs.1,26,000*12 =Rs. 15,12,000
- Average cost of charge controller =Rs.35,000
- Average cost of three phase inverter = Rs.1,75,000
- Average cost of civil structure and labor charge = Rs.17,50,000
- Average cost of wiring and earthing = Rs.2,00,000
- Average cost of DC-DC buck converter =Rs.3,00,000

  (Above price are taken on average following the installation manuals and its costs)

- Total investment = Rs.64,18,000
- Annual Operation & Maintenance cost per year =Rs.50,000+20,000+5,000+50,000+20,000

= Rs.1,45,000

(Rs.5,000 is the average maintenance and cleaning cost of the solar panels)

- Average income per year= Rs.80,80,000

  Assuming,

- Equity = 20% = Rs. 16,16,000
- Debt = 80% = Rs. 64,64,000
- Equity cost of capital = 15%
- Interest rate on debt = 12%
- Tax rate= 25%
- Annual escalation rate = 8%

  This gives, WACC = 10.2% (Pandey, 2005)

Taking a study period of 25 years including battery replacement in 5 years and inverter replacement in 10 years and based on the above data, the internal rate of return is calculated using the net present value equation. The IRR of the investment is found to be 53.81%, which is greater than the discount rate.

Using this rate, payback period of the investment is calculated as follows: (Pandey, 2005)

Table 8: Payback period calculation for charging vehicles from 50% solar PV system

Year	Cash Flow	Discount Factor	Annuity Factor	Present Value
0	-6418000	1	0	-6418000
1	1260000	0.650171	1	819215.0055
2	2620800	0.422722	2.08	1107869.451
3	4090464	0.274841	3.2464	1124228.616
4	5677701.12	0.178694	4.506112	1014569.824
5	-1478383.442	0.116181	5.866601	-171760.7222
6	9243270.586	0.075538	7.335929	698215.9859
7	11242732.23	0.049112	8.922803	552157.9658
8	13402150.81	0.031931	10.63663	427950.2938
9	15734322.88	0.020761	12.48756	326658.7077

Year	Cash Flow	Discount Factor	Annuity Factor	Present Value
10	-6185762.173	0.013498	14.48656	-83496.20827
11	20973314.2	0.008776	16.64549	184063.617
12	23911179.34	0.005706	18.97713	136436.0819
13	27084073.69	0.00371	21.4953	100477.6763
14	30510799.58	0.002412	24.21492	73593.00532
15	-6842332.71	0.001568	27.15211	-10730.3649
16	38208596.63	0.00102	30.32428	38958.18748
17	42525284.36	0.000663	33.75023	28191.11391
18	47187307.11	0.000431	37.45024	20338.43619
19	52222291.68	0.00028	41.44626	14634.42432
20	-19540358.76	0.000182	45.76196	-3560.242692
21	63532881.02	0.000118	50.42292	7526.151803
22	69875511.5	7.7E-05	55.45676	5381.790375
23	76725552.42	5.01E-05	60.8933	3842.104343
24	84123596.61	3.26E-05	66.76476	2738.888276
25	-18422696.87	2.12E-05	73.10594	-389.9752494

Therefore, the discounted payback period is 5.19 years, which is very good from the investment point of view.

Now, the Levelized cost of electricity for charging two vehicles is calculated using the following formula.

$$\text{LCOE} = \frac{\text{Capex} + \sum_{i=1}^{n} \frac{\text{Opex}}{(1+r)^{\wedge}i}}{\sum_{i=1}^{n} \frac{ei}{(1+r)^{\wedge}i}} \text{ (Lai, 2019)}$$

where,

Capex= capital cost (expenditure) in Nrs. = Rs.64,18,000

Opex= annual O&M cost (expenditure) in Nrs. = Rs.5,000

r= discount rate = 10.2%

ei= electricity generated in a year i (kWh) = 114839 kWh

n= service life in years = 25 years

LCOE = $\frac{6418000+\sum_{i=1}^{25}\frac{5000}{(1+0.102)^i}}{\sum_{i=1}^{25}\frac{114839}{(1+0.102)^i}}$ = Rs.6.3/kWh

Final LCOE= Rs.6.3*50%+Rs.5.6*50%

Where, Rs.5.6/kWh is the price per kWh from the conventional grid charging.

Therefore, Final LCOE = Rs. 5.95/kWh

5.3 Socio-economic analysis

Saving in carbon emission:

On average a diesel engine produces 2.7 kg of CO_2 per liter of diesel burnt. A 35seater public city bus has mileage of around 18 kms per liter. The bus does 6 trips of ring-road in a day which is of length 27km. So, on average a public city bus requires 10 liters of diesel in a day which produces 27 kg of CO_2 in a day. This is the amount of carbon dioxide emitted by a single public bus in a day on average which is 9.85 tons of CO_2 in year. So, this amount of carbon dioxide emission can be saved in a single bus if the diesel vehicles are replaced with the electric public bus.

Fuel saving:

A public bus on average requires 10 liters of diesel in a day. Current price of diesel is Rs. 172 per liter, so the average price of fuel for a diesel operated public bus is Rs. 1,720 in a day and similarly Rs. 6,27,800 per year. Likewise, the energy required for a 10.5m electric public bus in a day is 140 kWh, considering depth of discharge of the vehicle as 80%. Current price per unit of electricity is Rs. 5.6 and from the current charger it takes around 5 hours to fully charge the vehicle. It takes around Rs. 785 for the electric vehicle to charge and operate for a full day which is Rs. 2,86,160 per year. Comparing the cost of fuel and charging cost for diesel and electric vehicle, the electric vehicle can save nearly Rs. 3,41,500 per year. This amount is saved in a single vehicle if the diesel vehicle is replaced with the electric bus. The price of fuel is increasing recently and will surely go up in the near future but the price in the cost of electricity will remain same or probably decrease if the production of electricity is higher. Also, currently the charger used is 30kW, if higher rated charger is used the charging time is also reduced which will also reduce the charging time and eventually charging cost. This will increase the difference in the charging cost of electric vehicles and fuel cost of diesel vehicles.

5.4 Optimal Route Selection

All four vehicles run in the ring-road of Kathmandu valley. The length of the ring-road is 27 km and the vehicle does six trips in a day (Mishra, et al., September 2020). From the survey it is found that the vehicles operate for 17 hours in ring road in a normal day. And the total time to complete a trip in the ring road takes about 2 to 3 hours depending upon the time of the day. The trip takes about 103 mins in off peak hour and 146 mins in the peak hour (Prajapati, et al., October 2019). The route optimization is done for two vans by choosing an alternative shorted route inside the valley so that the vans could run for more trips in a day and eventually increase the profit from the vans. During this optimization, the buses are taken as running in the usual route i.e., ring road. The figure below shows the routes taken in this study along with the distance between the stops. The optimization is done using the solver add-in in MS Excel. The optimization is done twice, once for minimizing the driving kms and another for minimizing the driving time. The variables and constraints for both optimizations are shown in the figure 7 and 8 below respectively. In both the cases the variables taken are routes which is first column of table 10. Similarly, the constraints are also same for both cases. Two constraints are taken, first one is inequality constraint where the deciding values from the route is greater than or equal to one i.e., if 1 is displayed on the route we take that route and if 0 is displayed on the route we don't take that route. This is displayed as output in the first column of table 10. And another constraint taken is a hard equality constraint where the net flow column is strictly equal to the supply/demand column of table. -1 in this column signifies the vehicles departs from that stop and 1 in this column signifies the vehicles reaches at that stop whereas 0 in this column signifies the vehicles goes through that stops.

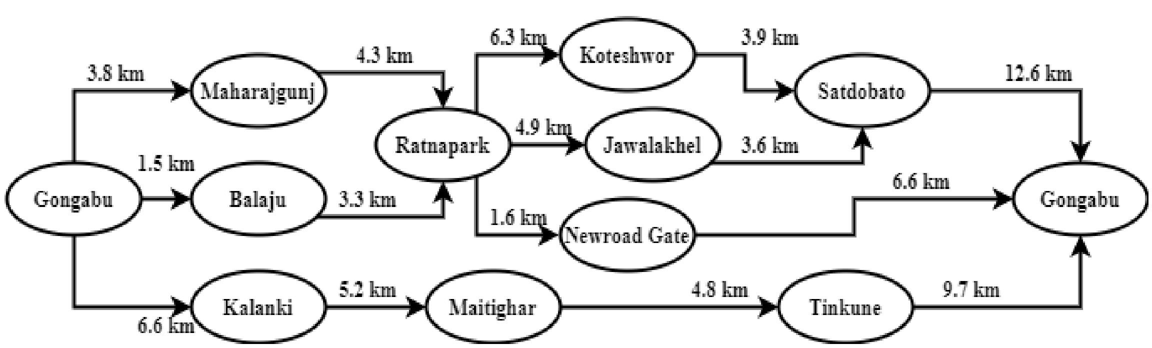

Figure 9: Routes taken for study

Since the vehicles start from the Gongabu bus station, various possible routes from this station are taken returning to the same station.

Mathematical model to propose the optimal route is developed for solving the problem through simplex linear programming:

Objective functions:

Minimize (for kms):

$3.8X_{1-2}+1.5X_{1-3}+6.6X_{1-4}+4.3X_{2-5}+3.3X_{3-5}+5.2X_{4-6}+6.3X_{5-7}+4.9X_{5-8}+1.6X_{5-9}$
$+3.1X_{6-10}+3.9X_{7-11}+3.6X_{8-11}+4.8X_{9-12}+8.1X_{9-12}+9.7X_{10-12}+12.6X_{11-12}$

And,

Minimize (for time):

$24X_{1-2}+16X_{1-3}+28X_{1-4}+32X_{2-5}+24X_{3-5}+30X_{4-6}+35X_{5-7}+30X_{5-8}+18X_{5-9}$
$+18X_{6-10}+20X_{7-11}+17X_{8-11}+26X_{9-12}+38X_{9-12}+42X_{10-12}+43X_{11-12}$

Constraints:

$-X_{1-2}-X_{1-3}-X_{1-4}=-1$,

$+X_{1-2}-X_{2-5}=0$,

$+X_{1-3}-X_{3-5}=0$,

$+X_{1-4}-X_{4-6}=0$,

$+X_{2-5}+X_{3-5}-X_{5-7}-X_{5-8}-X_{5-9}=0$,

$+X_{4-6}-X_{6-10}=0$,

$+X_{5-7}-X_{7-11}=0$,

$+X_{5-8}-X_{8-11}=0$,

$+X_{5-9}-X_{9-11}=0$,

$+X_{6-10}-X_{10-12}=0$,

$+X_{7-11}+X_{8-11}+X_{9-11}-X_{11-12}=0$,

$+X_{9-12}+X_{10-12}+X_{11-12}=1$ and

$X_{i-j}>=0$ for all i and j

Since the total supply equals the total demand to determine the optimal route, the constraints taken are stated as equalities. The first constraint in this mathematical model ensures that the 1 unit of supply available at node 1 is shipped to node 2, node 3 or node 4. The next ten constraints indicate that anything flowing to nodes 2 to node 11 must flow out of these nodes because each has a demand of 0. The last constraint indicates that the unit ultimately must low to node 11.

Table 9: Routes showing start and end stops

Nodes		Net Flow	Supply/Demand
1	Gongabu	-1	-1
2	Maharajgunj	0	0
3	Balaju	0	0
4	Kalanki	0	0
5	Ratnapark	0	0
6	Maitighar	0	0
7	Koteshwor	0	0
8	Jawalakhel	0	0
9	Newroad gate	0	0
10	Tinkune	0	0
11	Satdobato	0	0
12	Gongabu	1	1

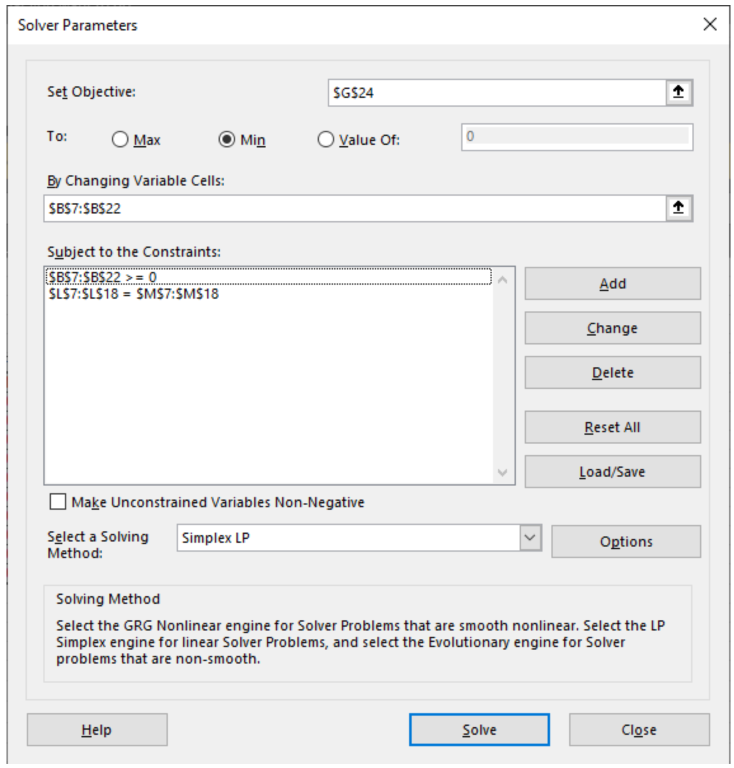

Figure 10: Solver window with objective to minimize driving kms

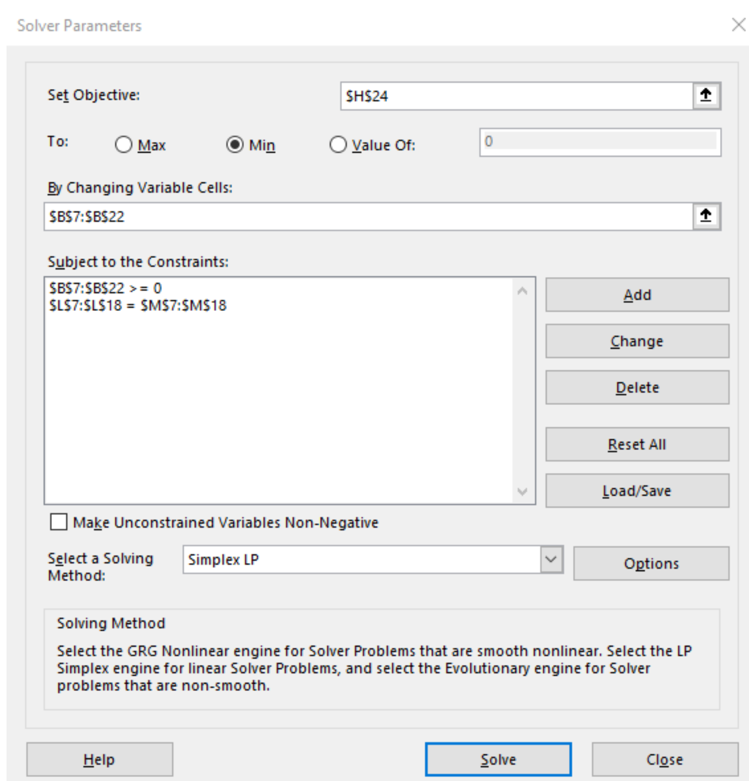

Figure 11: Solver window with objective to minimize driving time

Table 10: Results from solver for route selection

Route?	From		To		km	Time in mins
0.0	1	Gongabu	2	Maharajgunj	3.8	24
1.0	1	Gongabu	3	Balaju	1.5	16
0.0	1	Gongabu	4	Kalanki	6.6	28
0.0	2	Maharajgunj	5	Ratnapark	4.3	32
1.0	3	Balaju	5	Ratnapark	3.3	24
0.0	4	Kalanki	6	Maitighar	5.2	30
0.0	5	Ratnapark	7	Koteshwor	6.3	35
0.0	5	Ratnapark	8	Jawalakhel	4.9	30
1.0	5	Ratnapark	9	Newroad gate	1.6	18
0.0	6	Maitighar	10	Tinkune	3.1	18
0.0	7	Koteshwor	11	Satdobato	3.9	20
0.0	8	Jawalakhel	11	Satdobato	3.6	17
1.0	9	Newroad gate	12	Gongabu	4.8	26
0.0	9	Newroad gate	12	Gongabu	8.1	38
0.0	10	Tinkune	12	Gongabu	9.7	42
0.0	11	Satdobato	12	Gongabu	12.6	43

The route selection from the optimization is found to be Gongabu-Balaju-Ratnapark-Newroad Gate-Gongabu. The total distance covered in this route in a trip is 11.2 km. whereas, in the usual route the distance covered in a trip is 27 km. Also, the time taken by the vehicles to complete the trip is 84 mins whereas in the usual route the time taken by the vehicles to complete a trip is 146 mins. So, if the vans run in this route, it can do up to fourteen trips in a day for the same range of six trips in 27km if only distance is taken into consideration. And if time is also taken into consideration, the trip time is reduced by almost half, so the vehicles can do up to 11 trips in a day. The route obtained from the optimization is currently running routes for other vehicles also and is an active route, the flow of passengers in this route are similar to that of the ring road. So, following Gongabu-Balaju-Ratnapark-Newroad Gate-Gongabu route the vans can do up to minimum of 9 to 10 trips a day, which can eventually increase profit from the vans in daily basis.

From the above calculations and financial analysis of three approaches when 100% solar energy is used for supplying the demand to charge the vehicles, when 80% of the total energy demand is supplied from solar energy and when 50% of the total energy demand is supplied from solar energy i.e., solar-based charging system designed for charging all the four vehicles currently in operation of Sundar Yatayat Pvt. Ltd. the internal rate as well as discounted payback period in all three cases is determined using net present value calculation. It is found that the rate of return is nearly 41.76%, 46.87% and 53.81% for 100%, 80% and 50% energy supply from solar PV respectively which is greater than the discount rate of 10.2%. Also, the discounted payback period is nearly 5.03 years, 5.03 years and 5.19 years respectively for charging vehicles from 100%, 80% and 50% solar energy. These factors show that all three investments are feasible. For further analysis, the Levelized Cost of electricity is calculated for all three cases. The total LCOE for the system designed for charging vehicles with 100% share of solar energy is found to be Rs.5.88 per kWh, for the system designed for charging vehicles with 80% share of solar energy is found to be Rs.5.72 per kWh and that for the system designed for charging the vehicles with 50% share of solar energy in the total energy is found to be Rs.5.95 per kWh. All three approaches are compared based on IRR, discounted payback period and cost of electricity which is shown in the figure 7,8 and 9 below respectively. The rate of return is higher than the assumed discount rate in all the cases and the discounted payback period is similar for all the cases. Since the life of solar PV plant is more than twenty years, cost of electricity plays important role in the longer run. The LCOE of the approach when the vehicles are charged from 80% share of the solar energy to the total required energy if Rs.5.72/kWh which is less than other two approaches. So, this approach is proposed for installing solar PV system for charging the electric vehicles. Comparing the results with feasibility study of solar based vehicle charging station at Tribhuvan International Airport where the IRR of the project was 15.03% and payback period was 7.74 years with LCOE of Rs. 19.97 per kWh (Sunil Poudel, 2016), the results of this study are found feasible. Also, the optimum routes for the operation of two vans are determined with a distance of 11.2 km.

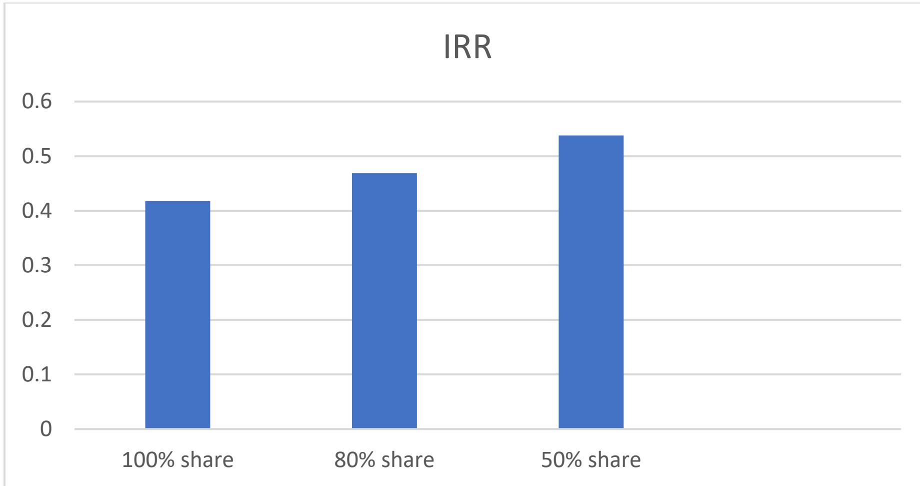

Figure 12: Comparison of IRR for all three approaches

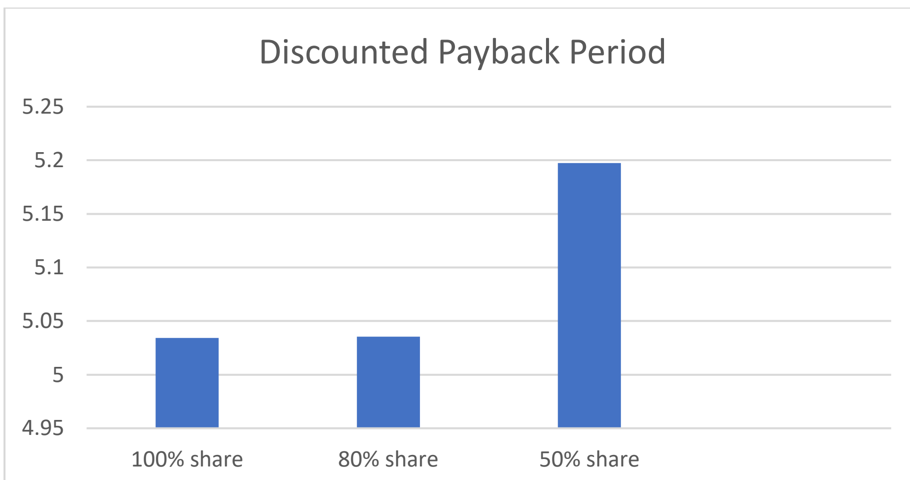

Figure 13: Comparison of discounted payback period for all three approaches

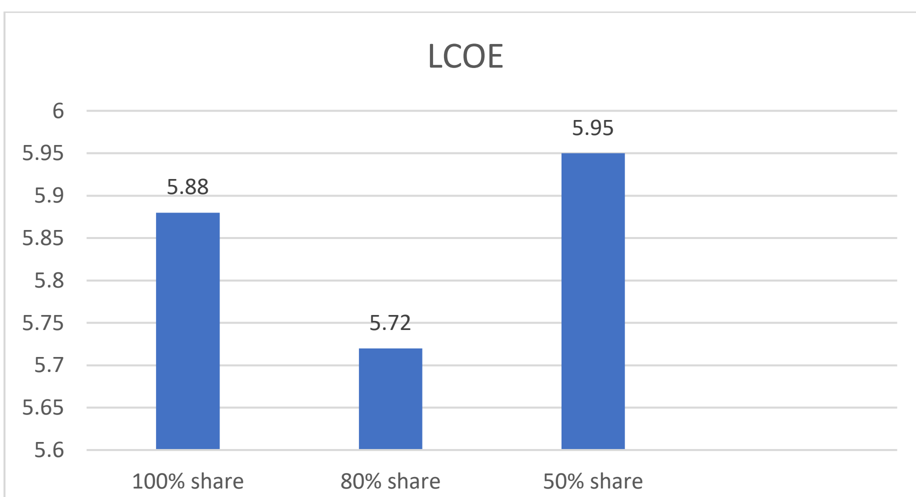

Figure 14: Comparison of cost of electricity for all three approaches

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

In conclusion, this paper attempted to use renewable energy sources for charging electric vehicles and replacing the conventional charging system. Electric vehicles from a private company running public vehicles in Kathmandu are taken for the study. The company operates four public vehicles i.e., two buses and two vans. The specifications of the vehicles, income from the vehicles, expenditures on the vehicles, current charging system and overall charging costs and other related data are extracted from the company but the overall expenses of the company are assumed since the financial statements of the company are confidential and were not provided for this study. The sizing of solar based charging system is done 100%, 80% and 50% share of total energy required for charging electric vehicles. From the calculation, it is found that for 100% share 378 numbers of 300Wp solar modules with 12 numbers of 2V, 3000Ah batteries are required. Similarly for 80% share 315 numbers of solar modules of 300Wp and 12 numbers of batteries of the same rating are required. And for 50% share 189 numbers of 300Wp and 12 numbers of 2V, 3000Ah batteries are required. From the financial analysis it is found that for 100% share the IRR and payback period are 41.76% and 5.03 years respectively, for 80% share the IRR and discounted payback period are 46.86% and 5.03 years respectively and that for 50% share the IRR and payback period are 53.8% and 5.19 years respectively. Comparing, all three approaches are found feasible the IRR is greater than the assumed discount rate. Since the cost of electricity is less for charging the electric vehicles from solar energy with 80% share of total energy i.e., Rs.5.72 per kWh as compared to that for charging with 100% share i.e., Rs.5.88 per kWh and 50% share i.e., Rs.5.95 per kWh. So, in the long run charging the vehicles from 80% share of solar PV system is found to be financially feasible. Comparing the results with feasibility study of solar based vehicle charging station at Tribhuvan International Airport where the IRR of the project was 15.03% and payback period was 7.74 years with LCOE of Rs. 19.97 per kWh and the results of cost of electricity from photovoltaic-powered electric vehicle charging station in Vietnam it was found 0.0846 $ per kWh which is Rs.9.94 per kWh, the results of this study are found feasible Also, the route optimization for two public electric vans is done using linear optimization technique. Alternative routes starting from Gongabu are taken for optimization and the routes with shortest length is proposed. From the optimization, Gongabu-Balaju-Ratnapark-Newroad Gate-Gongabu route is proposed which is of total length 11.2km. According to the proposed route, the electric vans can run more than ten trips in a day which is more than current six trips in a day.

6.2 Recommendations

This study proposed the charging of currently operated four vehicles by the company. But, in future if the number of vehicles increases necessary modifications in the calculations can be done to determine the size and cost of solar PV based charging system. Also, this study is done for existing charging station at Dhumbarahi-4, Kathmandu. With the financial statements of the company, concrete data can be used instead of assumptions for the financial analysis and more accurate results can be determined based on the rate of return and payback period also. Further study can be done if proposed charging stations come into operation in future. If the proposed charging stations come into operation, best possible route optimization can be done for all the vehicles. There are four vehicles in consideration as of now, but in the future, the number of vehicles might increase, and then modifications can be done. The outcome may vary slightly based on the costs assumed in this study. With further research and study maximum benefit can be obtained.

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ANNEX

Table 11: Specification of 10.5m electric city bus

Length*Width*Height(mm)	10500*2550*3150
Wheel base (mm)	5600
Motor model no.	KTZ57X55SD01
Max. Speed (km/h)	69 - 80
Seat	35
Max. Passenger capacity	85
Manufacturer of motor	Jing-Jin Electric
Motor Position	Rear
Motor Peak Power (kw/rpm/Nm)	196/2600/2900
Driving source	BAK Battery Co., Ltd, Ternary Lithium ion.
Capacity (kWh)	175.3
Storage battery	DC/DC + 12V/100AHx2 maintenance-free storage battery
Battery bank	7 nos. in Parallel
Maximum weight	17400 kg
Electric motor controlling mode	Turning Mode
Main motor model number	TM5035JA

Chassis model	Two step
Chassis brand	Dongfeng
Suspension	Leaf spring, Multiple-leaf spring
Front axle	Dongfeng Dana 6.4T
Rear axle	Dongfeng Dana 11T
Braking	Front disc/ Rear drum
ABS	Yes
Air condition	28000 kcal/h cool and warm electric air condition 28000 kcal/h
Light	driver lamp, passenger Strip penetrated LED lamp, step lamp

Table 12: Specifications of 8.5m electric city bus

Specifications	LSK6850GEV1
Length*Width*Height(mm)	8530*2420*3150
Wheel base (mm)	4250
Motor model no.	KTZ57X40SD02
Max. Speed (km/h)	69 - 80
Seat	31
Max. Passenger capacity	75

Manufacturer of motor	Jing-Jin Electric
Motor Position	Rear
Motor Peak Power (kw/rpm/Nm)	196/2600/2800
Driving source	BAK Battery Co., Ltd,Ternary Lithium ion.
Capacity (kWh)	127.5
Storage battery	DC/DC + 12V/100AHx2 maintenance-free storage battery
Battery bank	5 nos. in Parallel
Maximum weight	12700 kg
Electric motor controlling mode	Turning Mode
Main motor model number	TM5035J9
Chassis model	Two step
Chassis brand	Dongfeng
Suspension	Leaf spring, Multiple-leaf spring
Front axle	Dongfeng Dana 4.4T
Rear axle	Dongfeng Dana 8.5T
Braking	Front disc/ Rear drum
ABS	Yes

Air condition	24000 kcal/h cool and warm electric air condition 24000 kcal/h
Light	driver lamp, passenger Strip penetrated LED lamp, step lamp

Table 13: Specification of 6m electric van

Specifications	JAX6660GBEV
Length*Width*Height(mm)	5990*1880*2285
Wheel base (mm)	3720
Max. Speed (km/h)	130
Seat	18
Motor Position	Front
Motor Peak Power (kw)	100
Motor Peak Torque (Nm)	955
Capacity	86kwh
Storage battery	Lithium Iron Phosphate
Battery bank	2 nos. in Parallel
Braking System	Electromagnetic
Brake system	Front disc, rear drum, ABS

Table 14: Specifications of a 30kW DC charger

Condition	
Operating Temperature	-20ºC to 50ºC
Storage Temperature	-40ºC to 70ºC
Relative Humidity	5% - 95%
Altitude	≤ 2000 m
Others	No conductive dust, Corrosive gas, Inflammables or explosion-prone objects around
AC Input	
Input Current	≤ 58
Power Suppy	3 Phase
Input Voltage	323-456
Input Frequency	45-65
Power Factor	≥ 0.99
ThDi	≤ 3
DC Output	
Maximum Power Output	30 kW
Maximum Operating Current	52 A
Rated Output Voltage	100 V
Output Voltage	250-750 V
Efficiency	≥ 95
Other Features	
Maintenance Socket	220 V, 10 A, 1 pc
Electronic Lock	12 V, 3 A
Mechanical Endurance	No Load Insert/ Pull Connector
IP Degree	IP54

Table 15: Specifications of a 300Wp solar module

Maximum Power (Pmax)	300 Wp
Voltage at Maximum Power (Vmpp)	36 V
Current at Maximum Power (Impp)	8.3 A
Open Circuit Voltage (Voc)	44 V
Short Circuit Current (Isc)	8.9 A
Panel Efficiency	18.3%
Power Tolerance (Positive)	+ 1.5%

Table 16: Specifications of a 9m electric bus

Length*Width*Height(mm)	9000*2550*3400
Wheel base (mm)	4900
Motor model no.	KTZ60X40SP100F
Max. Speed (km/h)	69 - 80
Seat	30
Max. Passenger capacity	45
Manufacturer of motor	DANA
Motor Position	Rear
Motor Peak Power (kW/rpm/Nm)	200/2700/2463
Driving source	Lithium-Ion Battery Pack

Capacity (kWh)	175
Storage battery	DC/DC + 12V/100Ahx2 maintenance-free storage battery
Battery bank	7 nos. in Parallel
Maximum weight	13500 kg
Electric motor controlling mode	Turning Mode
Suspension	Electronic Controller Suspension System (ECAS)
Front axle	Dongfeng Dana 6.4T
Rear axle	Dongfeng Dana 11T
Braking	Front disc/ Rear drum
ABS	No, Electronics Braking System (EBS)
Air condition	28000 kcal/h cool and warm electric air condition 28000 kcal/h
Light	LED type