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Feasibility and Cost Analysis of Photovoltaic-Biomass Hybrid Energy System in Off-Grid Areas of Bangladesh

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Abstract: In this progressing technological advancement world, hybrid systems for power generation is one of the most promising fields for any researcher. In this context, photovoltaic-biomass hybrid systems with off-grid applications have become extremely popular with both Governments and individual users in rural areas of any part of the world. This system has gained popularity because of low cost, sustainability and very effective outcome with the use of natural resources at the rural areas. In this paper a proposed hybrid system which contains photovoltaics (PV) and biomass along with an additional storage has been considered to find the different aspects from an end user point of view. It also discusses the feasibility of the proposed model for an off-grid power system located in the remote areas of Ashuganj, Bangladesh. In order to analyse the pollutant emissions and calculate the cost parameters of the proposed system, RETScreen simulation software was deployed. This research also carries out a brief financial analysis considering the annual income of the end user and the payback periods for the installed system. It endeavours to provide complete information about different parameters which also includes the environmental impacts involved in establishing the proposed system. The conventional system in the pilot area is a kerosene-based system, hence in this research, a comparison between the proposed and the conventional system has been analysed using simulated results. The simple payback of the project was estimated to be 6.9 years and this model will be able to reduce the CO_2 emissions by approximately 3.81 tonnes per year. The results have significantly supported the proposed system to be more reliable, environmentally-friendly and less costly than the conventional kerosene-based system.

Keywords: photovoltaics (PV); biomass; battery storage; off-grid electrification; feasibility analysis; cost analysis; simple payback period; CO_2 emissions; renewable energy

1. Introduction

Electricity is the major source of energy in most urban systems worldwide. Since the first high-voltage Alternating Current (AC) coal power station was commissioned in London in 1890, electrification of residential and industrial installations has grown exponentially expanding toe 83% of all urban areas by 2010 [1]. Even with a projection of increased electricity use for future energy systems the electrification of rural areas still represents a relevant issue. Such expanded use will likely seriously affect different sectors of developing economies, ranging from industrial to transportation uses [2]. In particular, the augmenting of current electricity distribution grids in rural areas, which are located far from the main national grid, may result in excessive costs in terms of installation, transmission, distribution, and maintenance [3,4]. Indeed, the electrification of rural areas through the extension of grid connections may raise the overall generation costs, which could reach up to seven times the normal price obtainable in urban areas [4]. Some studies have been focussed on operational performance of the Bangladesh rural electrification program and its determinants with a focus on political interference [5–8]. Per [5] for instance, complete electrification through Bangladesh will take many years, and thus the diminishing returns to scale of incremental investment for further rural electrification will be faced in the long run. The authors suggested that both Bangladesh and international donors revisit the original principle of the Rural Electrification Program, eradicate political hindrances from the program, and make sustained efforts to develop more efficient infrastructure of delivering electricity to the rural poor and encouraging local economic development.

Another issue of concern is the unreliability in frequency, blackouts, power losses, and fluctuations of the grid voltage. In such cases, the proper use of Renewable Energy Sources (RESs) in remote areas could represent a viable and economical alternative to the extension of electricity grids [9–11].

Authoritative studies have shown that hybrid stand-alone electricity-generating systems are more economically feasible for off-grid consumers located in distant areas [12,13]. In addition, RES installations can also reduce the amount of CO_2 emissions emanating from electrical energy generation. Studies in Bangladesh have demonstrated, in fact, that 1kWh of electricity generated by solar photovoltaic (PV) systems can reduce the amount of CO_2 emissions by approximately 660 tonnes per year [14]. However, the use of stand-alone PV systems in off-grid applications also presents certain drawbacks, mainly related to the intrinsic intermittency and stochasticity of the solar source. To overcome these drawbacks, the use of electrical Energy Storage System (ESS) solutions is usually implemented [15,16], along with the adoption of hybrid configurations, i.e., by adding traditional controllable power generators (such as diesel-electric motors), to support the intermittency and unreliability of PV systems.

Currently, in off-grid PV systems, the use of large ESS solutions is usually considered economically unviable due to the high investment costs, that is, high costs of storage devices [17,18], whereas the combined adoption of PV with ESS and diesel-electric generators has been widely adopted [19]. Nevertheless, increasing concern about global warming and environmental pollution is propelling the replacement of generators that were traditionally powered by fossil fuels, while there is more interest in adopting greener solutions. To this end, the use of biomass generators could indeed represent an interesting alternative, due both to its low carbon impact and its lower investment and developmental costs.

As indicated in the literature, numerous feasibility and techno-economic studies were performed on micro-grid projects in different countries, specifically on stand-alone hybrid energy systems for applications in remote areas [20–45]. The inference drawn is that it appears that no feasibility study or other similar work has been conducted on such a system in the remote communities of Bangladesh; thus, the present study is an original research initiative and a firm contribution to knowledge.

Considering the environmental and cost concerns described earlier, the purpose of this paper is a feasibility study of the potentials and likely impact of a hybrid PV-biomass system as a possible option for the provision of power in a rural area of Bangladesh. The primary objective of the study is to present a preliminary design of a hybrid PV-biomass system that is capable of satisfying the energy needs of the selected off-grid application, and to compare its economic performance in respect of existing solutions, by making use of discounted cash flow and payback period analyses. The paper examines the technical, economic and environmental feasibility, both the integration and sizing of a hybrid PV-biomass system, and the energy storage of microgrid for remote electrification within Ashuganaj, Bangladesh. In addition, the impact of related CO_2 emissions is also analysed, and compared to traditional solutions. The study is essentially performed employing the simulation tool referred to as RETScreen [46].

The paper is organised as follows: Section 2 gives a full description of the proposed project location as well as the simulation methods; also provides the load profiles and climate data related to the project location and Section 3 presents details on the proposed PV-biomass hybrid system. Simulation results are discussed in Section 4, including the sizing of the system, the cost and emissions analyses, while conclusions are drawn in Section 5.

2. Project Location and Simulation Methods

2.1. Simulation Method

Many studies have analysed renewable energy systems using RETScreen [47–51]. RETScreen software was employed in this design to achieve the least energy costs that people will find affordable [52]. The RET Screen Clean Energy Management Software (usually shortened to RET Screen) is a clean energy software package developed by Ministry of Natural Resources Canada (Government of Canada) for evaluating both financial and environmental costs and benefits of different renewable energy technologies for any location in the world. This software uses visual basic and C language as working platform. RETScreen PV model also covers off-grid PV applications and include stand-alone, hybrid and water pumping systems also. It has a global climate data database of more than 6000 ground stations (month wise solar irradiation and temperature data for the year), energy resource maps (i.e., wind maps), hydrology data, product data like solar photovoltaic panel details and wind turbine power curves. It also provides link to NASA climate database. It enables comprehensive identification, assessment and optimization of the technical and financial viability of potential renewable energy and energy-efficient projects. It also allows measurement and verification of the actual performance of facilities and identification of energy savings/production opportunities. The software tool can determine the technical and financial viability of renewable energy, energy efficiency and cogeneration projects. The area number of worksheets for performing detailed project analysis includes Energy Modelling, Cost Analysis, Emissions Analysis, Financial Analysis and Sensitivity and Risk Analyses sheets. The analysis of different types of energy efficient and renewable technologies (RETS) covers mainly energy production, life-cycle costs and greenhouse gas emission reduction. In summary, RETScreen Plus is a Windows-based energy management software tool to study the energy performance [51,52].

This simulation process empowers experts and decision-makers to identify and evaluate the technical and financial viability of potential clean energy projects and also to measure and verify the actual and ongoing energy performance of energy-efficiency projects. The process also enables the evaluation of energy production, life-cycle costs and greenhouse gas emission reductions for the proposed Hybrid system [46]. The flowchart used in the simulation tool is shown in Figure 1.

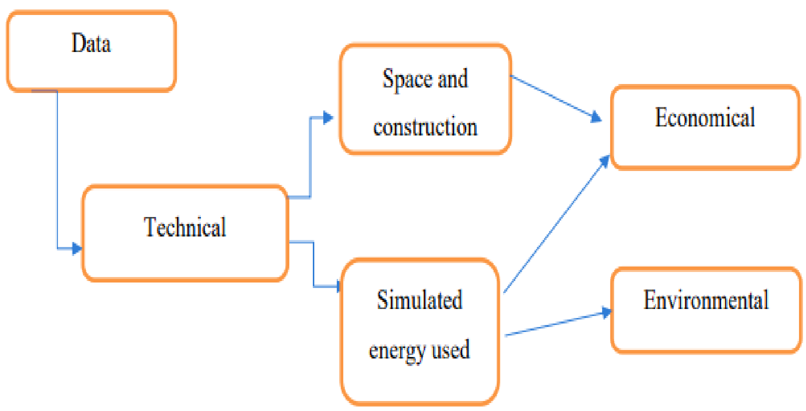

Figure 1. RETScreen technical evaluation structure flowchart [53].

Ashuganj city located in the Brahmanbaria District of Chittagong Division in Bangladesh, was selected as the reference site for the application and evaluation of the proposed hybrid PV-biomass system. The city was selected because of its residents' pervasive dependence on fossil fuels to meet their energy needs, due to the absence of a power grid extension. Residents situated close to the city depend mainly on horticulture and animal husbandry for their livelihood. Therefore, in rural areas, it is economical to use hybrid systems comprising solar and biomass, provided the biomass supply is consistently available. In most of the areas, manure, crop wastes and cooking wastes are accessible free of charge.

2.2. Load Profile and Climate Data of Project Location

The load demand of the proposed system is estimated by reference to a household load (4 LED light, 2 DC fan and 1 DC TV) for a typical lower middle-class family. The study evaluated fifty houses for provision of electricity for the proposed hybrid system (Table 1). The actual daily average energy demand for fifty houses is calculated as 45.6 kWh.

Table 1. Load profile.

Daily Load Profile						
Appliance	**Type**	**Unit**	**Watt**	**Hour of Operation (h)**	**Total Power (W)**	**Total Energy Demand (Wh)**
LED	DC	4	6	8	24	192
Fan	DC	2	20	14	20	560
TV	DC	1	40	4	40	160
Daily Demand for each house					84	912
Daily Demand for 50 houses					4.2 kW	45.6 kWh

The load characteristics are calculated on the basis of three seasons: summer (March–June), spring (July–October) and winter (November–February). The RETScreen software calculates the monthly and yearly energy consumptions for the load based on the following indices: appliance used, season, weather condition based on location, number of people per house and number of total houses. Considering the system loss, the daily average energy demand is estimated as 47.2 kWh which is higher than the actual demand and annual energy demand is 14.161 MWh for both the base case and the proposed case. The detailed data of monthly and yearly energy consumption is shown in Table 2. In winter season the load demand is comparatively lower than the other two seasons. Therefore, it is considered 54%. In spring season considering the weather condition, the percentage of energy use is 93%. Due to the extreme hot weather in summer the percentage of energy is considered 99%.

As mentioned earlier, this paper discusses the feasibility study of the proposed hybrid system with RETScreen. The financial analysis has been carried out for systematic progression towards a PV-Biomass-based hybrid system. We need to determine the latitude and longitude of the study area and analysis is done to derive the climate data. The RETScreen software gives complete weather details based on climate location. Table 3 indicates the climate data location and the project location which has been collected from NASA by RETScreen. The daily solar radiation, air temperature, humidity and earth temperature data are also collected for the reference location to check the feasibility of solar project implementation. The detailed data are shown in Table 4.

Table 2. Load characteristics of base and proposed cases.

Load Characteristics		
Electricity-DC	**Base Case**	**Proposed Case**
Daily	47.2 kWh	47.2 kWh
Annual	14.161 MWh	14.161 MWh
Peak Load-Annual	4.7 kW	
Percentage of Month Used		
Month	**Base Case**	**Proposed Case**
January	54%	54%
February	54%	54%
March	93%	93%
April	93%	93%
May	93%	93%
June	93%	93%
July	99%	99%
August	99%	99%
September	99%	99%
October	99%	99%
November	54%	54%
December	54%	54%

Table 3. Ashuganj site reference data.

Parameter	Unit	Climate Data Location	Project Location
Latitude	°N	24.1	24.1
Longitude	°E	91.9	91.9
Elevation	m	14	14
Heating design temperature	°C	13	
Cooling design temperature	°C	30.9	
Earth temperature amplitude	°C	13.5	

Table 4. Site reference conditions.

Month	Ambient Air Temperature °C	Relative Humidity %	Daily Solar Radiation $kWh/m^2/d$	Earth Temperature °C
January	20.4	54.7	4.42	21.6
February	22.7	55.3	4.98	23.9
March	25.2	61.7	5.44	27
April	26.3	73.1	5.51	28.1
May	27.1	79.1	5.11	28.8
June	27.5	84.7	4.16	28.4
July	27.3	85.9	4.04	27.9
August	27.1	85.5	4.18	27.8
September	26.7	84.1	4.02	27.6
October	26	77.9	4.28	26.8
November	23.8	69.4	4.25	24.4
December	21.3	60.1	4.28	22.1
Annual	25.1	72.7	4.55	26.2

3. The Proposed PV-Biomass Hybrid System

The proposed system consists of electric DC loads, solar PV, biomass generator, battery, and converter. Figure 2 demonstrates the block diagram of the proposed system. The system is fed by

PV arrays and a biomass generator. There is no grid connection between the systems. Biomass is an abundant source of energy around the world, which is composed of organic matter including agricultural residues, and wood, animal and human wastes. Use of biomass for the purpose of power generation has become very popular, especially since it is an easily obtainable source of energy in the rural parts of Bangladesh. Additionally, it is a cleaner source of energy than fossils throughout the world. Its relative abundance makes it a viable option for use as a potential source of energy for electricity-generation in the country where it comprises animal manure that can either be converted through the absorption process or its residues extracted through the combustion process. In this system hybrid solar and biomass system was chosen as biomass is accessible effectively in the form of manure throughout the year. This hybrid system using biomass and solar with a battery as a storage system for electricity generation is more economical, because it can generate electricity during cloudy days also.

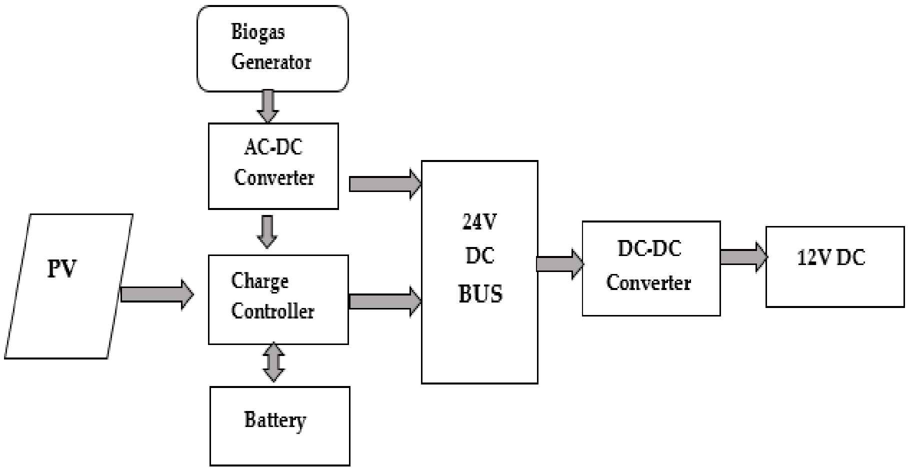

Figure 2. Block diagram of proposed photovoltaics (PV)-biomass hybrid energy system.

In the proposed system, the AC generator is used. Here, the output of the generator is converted into 24 V DC using the AC to DC converter and then connected to 24 V DC bus bar. Finally, DC to DC converter is used in every house to convert 24 V DC to 12 V DC to operate the DC house load.

The total capital cost of 1 kW biogas fuel-based generator considered as BDT (Bangladeshi Taka) 60,000/kW (USD $714.29/kW) and the lifetime of the generator is specified in hours of operation. The lifetime of the generator is considered as 15,000 hr. The efficiency of the generator is considered as 80%. We estimate the cost per tonne of biogas at BDT 70 (USD $0.833) based on biomass resources being obtainable almost free of charge.

4. Results and Discussion

RETScreen software has been used to analyse the different parameters of the proposed case and finally, the proposed case was compared with the base case. After the comparison, based on the financial viability, annual savings and evaluation of GHG emissions it can be easily deduced that the proposed case is more beneficial than the existing one. Analysis types and methods selected in RETScreen are mini-grid and method two respectively.

4.1. Base Case Power Study

Having chosen an off-grid area, the kerosene lamp was evaluated as a power source in the base case. Estimated total power capacity for base case is 4.70 kW. We estimated the cost of a litre of kerosene to be BDT 65 (USD $0.77) and so the total cost of electricity is calculated as BDT 474,702 (USD $5651.21) for the existing kerosene-based system by RETScreen. Table 5 indicates the unit cost and total electricity cost for the base case.

Table 5. Base case power system.

Parameter	Value
Grid Type	Off-grid
Fuel type	Kerosene-L
Fuel rate	65 BDT/L
Capacity	4.7 kW
Heat rate	8 kJ/kWh
Annual O& M cost	BDT 474,500
Electricity rate-base case	33.512 BDT/kWh
Total electricity cost	**BDT 474,702**

From the simulation, it was evident that the unit cost of electricity for the existing system is very high and also harmful to the environment. A new system has been proposed for this reason.

4.2. Proposed Case Power Study

In the proposed case analysis, mono-crystalline silicon PV solar cell with a power capacity of 12.9 kWp, and an efficiency of 13.1% was used. In this model maximum power point tracker is used as a control method and miscellaneous losses are considered as 5%. To fulfil the peak time energy demand biomass generator is used where the biomass rate is BDT 70/tonne (USD $0.83/tonne) and capacity of the generator is considered as 1 kW. As a storage system and an emergency backup, battery has been used. In this system, a total of 9 batteries are considered where each battery has a capacity of 24 V, 200 Ah. A one-day autonomy has been estimated for reliable power supply. The total capacity of the battery bank of 1800 Ah and 43 kWh is considered. Figure 3 presents the battery, PV and biomass generator specification that is given as an input in RETScreen and also shows that for the given combination approximately 81.2% of total energy comes from PV while the remainder of the energy comes from biomass generator. Thus, the total annual energy delivered to the load from PV and biomass generator are 13.98 MWh and 3.2 MWh respectively. Therefore, from the proposed system yearly 17.185 MWh energy can be produced which can easily fulfil the required load demand of 14.161 MWh.

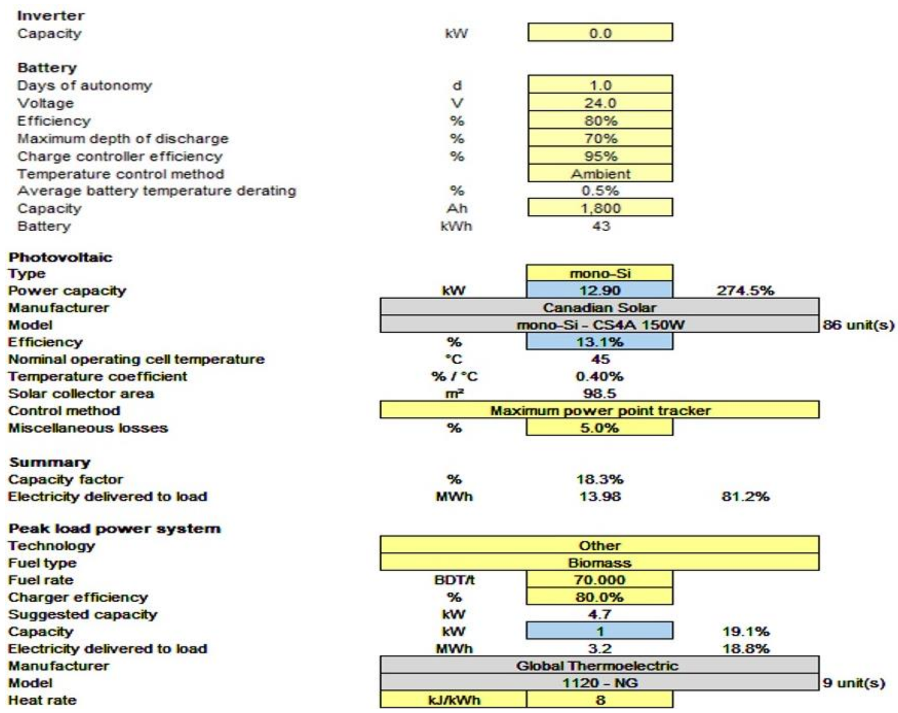

Figure 3. The specification of different components and energy produced by each source. Notation—Mono-Si: Monocrystalline silicon; CS4A: Multi-contact connector type 4.

In the proposed system, since most of the energy comes from PV, it produces clean energy and reduces CO_2 emissions compared to the existing system.

4.3. Cost Analysis

In order to analyse the costs of the proposed system, the initial, annual, and periodic costs as well as credits for any base case costs that are avoided in the proposed system are analysed. Before implementing the project in Ashuganj it is necessary to test the feasibility of the project to determine its suitability for the selected area. To check the climate feasibility, some testing is necessary which comes at a cost. For a "Feasibility analysis," more detailed and more accurate information is usually required. The calculations performed by the RETScreen Software for this step are straightforward and relatively simple (addition and multiplication). Figure 4 shows the detailed cost calculation for the project.

Initial costs (credits)	Unit	Quantity	Unit cost	Amount
Feasibility study				
Feasibility study	cost	2	BDT 3,000	BDT 6,000
Subtotal:				**BDT 6,000**
Development				
Development	cost	2	BDT 3,000	BDT 6,000
Subtotal:				**BDT 6,000**
Engineering				
Engineering	cost	2	BDT 4,000	BDT 8,000
Subtotal:				**BDT 8,000**
Power system				
Base load - Photovoltaic	kW	12.90	BDT 28,000	BDT 361,200
Peak load - Other	kW	0.90	BDT 60,000	BDT 54,000
Road construction	km	0	BDT -	BDT -
Transmission line	km	1	BDT 1,200,000	BDT 1,200,000
Substation	project	1	BDT 100,000	BDT 100,000
Energy efficiency measures	project	1	BDT 20,000	BDT 20,000
Battery	cost	9	BDT 24,000	BDT 216,000
				BDT -
Subtotal:				**BDT 1,951,200**
Balance of system & miscellaneous				
Spare parts	%	0.0%	BDT -	BDT -
Transportation	project	15	BDT 400	BDT 6,000
Training & commissioning	p-d	8	BDT 1,000	BDT 8,000
User-defined	cost		BDT -	BDT -
Contingencies	%	10.0%	BDT 1,985,200	BDT 198,520
Interest during construction	7.00%	1 month(s)	BDT 2,183,720	BDT 6,369
Subtotal:				**BDT 218,889**
Total initial costs				**BDT 2,190,089**

Figure 4. Initial cost of proposed system. Notation—BDT: Bangladeshi Taka.

In cost analysis, it has been observed that the total initial cost is BDT 2,190,089 (USD $26,072.49) where 89.1% cost comes from power system sources such as PV, battery, biomass generator while the remaining cost components are from feasibility study and system miscellaneous. In the proposed system the lifetime of the PV, battery and converter have been based on 25 years, 5 years and 10 years respectively. Therefore, at full project life in 25 years the battery will require replacement 4 times, while the converter will be replaced twice. For the proposed system the total annual cost is BDT 167,696 (USD $1996.38). In periodic cost, it is seen that the battery replacement cost in full project life is BDT 403,200 (USD $4800), and converter cost is BDT 89,600 (USD $1066.67). After all the expenses the annual savings from the project is BDT 474,702 (USD $5,651.21) which is provided in Table 6.

Table 6. Annual saving of proposed system.

Project Costs and Saving/Income Summary			
Initial Cost			
Feasibility study	0.3%	BDT	6000
Development	0.3%	BDT	6000
Engineering	0.4%	BDT	8000
Power system	89.1%	BDT	1,951,200
Balance of system & misc.	10.0%	BDT	218,889
Total initial costs	100%	BDT	2,190,089
Annual Costs & Debt Payments			
O & M		BDT	159,375
Fuel cost-proposed case		BDT	0
Debt payments-25 yrs		BDT	8321
Total Annual costs		BDT	167,696
Periodic Costs (credits)			
Battery-5 yrs		BDT	403,200
Converter-10 yrs		BDT	89,600
End of project life-cost		BDT	376,832
Annual Savings and Income			
Fuel cost-base case		BDT	474,702
Total annual savings and income		BDT	474,702

4.4. Financial Viability & Cumulative Cash Flow Analysis

The RETScreen Software enables a user to input various forms of financial data such as discount rates, etc., which it automatically calculates to produce key financial feasibility indicators such as simple payback, equity payback, and net present value. Based on the data entered by the user, financial indicators for the project being analysed are provided, thus deriving vital information which facilitates the project evaluation process for planners and decision-makers [54].

The simple payback SP is the number of years it takes for the cash flow (excluding debt payments) to equal the total investment (which is equal to the sum of debt and equity):

$$SP = \frac{C - IG}{\left(C_{energy} + C_{capacity} + C_{RE} + C_{GHG}\right) - \left(C_{O\&M} + C_{fuel}\right)} \tag{1}$$

where, C is the total initial cost of the project and IG is the value of incentives and grants. C_{energy}, $C_{capacity}$, C_{RE}, and C_{GHG} are annual energy saving or income, annual capacity saving or income, annual renewable energy production credit income and greenhouse gas reduction income respectively. $C_{O\&M}$, C_{fuel} represent the yearly operation and maintenance cost and yearly cost of fuel or electricity respectively.

Similarly, the year-to-positive cash flow (also equity payback), N_{PCF} is the first year that the cumulative cash flows for the project are positive. It is calculated by solving the following equation for N_{PCF}:

$$0 = \sum_{n=0}^{N_{PCF}} \overset{>}{C}_n \tag{2}$$

where, $\overset{>}{C}_n$ is the after tax cash flow in year n.

The net present value NPV of a project is calculated by discounting all cash flows as given in the following equation:

$$NPV = \sum_{n=0}^{N} \frac{\overset{>}{C}_n}{(1+r)^N} \quad (3)$$

where, N is the project life in years and r is the discount rate.

Discounted payback period, DPBP can be calculated that can be calculated that the discounted cash flow method discounts each inflow considering the time value of money until NPV equals zero at the certain year n of the system operation as indicated in Equation (4) [55,56].

$$\sum_{n=0}^{DPBT} \frac{CIn - COn}{(1+c)^n} = 0 \quad (4)$$

where, CI: cash inflow; CO: cash outflow; C: cost opportunity of capital; n: time period.

The annual life cycle savings ALCS is calculated using the following formula:

$$ALCS = \frac{NPV}{1 - \frac{1}{(1+r)^N}} \quad (5)$$

From the cash flow diagram depicted in Figure 5 using RETScreen, it can be estimated that it takes 7.2 years for cash flow to become positive and that the simple payback period will be 6.9 years. From the financial viability analysis, we get a Net Present Value (NPV) of BDT 855,428 (USD $10,183.67) and annual life cycle saving is BDT 73,405 (USD $873.87) and equity payback period is 7.2 years. In terms of the project's economics, we can say that the proposed hybrid system is the most economical one because after 7 years the project will start to generate profit and reduce the system's overall costs.

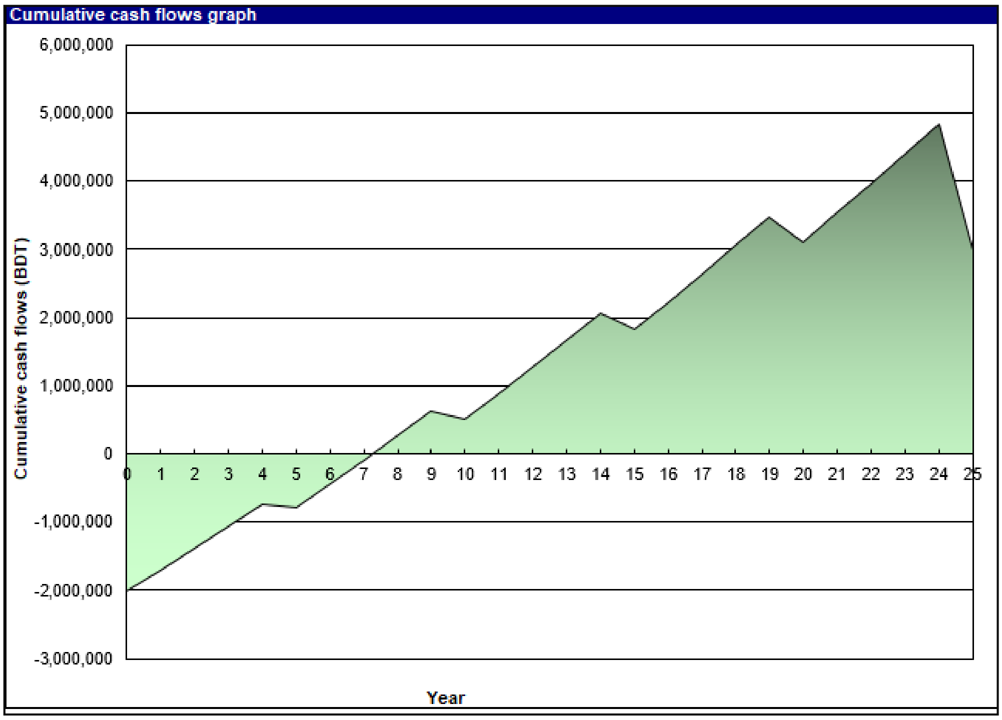

Figure 5. Cumulative cash flows.

4.5. Emissions Analysis

The emissions' analysis estimates the greenhouse gas emission-reduction (mitigation) potential of the proposed case. RETScreen estimates the annual GHG emission reduction, ΔGHG of electricity by utilising the following Equation:

$$\Delta_{GHG} = \left(e_{base} - e_{proposed}\right)E_{proposed}\left(1 - \lambda_{proposed}\right)(1 - e_{credit}) \quad (6)$$

where e_{base}: base case GHG emission factor; $e_{proposed}$: proposed case GHG emission factor; $E_{proposed}$: proposed case annual electricity produced; $\lambda_{proposed}$: the fraction of electricity lost in transmission and distribution (T&D) for the proposed case. For off grid system consider the value of $\lambda_{proposed}$ is zero; e_{credit}: the GHG emission reduction credit transaction fee.

For a single fuel type or source, the following formula is used to calculate the base case electricity system GHG emission factor, e_{base}:

$$e_{base} = (e_{CO2}GWP_{CO2} + e_{CH4}GWP_{CH4} + e_{N2O}GWP_{N2O})\frac{1}{\eta}\frac{1}{1-\lambda} \quad (7)$$

where e_{CO2}, e_{CH4}, and e_{N2O} are respectively the CO_2, CH_4 and N_2O emission factors for the fuel/source considered, GWP_{CO2}, GWP_{CH4}, and GWP_{N2O} are the global warming potentials for CO_2, CH_4 and N_2O, η is the fuel conversion efficiency, and λ is the fraction of electricity lost in transmission and distribution. For standard analysis consider GWP_{CO2}, GWP_{CH4}, and GWP_{N2O} as 1, 21, and 310.

In cases for which there are a number of fuel types or sources, the GHG emission factor $e_{proposed}$ for the electricity mix is calculated as the weighted sum of emission factors calculated for each individual fuel source:

$$e_{proposed} = \sum_{i=1}^{n} f_i e_{proposed,i} \quad (8)$$

where n is the number of fuels/sources in the mix, f_i is the fraction of end-use electricity coming from fuel/source i, and $e_{proposed,i}$, is the emission factor for fuel i, calculated through a formula similar to Equation (8):

$$e_{proposed,i} = (e_{CO2,i}GWP_{CO2} + e_{CH4,i}GWP_{CH4} + e_{N2O,i}GWP_{N2O})\frac{1}{\eta_i}\frac{1}{1-\lambda_i} \quad (9)$$

where, $e_{CO2,i}$, $e_{CH4,i}$, and $e_{N2O,i}$ are respectively the CO_2, CH_4 and N_2O emission factors for fuel/source i, η i is the fuel conversion efficiency for fuel i, and λ_i is fraction of electricity lost in transmission and distribution for fuel i. Consider all λ_i are zero in case of mix of duel/sources [54].

Table 7 reports the estimated GHG emissions reduction in the proposed system. From the result, it is evident that the proposed system reduces the CO_2 emissions by 0.269 tonne/MWh compared to the base case.

Thus, using Equation (6), we can calculate the yearly CO_2 reduction in the proposed system for 14.161MWh annual electricity production which is 3.81 tonnes. Therefore, we can say that the proposed system is cost effective and also environmentally-friendly.

$$\Delta_{GHG} = (0.269 - 0)X\ 14.161 = 3.81\ tonnes \quad (10)$$

Table 7. Emissions analysis.

Base Case System GHG Summary (Baseline)						
Fuel type	**Fuel Mix %**	**CO_2 emission factor Kg/GJ**	**CH_4 emission factor Kg/GJ**	**N_2O emission factor Kg/GJ**	**Fuel Consumption MWh**	**GHG emission factor tCO_2/MWh**
Kerosene	100%	73.9	0.0070	0.0020	0	0.269
Total	100%	73.9	0.0070	0.0020	0	0.269
Proposed Case System GHG Summary (Power Proposed Project)						
Fuel type	**Fuel Mix %**	**CO_2 emission factor Kg/GJ**	**CH_4 emission factor Kg/GJ**	**N_2O emission factor Kg/GJ**	**Fuel Consumption MWh**	**GHG emission factor tCO_2/MWh**
Biomass	0.1	0	0.032	0.004	0	0.007
Solar	99.9	0	0	0	14	0
Total	100%	0	0	0	14	0

5. Conclusions

This paper highlighted the benefits of using a hybrid energy system consisting of both solar energy and biomass energy to reduce energy costs and CO_2 emissions. The design was compared with data from the RETScreen data and also with the existing kerosene-based system. Due to the lack of the regional power grid, and available local resources, photovoltaic panel, biogas generator along with battery storage bank are the best solution for providing electricity in future. The paper demonstrated that the hybrid mini-grid system is the most economical and reliable for rural areas. Another useful part of employing a hybrid system is the minimal use of biomass generator which ultimately reduces the greenhouse gas emissions. The only drawback in this system is the battery cost. So, to make this proposed system a reliable one the government should take step to reduce the battery cost. In this hybrid energy model, simulation results showed that 81.2% of total energy is produced by PV and the rest of the energy comes from biomass generator. The simple payback of the project was estimated to be 6.9 years and this project will be able to reduce the CO_2 emissions by approximately 3.81 tonnes per year. The study proved that the proposed system is more reliable and cost-effective and also more environmentally friendly when compared with the kerosene-based system.

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