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Study of solar powered electric vehicles charging station in Kathmandu valley-A case study of sundar yatayat

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Abstract

In this paper, a feasibility study is done about the techno-economical 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.

1. Introduction

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 [1]. 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 are private. The registered number of public vehicles has been decreasing to 3% from 11% within 25 years from 1990 but at the same time private vehicles are increasing [2]. This significant increase in private vehicles is the major source for the emission of greenhouse gases. The pollution level recorded is much greater than the standard limit set by the World Health Organization. The demand and supply are increasing every day. Since 1975 the supply in the petroleum products had expanded by right around 70 folds. The period between 1987-1997 is viewed as the first time when there was more demand in Liquefied Petroleum Gas (LPG) [3]. 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), experiencing the issue of deficiency. NOC keeps up an extremely low load of oil-based goods, uplifting dangers of lack whenever

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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. The European countries are planning to prohibit gas vehicles from 2050. Now a days, most of the vehicle manufacturer company has been producing electric vehicles [4]. Moreover, 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 [5]. Enhancements in effectiveness, more research should be made.

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 has been improving in the production sector as well as reducing per-unit cost for its operation. The electric vehicle consists of four parts, i.e. 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.

For charging of electric vehicles, various studies have been carried out like penetration of renewable energy sources for charging and their integration in the system [6]. Similarly, the linear optimization model has been used for the penetration of PV system [7]. The stochastic charging and discharging method implemented for both PV and distributed system in an intelligent parking lot reduced the pressure in the PV system [8]. To reduce the charging costs and losses during charging of electric vehicles, the distribution system operator and the charging service provider were treated as separate system [9]. The tariff rates play significant role to shift from conventional grid charging to using PV system for charging. The consumer is attracted towards low charging costs. Optimization can be done to reduce charging costs. PSO can be implemented to determine the tariff rates based on the charging current adjusted in the electric vehicles [10].

2. Materials and Methods

2.1. Vehicle selection

Currently, there are only four vehicles in operation by Sundar Yatayat Pvt. Ltd. Two are city buses of length 10.5m and 8.5m and two Hiace vans of length 6 m with a battery capacity of 175.3 kWh, 127.5 kWh, and 86kWh respectively. The vehicles are manufactured by the Chinese company BYD. The specification of the vehicles is taken from the technical data report of the company. Each vehicle runs 6 trips daily in the ring-road of Kathmandu valley i.e., 27 km in a trip. The vehicles operated are listed below:

1. LSK6105GEV1 (Electric city bus 10.5 m)
2. LSK6850GEV1 (Electric city bus 8.5 m)
3. JAX6660GBEV (Electric van 6m)

2.2. Charging location

There is currently one charging location of Sundar Yatayat Pvt. Ltd. which is inside Kathmandu Valley. To be more precise the charging location is at the garage of the company situated at Kalopul, Kathmandu. As per the company, the total area of the current charging location is nearly 3.5 ropani which is around 1780 square meters. The aerial view of the current charging location is shown in the picture below which is extracted from google earth.

Figure 1: Aerial view of the current charging location

2.3. Charging unit

There are three charging units installed in the charging location out of which two units are in operation. The vehicles are currently charged by a DC charger of 30 kW operated at 750V, DC. Normally, the charging system for electric vehicles is rated at 30, 60, 90 and 120 kW based on the ratings of the vehicles. The higher rating of the charger, charges the vehicle faster. But the condition is that both the charging unit and vehicle should have the 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 a full charge of 20% daily.

2.4. Income and operation & Maintenance costs

1) Income

The per-day income and expenditure of 10.5m, 8.5m electric buses, and 6m electric Hiace van is presented in this section of the paper. These are the data taken from technical specification report of Sundar Yatayat Pvt. Ltd, since only income from the vehicles are given in the report.

I. For 10.5m bus

- Total distance travelled = 200 km
- Energy 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 200km = Rs.4.87 × 200 = Rs.974
- Average income for 200km = Rs.8.500
- Average income per km = Rs.8500/200 = Rs.42.50
- Gross Profit per km = Rs. 42.50 - 4.87 = Rs. 37.63

II. For 8.5m bus

- Total distance travelled = 170 km
- Energy 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 = 7,500
- Average income per km = Rs. 7500/170 = Rs. 44.11
- Gross Profit per km = Rs. 44.11 - 4.14 = Rs. 39.97

III. For 6m Hiace Van

- Total distance travelled = 200 km
- Energy 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 =3,000
- Average income per km = Rs.3000/200 = Rs. 15
- Gross Profit per km = Rs. 15 - 2.41 = Rs. 12.59

From the above data, we can determine the average cost of energy consumed in a day and similarly in a day. Also, we can determine the average profit from the vehicles in a day and 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. 2,160 = Rs .7,88,400
- Average profit in a year = Rs. 70,00,000 (updated from report provided by Sundar Yatayat Pvt. Ltd.)

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.

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

2) Operation and Maintenance costs

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

2.5. 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. 15,600. The dimension of the module is 990*1956*40 mm.

2.6. 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.

2.7. Sizing of the solar PV charging system

In this section, the sizing of the solar PV system is determined to charge the electric vehicles. 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.

A. Calculations for 100% share of solar PV system

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. The vehicles chosen are 10.5m electric city bus and 6m Hiace van.

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 the vehicles
  = (175.3 + 127.5 + 86 + 86) ×0.8
  = 379.84 kWh = 380 kWh (approx.)
  = 380000 Wh

The average sun-hours at the charging location is 5.549 hours per day [11].

Total watts required from the panel [12]

$$\begin{aligned} &= \frac{\text{Energy Required in Watt-hours}}{\text{Average sun-hours per day} \times \text{Temperature loss} \times \text{Inventer Efficiency} \times \text{Derating factor}} \\ &= \frac{380000}{5.549 \times 0.88 \times 0.96 \times 0.722} \\ &= 112273\ W \end{aligned} \tag{1}$$

Total number of solar panels required = 112273/300 = 374.24 = 375 numbers.

With total modules in series = 21 and total modules in parallel = 18, then total number of solar modules required = 378 numbers.

Where, from [13]

$$\begin{aligned} \text{Modules in series} &= \frac{\text{Nominal operating voltage}}{\text{voltage at } P_{max}} \\ &= \frac{750}{36} \\ &= 21 \end{aligned} \tag{2}$$

Battery capacity

$$\begin{aligned} &= \frac{\text{Total Watt-hour from the panels}}{\text{battery efficiency} \times \text{DOD} \times \text{nominal voltage of battery} \times \text{days of autonomy}} \\ &= 32986 \text{ Ah @ 24 V} \\ &= 112273\ W \end{aligned} \tag{3}$$

Where,

Battery efficiency	=	80%
Depth of Discharge	=	60%
Nominal voltage of battery	=	24V
Days of autonomy	=	1 day

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

- Total number of batteries required = 12 numbers
- Size of MPPT charge controller
  = Current at P_{max} × 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

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.

- 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

B. Calculations for 80% energy from solar PV system

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 to charge the vehicles
= Energy required to charge all four vehicles × 0.8
= 380 × 0.8
= 304 kWh
The average sun-hours at the charging location is 5.549 hours per day.

Total watts required from the panel [12]

$$= \frac{\text{Energy Required in Watt-hours}}{\text{Average sun-hours per day} \times \text{Temperature loss} \times \text{Inventer Efficiency} \times \text{Derating factor}}$$
$$= \frac{304000}{5.549 \times 0.88 \times 0.96 \times 0.722}$$
$$= 89819\ W \tag{4}$$

Total number of solar panels required = 89819/300 = 299.4 = 300 numbers

With total modules in series = 21 and total modules in parallel = 15, then total number of solar modules required = 315 numbers.

Where, modules in series
= Nominal operating voltage/voltage at Pmax
= 750/36 = 21

Battery capacity

$$= \frac{\text{Total Watt-hour from the panels}}{\text{battery efficiency} \times \text{DOD} \times \text{nominal voltage of battery} \times \text{days of autonomy}}$$
$$= 26389 \text{ Ah @ } 24 \text{ V}$$
$$= 112273\ W$$

Where,

Battery efficiency	=	80%
Depth of Discharge	=	60%
Nominal voltage of battery	=	24V
Days of autonomy	=	1 day

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

• 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.

• 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

C. Calculations for 50% energy from solar PV system

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 to charge the vehicles = Energy required to charge all four vehicles × 0.5
= 380 × 0.5
= 390 kWh

The average sun-hours at the charging location is 5.549 hours per day.

Total watts required from the panel [12]

$$= \frac{\text{Energy Required in Watt-hours}}{\text{Average sun-hours per day} \times \text{Temperature loss} \times \text{Inventer Efficiency} \times \text{Derating factor}}$$
$$= \frac{190000}{5.549 \times 0.88 \times 0.96 \times 0.722}$$
$$= 56137\ W$$

Total number of solar panels required
= 56137/300 = 187.12 = 188 numbers

With total modules in series = 21 and total modules in parallel = 9, then total number of solar modules required = 189 numbers.

Where, modules in series = Nominal operating voltage/voltage at Pmax =750/36 =21

Battery capacity

$$= \frac{\text{Total Watt-hour from the panels}}{\text{battery efficiency} \times \text{DOD} \times \text{nominal voltage of battery} \times \text{days of autonomy}}$$

$= 32986$ Ah @ 12 V

Where,

Battery efficiency	=	80%
Depth of Discharge	=	60%
Nominal voltage of battery	=	12V
Days of autonomy	=	1 day

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

- 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 @ 12V (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.

- 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

3. Results and Discussion

3.1. 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.

A. 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 [14]
= Rs. 1,26,000 × 12 = Rs. 15,12,000
- Average cost of charge controller [14]
= Rs. 70,000
- Average cost of three phase inverter [14]
= 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, Rs. 50,000 is maintenance cost of bus and Rs. 20,000 is maintenance cost of vans)

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

From the current policies for EV,

- Equity = 20%
- Debt = 80%

Assuming,

- Equity cost of capital = 15%
- Interest rate on debt = 12%
- Tax rate= 25%
- Annual escalation rate = 8%

This gives, WACC = 10.2%

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.

$$0 = NAP = \sum_{n=0}^{N} \frac{CF_n}{(1 + IRR)^n}$$

Where,

CF	=	cash flows
N	=	holding period
n	=	each period
NPV	=	Net Present Value
IRR	=	Internal Rate of Return

The IRR of the investment is found to be 41.76%, which is greater than the discount rate. The discounted payback period is calculated 5.03 years [15] which is very good from the investment point of view.

Now, the Levelized cost of electricity for charging vehicles is calculated using the following formula [3].

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

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)
	=	kW $\times$ sun-hours $\times$ efficiency $\times$ 365
	=	229678 kWh
n	=	service life in years = 25 years

= Rs. 5.88 /kWh

B. 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 [14] =Rs.1,26,000×12 =Rs. 15,12,000
- Average cost of charge controller [14] =Rs.56,000
- Average cost of three phase inverter [14] = 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

From the current policies for EV,

- Equity = 20%
- Debt = 80%

Assuming,

- Equity cost of capital = 15%
- Interest rate on debt = 12%
- Tax rate= 25%
- Annual escalation rate = 8%

This gives, WACC = 10.2%

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 calculated to be 46.87%, which is greater than the discount rate. The discounted payback period is calculated 5.03 years [15], 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 [3]

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

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)
	=	kW $\times$ sun-hours $\times$ efficiency $\times$ 365
	=	191399kWh
n	=	service life in years = 25 years

$$= \frac{9750000 + \sum_{i=1}^{25} \frac{10000}{(1+0.102)^i}}{\sum_{i=1}^{25} \frac{191399}{(1+0.102)^i}}$$

= Rs. 5.75 /kWh

Final LCOE $= \text{Rs.}5.75 \times 80\ \% + \text{Rs. } 5.6 \times 20\ \%$
$= \text{Rs.}5.72/\text{kWh}$

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

C. 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 [14] =Rs.1,26,000×12 = Rs. 15,12,000
- Average cost of charge controller [14] = Rs.35,000
- Average cost of three phase inverter [14] = 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.10,000 is the average maintenance and cleaning cost of the solar panels)
• Average income per year= Rs.80,80,000
From the current policies for EV,

- Equity = 20%
- Debt = 80%

Assuming,

- Equity cost of capital = 15%
- Interest rate on debt = 12%
- Tax rate= 25%
- Annual escalation rate = 8%

This gives, WACC = 10.2%

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. The discounted payback period is 5.19 years [15], 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 [3]

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

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)
	=	kW × sun-hours × efficiency × 365
	=	114839 kWh
n	=	service life in years = 25 years

$$= \frac{6418000 + \sum_{i=1}^{25} \frac{10000}{(1+0.102)^i}}{\sum_{i=1}^{25} \frac{114839}{(1+0.102)^i}}$$

$= \text{Rs.}6.3\ /\text{kWh}$

Final LCOE $= \text{Rs. } 6.3 \times 50\ \% + \text{Rs. } 5.6 \times 50\ \%$
$= \text{Rs.}5.95/\text{kWh}$

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

Figure 2: Comparison of IRR for all three approaches

3.2. 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. 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

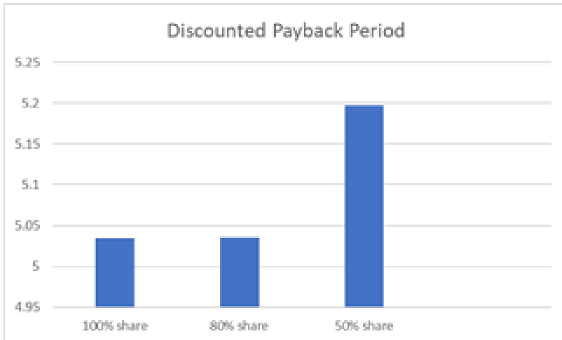

Figure 3: Comparison of discounted payback period for all three approaches

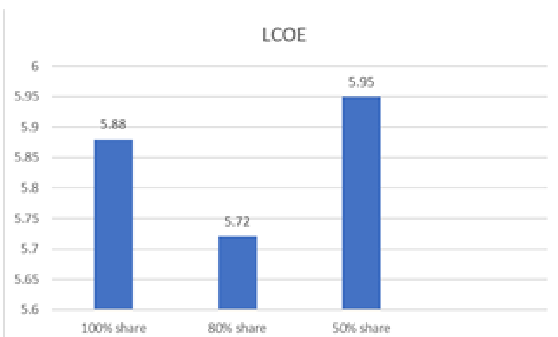

Figure 4: Comparison of cost of electricity for all three approaches

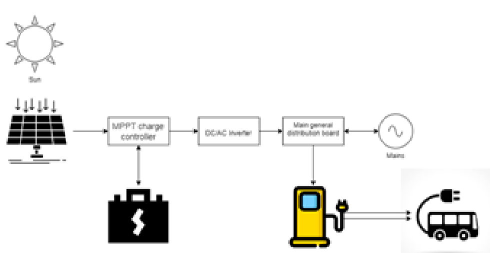

Figure 5: Proposed solar based charging scheme

in the ring road takes about 2 to 3 hours depending upon the time of the day [16]. The trip takes about 103 mins in off peak hour and 146 mins in the peak hour [17]. 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. 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.

Since the vehicles start from the Gongabu bus station,

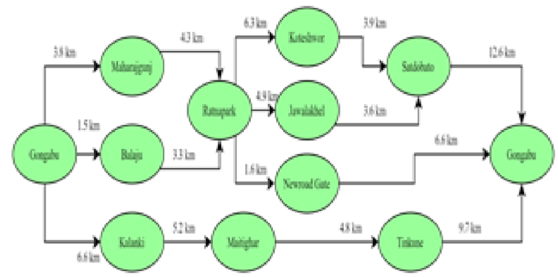

Figure 6: Various routes taken for the study

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):

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

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

The route selection from the optimization is found to be Gongabu-Balaju-Ratnapark-Newroad Gate-Gongabu based on the shortest path and minimum time required to complete the trip. 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

Table 1: 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	Kalanlki	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

to complete a trip is 146 mins. So, if the vans run in this route, it can do up to 11 trips in a day. So, following the optimized 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.

3.3. Discussions besides route optimization

From the above calculations and financial analysis of three approaches 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. 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. 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 [18] and the results of cost of electricity from photovoltaic-powered electric vehicle charging station in Vietnam it was found $ 0.0846 per kWh [5] which is Rs. 9.94 per kWh, 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.

4. Conclusion

In this paper, study was done regarding to use renewable energy sources for charging electric vehicles to substitute the conventional charging system. A survey was done to collect required data taking into account the vehicle operated by a private company; Sundar Yatayat Pvt. Ltd. The financial analysis was done on the basis of different economical parameters such as; LCOE, IRR and payback period. The both technical and financial analysis showed that the installation of Solar PV charging station for electric vehicle in Kathmandu valley was practicable in comparison to conventional charging system.

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Conflict of interest

No conflict of interest

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