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Economic Feasibility and Environmental Aspects of an Electric Vehicle by using Standalone Photovoltaic Energy

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ABSTRACT: Today, electric vehicles (EVs) have obtained much consideration for the transportation sector. However, charging EVs is a challenging task without polluting the environment. Again, almost all the EVs in Bangladesh are grid-dependent. A solar-based charging system of an EV is challenging especially when it comes to the sub-tropical monsoon area. In this research work, a solar-based charging system of an EV is investigated. The analysis found that this technology is economically viable and needs government support for ensuring clean mass transport. The internal rate of return (IRR), net present value (NPV), the benefit-cost ratio (BCR), annual life cycle savings are also found high enough for investment though the initial cost is high. Another important finding is the determination of greenhouse gas (GHG) emission savings as this technology is not dependent on traditional fuel sources.

Keywords: EV, Economic feasibility, GHG, Investment, Solar system.

Abbreviations: GHG, greenhouse gas; EV, electric vehicle; PBP, payback period; NPV, net present value; IRR, internal rate of return; BCR, benefit-cost ratio; PV, photo voltaic; V, voltage; BDT, Bangladesh taka; AMP, ampere; WH, watt-hour.

I. INTRODUCTION

Sustainable energy is now a burning issue in today's world. However, fossil fuels are the primary energy resources to mitigate the energy demand. Previous studies of Shafiee S. and Topal E. have discussed that the energy consumption rate increases 2% per annum [1]. Price is an exogenous variable that influences the consumption of fossil fuels. Consumers have to pay the highest amount for the residential electricity consumption per MW [2]. Renewable energy can play a significant role here, especially solar energy. It is more reliable, and less maintenance is needed. Within a week, total solar radiation is equal to the world's fossil fuel reserves [3]. This energy can be used not only for electricity generation purposes but also for the transportation sector. GHG emission is another parameter that leads to minimizing the use of fossil fuels. A study by Jaffery *et al.,* (2014) discussed that the transportation sector is responsible for 13.4% of total GHG emissions [4]. So, the solar photovoltaic projects have gained attention on EV charging.

Vogel (2009) described that EVs have more advantages than conventional ones [5]. Conversely, Zivin *et al.*, (2014) argued that EVs' advantages are lacking clarity when the emission is considered [6]. Electric vehicles have a negative impact on the environment. Fossil fuel is the main reason behind this result as the electricity produced from it. Nevertheless, electric vehicles are environmentally friendly in solar energy [7]. Over the past decade, most research in electric vehicles has emphasized clean energy sources like solar. Hafez and Bhattacharya (2017) investigated the optimum design for the EV charging station and found that the smart energy hub, including the solar energy, was the most optimum one [8]. One of the well-known tools for assessing the feasibility of a solar project is Retscreen software. This method is beneficial in studying the economic analysis of a project. In a study conducted by Akram *et al.*, (2016), it was shown that the design comparison between two solar projects based on performance ratio [9]. In 2013, Tulpule *et al.* published a paper on parking garage charging stations in which they found ten years of simple payback period and the NPV of $120,000 in 30 years [10]. Tulpule's (2013) work on economic feasibility is complemented by Castro's (2017) study of the feasibility of EV. In the study, Castro *et al.,* (2017) found that the investment return is near about six years for an EV with a particular solar system [11].

II. MODEL REPRESENTATION

Sizing of the System. Sizing a photovoltaic (PV) plant is essential to provide sufficient energy supply to the specific electric vehicles. The latitude of the Chittagong division in Bangladesh is 22.3, and the longitude is 91.8 as the project location. For the PV plant, the selection of a solar module is essential. In Table 1, different solar modules' specifications and their prices are described. Model 4 has been selected for investigation based on the efficiency size, and price.

Battery storage is also essential for any solar project. Different battery specification has been considered in Table 2. For this analysis, among them, Model 3 is considered. Moreover, the preferred inverter specification along with the price is shown in Table 3.
For a battery-based system, a solar charge controller is a critical component. It is generally not used in the grid-type solar system as there is no battery to charge. The charge controller's first goal is to manage charge for the battery bank—prevention of overcharging and managing the rate of current and voltages, which helps to protect the battery life. The specifications of the selected charge controller are given in Table 4.
For this research work, BYD e6 electric car has been selected. This electric car is composed of a 90 KWh motor and 61KWh battery capacity. The top speed of this vehicle is about 140Km/h. With an average speed of 85Km/h, the daily range is considered 1.1h or 93.5Km [14]. The average energy consumption is calculated based on the average energy demand in Watt-hour per day in Table 5.

Table 1: Specification of solar panel [12].

	Model 1	Model 2	Model 3	Model 4
Model name	PLM-310M-72	SW270P-60	ESPSC 285~310	Ine-275W-6M
Power(watt)	300	270	310	275
Cell type	Mono	Poly	Mono	Mono
Dimension	1956*992*40mm	1640*992*40mm	1956*992*45mm	1640*990*35mm
Max. operating (V)	36.59	30.88	37.3V	31.2
Short circuit current	8.78A	9.41	8.9A	9.26A
Max power current	8.20A	8.74	8.31A	9.09A
Efficiency	21.24%	16.97%	16%	18.85%
Warranty	25	25	25	25
Price(BDT)	12,540	7,900	11,144	9,886

Table 2: Specification of battery [13].

Model No.	Model Number	Voltage	Nominal Capacity	Weight	Type	Price(BDT)
Model 1	FCDG12-200	12V	200Ah	58.6 kg	Deep cycle solar gel	18,643
Model 2	RT122000	12V	200Ah	59 kg	Lead acid	17,640
Model 3	HTL12-300Ah	12V	300Ah	77 kg	Deep cycle solar gel	22,823
Model 4	CS12-250	12V	250Ah	70 kg	Deep cycle solar gel	21,736

Table 3: Specification of the selected Inverter [13].

Brand name	Hinergy
Model number	IVT3.0KW
Output power	1-200KW
Output current	30A-75A
Input voltage	12V/24V/48V
Output voltage	AC 120/220V/230V/240V
Warranty	3 years
Price(BDT)	22,238

Table 4: Specification of selected charge controller [13].

Brand name	I-panda
Model number	Master-100A
Type	Maximum power point tracking
Maximum current	100A
Rated voltage	12V/24V/48V
Weight	7.5 kg
Efficiency	96.5%-99%
Price (BDT)	27,588

Table 5: Daily energy consumption for BYD e6 electric car system.

Load	Quantity	Total Power	Use/ day (hr.)	Wh AC per day
Motor	1	90000	1.1	99000 Wh

Sizing of the Solar Array. Based on the efficiency, the required energy is calculated. The required energy can be found by the daily energy consumption ratio and the overall component's efficiencies [15].

Required energy $R_e = \frac{\text{daily avareage energy consumption}}{\text{overall component efficiencies}}$

$= \frac{99000}{.8}$ =123750 Wh

The selected location's average sunshine hours are about $T_{min} =$ 6.8h [16]. For determining the peak power, the required energy is divided by the average sun hours per day [17].

Peak power, $P_p = \frac{R_e}{T_{min}} = \frac{123750}{6.8}$=18199Wp

The total current is needed is calculated by the ratio of the peak power and the system DC voltage. For this research study, 24V is selected as the system voltage [17].

Current needed, $I_{dc} = \frac{\text{peak power}}{\text{system voltage}} = \frac{18199}{24}$=759 Amps

For getting the desired voltage and current, the modules are connected in series and parallel. The rated current for one module is determined by the ratio of the selected module power and the maximum operating voltage [18].

Rated current of one module = $\frac{275}{31.2}$

=8.82 Amps

The number of parallel modules is found as the equation given below [19]:

Number of parallel modules,

$N_p = \frac{\text{whole module current}}{\text{rated current of one module}} = \frac{759}{8.82}$ = 86

As the maximum operating voltage is 31.2V for the selected solar module, so 24V is taken as the module rated voltage for this research work [28].

Number of series modules, $N_s = \frac{\text{system DC voltage}}{\text{module rated voltage}} = \frac{24}{24}$ =1

Finally the total number of modules needed for the system are, $N_m = N_p \times N_s$=86 × 1 =86

For the natural law, the module's efficiency and the ability to produce energy is decreased. 4% is considered as the decreasing rate for this investigation. The project will start with 86 panels, and after the year of 25, this project is needed 121 solar modules. The optimal azimuth and slope for Chittagong region are 0°, 24° respectively [20].

Sizing of the Battery. Sizing of the battery is important for the solar system. The amount of energy required can be calculated as the equation given below [21]:

$$= \frac{\text{total average energy use} \times \text{days of autonomy}}{\text{maximum depth of discharge} \times \text{DC voltage}} = \frac{99000 \times 1}{.8 \times 12}$$

$$= 1032\ Wh$$

The number of batteries required,

$N_b = \frac{capacity\ of\ the\ battery\ bank}{nominal\ capacity\ of\ the\ selected\ battery} = \frac{1032}{300}$= 4 batteries

The number of batteries in series N_s and parallel N_p will be determined as below [22]:

$N_s = \frac{system\ voltage}{voltage\ of\ the\ battery} = \frac{24}{12}$= 2

Number of batteries in parallel, $N_p = \frac{N_b}{N_s} = \frac{4}{2}$ =2

III. FINANCIAL AND ECONOMIC VIABILITY

In this section, IRR, NPV, BCR and PBP are determined. NPV can be determined from the difference between the present value benefit and present value cost, which can be shown as below [22]:

$$\sum_{n=0}^{N} \frac{B_n}{(1+i)^n} - \sum_{n=0}^{N} \frac{C_n}{(1+i)^n} = PVB - PVC$$

Here, B_n= expected benefit at the end of the year n, C_n= expected cost at the end of year n, i = discount rate, n=project duration in years, N= project period, PVB = present value benefit and PVC = present value cost. If the NPV is greater than zero, it means that the project will add value to the firm or investor and create wealth for shareholders.

The IRR that can be gained on the unrecovered project balance of the investment [29]. If the IRR is greater than the minimum acceptable rate of return or discount rate, the PV project is known as an economic viable project. This can be shown as below equation [22]:

$$\sum_{n=0}^{N} \frac{B_n}{(1+i)^n} - \sum_{n=0}^{N} \frac{C_n}{(1+i)^n} = 0$$

Here, i=IRR.

BCR is the ratio between the total present value benefit and total present value cost as shown in the below [17]:

$$BCR = \frac{PVB}{PVC}$$

By the payback period, the project break-even point can be shown and it is calculated as given below [17]:

$$\sum_{n=0}^{N} (B_n - C_n)$$

The total cost of this project is shown in Table 6. Now, the total development cost for the electric car= Solar panel cost + Battery cost + Charge controller cost + inverter cost + installation cost = 1196206+91292+22238+27588+119621 = BDT 1456945.

The financial analysis deals with whether the investment or the developed model is financially stable or not. For this purpose, RETscreen software is used. Different influencing factors have been considered for this analysis. The inflation rate is considered 5.70% [23]. The fuel cost escalation rate is also considered, and that is 7%. Again, for the low single phase 230V and 50Hz cycle, the electricity bill rate for the business and commercial is 12.36 BDT/KWh [24]. Moreover, the minimum discount rate in Bangladesh is 5% [25]. Considering the current energy prices and required energy, through the Retscreen software saving income summary was found. The periodic cost is considered about 8% of the PV cost per 4 Years. Moreover, the spare parts cost is considered 2% of the PV cost. Table 7 shows an overview of the financial viability of the project.

Table 6: Total cost of the project.

Item	Required unit	Cost per unit BDT/unit	Cumulative cost BDT
Solar panel	121	9886	1196206
Battery	4	22823	91292
Inverter	1	22238	22238
charge controller	1	27588	27588
Installation cost		10% of PV cost	119621
Operation and maintenance cost/ year		3% of PV cost	35887
Total			1492832

Table 7: Financial viability of the project.

	Financial viability	
Pre-tax IRR – equity		41.6%
Pre-tax IRR – assets		41.6%
After-tax IRR – equity		41.6%
After-tax IRR – assets		41.6%
Equity payback	Year	2.6
Simple Payback	Year	3.0
Annual life cycle savings	BDT/year	986,855
Benefit-Cost (BCR) ratio		10.39
Net present value	BDT	13,908,675
GHG reduction cost	BDT/tCO_2	42,950

A project's investment will be profitable if the IRR exceeds the market interest rate and the NPV also more remarkable than zero [26]. It is apparent from this table that the IRR is far greater than the minimum discount rate. Moreover, the NPV is BDT 13,908,675, which is much greater than zero. While saving can be defined as expanding the reserve against unexpected accidents [27]. For annual life cycle saving, it is BDT/year 986,855. The single most striking observation is the simple PBP which is only three years in a 25 years lifespan. The cumulated cash flow is also given in Fig. 1.

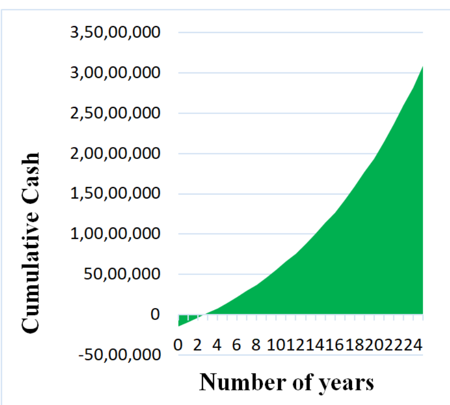

Fig. 1. Cumulated cash flow of the project.

IV. EMISSION ANALYSIS

GHG emission is also analyzed for the project. Natural gas is the main energy source to produce electricity in Bangladesh. In this research work, natural gas is exchanged by the PV system to determine the emission analysis. For electricity producing purpose, 0.578 tone CO_2 is decreased if the solar system is used rather than using the natural gas. By using this project, per year 23 tones of CO_2 emission can be reduced.

V. DISCUSSION

Prior studies that have noted the importance of electric vehicle for the transportation sector. Several reports have shown that for charging the electric vehicle, solar-based charging stations have gained attention. The initial objective of this project was to identify economic viability. Based on IRR, NPV, and BCR values, the project is an economically captivating one. Another interesting finding was that the project would be helped in maintaining the GHG reduction cost BDT/tCO_2 42,950 per year. Surprisingly, the project's simple payback period is three years only in 25 years of project life. These results further support the research of Castro *et al.* (2017) [11]. Therefore, the solar system may be a crucial source shortly.

VI. CONCLUSION

The present research aimed to examine the economic feasibility of a solar system for an electric vehicle. This study has shown that the proposed project of the solar system is financially viable for the investor. The second significant finding was the greenhouse gas emission analysis of the system. These findings suggest that the project is a profitable one in general though the initial investment cost is high.

VII. FUTURE SCOPE

This study lays the groundwork for future research into a solar-based electric vehicle. The scope of this study was limited in terms of risk analysis. Further research could usefully explore how this system can be implemented in the mass transportation sector.

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Conflict of Interest. No.

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