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GHG Emission Reduction Analysis Regarding Financial Viability of Grid-connected PV Solar System

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Abstract

Sustainable Development Goal 13 is an activity committed with the intention of stabilizing greenhouse gas (GHG) levels in the environment to stop potentially harmful human meddling with the climate system. GHG are released into the environment from various non-renewable energy sources of power generation and many industries that cause extensive damage to the environment. Some countries have begun to implement various pollution prevention strategies such as power generation from renewable energy sources, which emit no greenhouse gases (GHG) or CO_2. This study focuses on an analysis of GHG emission reduction along with the financial feasibility of a grid-connected 100MW PV solar system. This study uses the RETScreen software to evaluate the GHG emission reduction analysis as well as a financial analysis of the system. The annual electricity supplied to the local grid of the proposed PV power plant is 137,481 MWh. The cost of reducing CO_2 emissions has a positive impact on the overall cumulative cash flow of the proposed system.

Keywords: *GHG Emissions, Sustainable Energy, Environment, PV System, RETScreen Software.*

1. Introduction

Nowadays, the demand for electricity is increasing day by day from every small scale to large scale. To produce electricity according to the demands of the people, the demand for fuels is also increasing. Electricity is produced from two types of energy sources, non-renewable and renewable energy sources. Non-renewable energy sources are mostly used for electricity generation in all the countries of the world including Bangladesh. The use of generating power from renewable sources of energy in power plants is very low compared to non-renewable sources of energy. However, the non-renewable fuels are limited, and have harmful effects on the environment. The burning of these non-renewable energy sources produces a significant amount of greenhouse gases (GHG) including carbon dioxide, sulfur dioxide, and nitrogen dioxide, which damage the atmosphere and population health [1]. As global energy consumption is increasing, one of the most pressing challenges of the 21 century is avoiding an energy crisis and global warming, both of which are linked to the usage of finite fossil fuels that emit greenhouse gases [2]. As the threat of global warming grows, this is critical that significant emitters among industrialized countries adopt measures to minimize greenhouse gas emissions [3]. By keeping the demand for generating electricity and minimizing GHG emissions, the production of electricity from renewable energy sources such as wind and solar should be increased.

Several analyses have been evaluated on GHG emissions reduction. Aboumahboub *et al*. [4] established a model using a process of iteration with actual data and calibrated by simulation according to sequential optimization to analyze the effects of wind power on the system for producing energy, both economically and environmentally. Balaji *et al*. [5] analyzed the effort of greenhouse gas (GHG) emissions reduction from a 5 kW central receiver PV power plant. Juwita *et al*. [6] calculated the CO_2 emission and the greenhouse gas (GHG) emission reduction from a restoration power plant of coal in which the power plant is 2 x 400 MW by comparing 2 methods: IPCC 2006 and UNFCCC AM0061 in Indonesia. Meissen *et al*. [7] reviewed a method to determine and rank climate leader businesses within a certain industrial sector according to their achievement in lowering absolute GHG emissions and focuses on important methods for reducing emissions. Ameri *et al*. [8] evaluated an approach for achieving a zero-energy building regarding GHG emissions in the environment of Tehran, Iran. Gholami *et al*. [9] evaluated an opportunity assessment for the production of renewable energy regarding the gross yearly GHG emission and feasibility analysis of a dairy farm in Shahroud, Iran. Ozgoli *et al*. [10] proposed an innovative evaluation method for the viability of consuming renewable fuels (solar, wind, and biomass) in the industry of water and wastewater and GHG emissions. Aburub *et al*. [11] studied the emissions rate for a power plant which is suggested by the United States Environmental Protection Agency (EPA) by providing a planning analysis for 10 years. Sakurai *et al*. [12] presented the most recent analysis of the energy efficiency and greenhouse gas (GHG) emissions of the power generation systems in Japan. Francke *et al*. [13] discussed electrical efficiency and greenhouse gas (GHG) emissions for the life cycle analysis of a solar basis power plant of 579 MWp in California. Enbang W. *et al*. [14] employed a strategy to analyze the effects of China's carbon dioxide emissions from various technologies in the energy supply, which suggested the emergence of technology for supplying renewable energy. Imran *et al*. [15] examined the opportunities for reducing greenhouse gas (GHG) emissions in power generation. Xiao *et al*. [16] studied the uses of HTS energy for energy saving and exhaust emissions, including potential and potential advantages, and discussed financial difficulties for HTS power supplies. Monsur *et al*. [17] examined the impact on climate change per unit kWh of power generated in a thermal power plant of natural gas in order to calculate the greenhouse gas (GHG) emission and its influence on global warming. Riekstin *et al*. [18] presented a method on existing GHG emissions to predict the best time for GHG emissions of the day in Canada. Khmel *et al*. [19] analyzed the effect of GHG emissions presume that power plants follow the merit order when competing in energy markets.

To protect the environment from the emissions of GHG and CO_2 gases. Adam *et al*. [20] analyzed a solar PV system of a 500 kWp capacity for produced electricity and makes a significant contribution to the reduction of GHG emissions, as well as the potential benefit of reducing CO_2 emissions in solar PV energy generation. This experiment was performed in Gaziantep, Turkey, but nearly no such analysis has been performed in Bogura, Bangladesh. As a result, this study concentrated on Bogura, Bangladesh, as shown in figure 1, to analyze the suggested system.

This study examines GHG emission reduction from a 100 MW PV solar system in Bogura, Bangladesh that is grid-connected. This research work aims to analyze GHG emission reduction, financial feasibility, sensitivity analysis, and power estimation by using the RETScreen software.

The remaining content of this analysis is organized as what follows. The methodology is introduced in Section 2. The results and discussions are discussed in Section 3. The conclusion is indicated in Section 4.

2. Methodology

2.1 GHG terminologies

Greenhouse gases are atmospheric gases that store heat and contribute significantly in response to climate change. Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are the components of these gases. Carbon dioxide (CO_2) emerges from the use of fossil fuels, forests and wood products, waste products, as well as certain biochemical processes. Nitrous oxide (N_2O) is a by-product of solid waste generation from agriculture and industry, burning of fossil fuels, and other factors. Methane (CH_4) is caused by the movement and processing of natural gas, oil, and coal, as well as various agricultural techniques and animal raising, among other things. Global greenhouse gas emissions have increased since industrialization. Regardless of economic growth, income status, population, environment, and agricultural use, every country generates these harmful gases. Due to this, the number of greenhouse gases present in the environment significantly increased [21].

2.2 GHG emission factor, fuel mix, and GHG avoidance

A fuel mixture is a mixture of many energy sources used to generate electricity in a country. This is essential to safeguard the ecology and ecosystem from GHG emissions, prevent entire reliance on a single source, investigate local natural resources, and avoid becoming totally dependent on one source. GHG prevention is a method used to reduce the quantity of GHG emissions during the production of electrical power using traditional energy sources. As a result, in order to reduce GHG emissions, the fuel mix should include a high proportion of renewable energy in a country. The GHG emission aspect measures the amount of GHG

(CO_2, CH_4, N_2O, etc.) released for each kWh of energy produced. Considering the technology and power source being used, this variable might differ from one power generation organization to another. The amount of CO_2 that is saved is often expressed as “kg/ kWh” or “t/kWh” since all other gases are transformed to CO_2 corresponding in respect of the global warming potential (GWP) [21].

2.3 Study location

The construction and implementation of 100 MW solar photovoltaic system in Bogura of Bangladesh has been considered for investigation. The RETScreen software provides all the relevant sunshine radiation statistics for the design. The average daily sun irradiation for the Bogura of Bangladesh is 4.74 kWh/m^2, according to the data by RETScreen software. Bangladesh is a south Asian country located of the border of India and the Bay of Bengal. The geographical position of Bangladesh extends between Latitude: 20˚34'N to 26˚38'N and longitude: 88˚01'E to 92˚41'E, as shown in figure 1 [22].

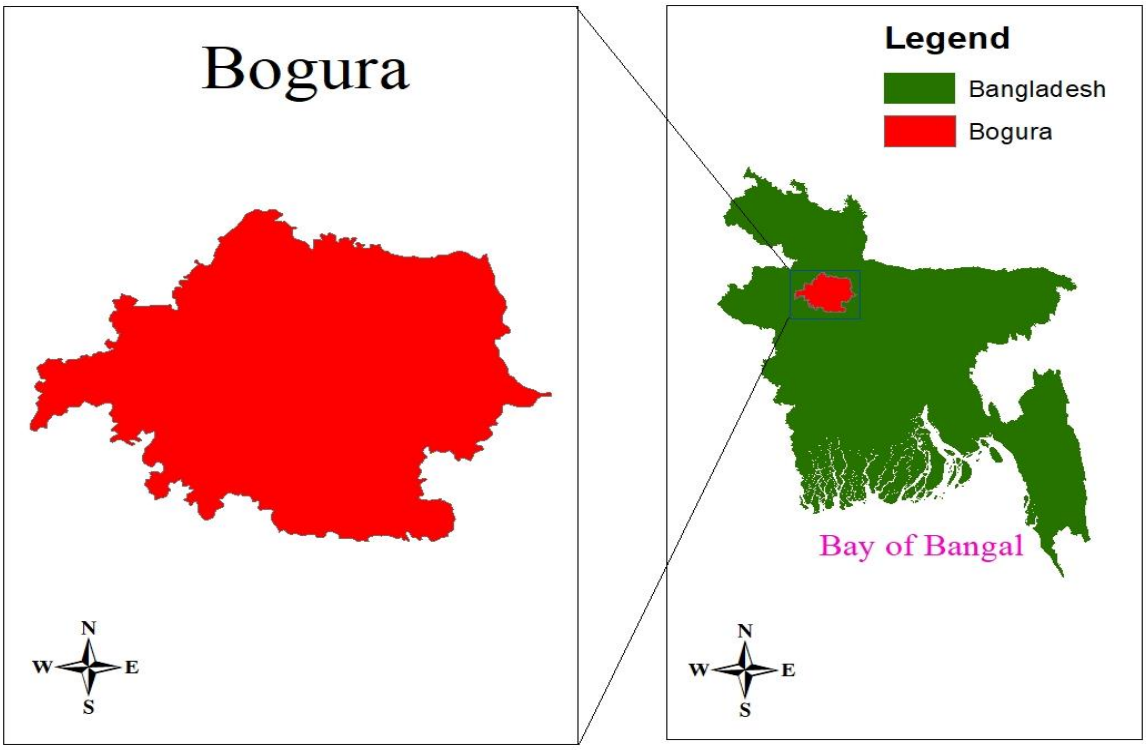

Figure 1. Geographic location of Bogura, Bangladesh.

3. Results and discussion

The GHG emission reduction, financial analysis, and sensitivity analysis of the suggested energy model have been analyzed using RETScreen software technology. The average GHG emission reduction for the project has been assessed by comparing with traditional technology-based cases: coal, oil, and natural gas. The outcomes are expressed in tons of carbon dioxide annually, which will be comparable in order to reduce GHG emissions, irrespective of the individual gases encompassed in the output. By transforming CH_4 and N_2O corresponding to CO_2 emission measured as the respective global warming potential (GWP), this is accomplished. The decrease is then adjusted to consider transmission and distribution losses as well as any available GHG credit [23]. The software includes GHG emission factors for the proposed system as compared to the equivalent quantity of energy produced by utilizing oil, coal or natural gas as an energy source.

3.1. Power plant

This section summarizes key results of the proposed system such as power capacity, capacity factor, and electricity supplied to the local grid. Table 1 shows the overview of the projected power system. The power capacity of the proposed system is 100 MW and the capacity factor is 15.7%. Annually, 137,481 MWh of power is exported to the local grid. The energy production cost is 0.097 $/kWh for the proposed system. The capacity factor and the electricity supplied to the local grid were calculated by using the RETScreen software.

Table 1. Proposed power system.

System type	Photo-voltaic
Power capacity	100 MW
Longitude and latitude	24.8^0N and 89.4^0E
Heating and cooling design value	14 ^{0}C and 31.7 ^{0}C
Earth temperature	15 ^{0}C
Capacity factor	15.7%
Electricity exported to the grid	137,481 MWh/yr
Energy production cost	0.097 $/kWh

3.2. GHG emission reduction analysis

The RETScreen Clean Energy Management software includes an emission analysis worksheet to calculate the potential for the suggested facility to reduce greenhouse gas emissions. The emission parameters for the proposed system as compared to the equivalent quantity of electricity produced using oil, coal or natural gas as the energy source are recognized by RETScreen software, shown in table 2. The proposed PV system contributes to reducing 153,747.7, 146,009.2, and 73,846.9 tons of gross annual GHG emissions into the environment in comparison to the equivalent amount of energy produced by utilizing oil, coal or natural gas as an energy source respectively. Table 2 shows the GHG emission factor considering the overall yearly reduction in GHG emissions. The reduction in emissions could be greater if PV power generation could contribute to a higher percentage of the sector of power generation. This is only feasible if the government can offer rewards for the construction of solar PV systems, which could also act as a method of motivating private investment. Incentives may potentially promote massive investment in the industry, which would reduce GHG emissions significantly.

Table 2. GHG emission reduction.

Fuel type	Oil	Coal	Natural gas
GHG emission factor excluding (T&D) losses (tCO_2/MW h)	1.118	1.062	0.537
Base case (tCO_2)	165,320.1	156,999.2	79,405.2
Proposed case (tCO_2)	11,572.4	10,989.9	5,558.4
Gross annual GHG emission reduction (tCO_2)	153,747.7	146,009.2	73,846.9

The software determined the revenue from GHG reduction for the proposed system as compared to the equivalent quantity of electrical energy produced using oil, coal or natural gas as the energy source which is listed in table 3. Exporting GHG reduction emissions via carbon trading is a way for investors to make money. With a 2% annual inflation rate, the projected credit rate for GHG reduction of $50 was considered over a 20-year period. The net GHG reduction of 153,748 tCO_2/yr, 146,009 tCO_2/yr, and 73,847 tCO_2/yr. in comparison to the equivalent quantity of electrical energy produced using oil, coal or natural gas as the power source respectively. The GHG reduction revenue is $7,687,383.98, $7,300,462.24, and $3,692,343.27 as compared to the equivalent amounts of power generated from oil, coal, or natural gas as the fuel, respectively.

Table 3. Annual GHG emissions revenue for the three types of fuel.

Fuel type	Oil	Coal	Natural gas
Net GHG reduction (tCO_2/yr)	153,748	146,009	73,847
Net GHG reduction for 20 yrs (tCO_2/yr)	3,074,954	2,920,185	1,476,937
GHG reduction credit rate ($/($tCO_2$/yr)	50	50	50
GHG reduction revenue ($)	7,687,383.98	7,300,462.24	3,692,343.27
GHG reduction credit duration (yr)	15	15	15
Net GHG reduction for 15 yrs. (tCO_2/yr)	2,306,215	2,190,139	1,107,703

Reductions in greenhouse gas emissions can enhance air quality and also save lives. Over the period of the next century, reducing greenhouse gas emissions globally to combat climate change might prevent millions of premature deaths. The total GHG emissions of a project are referred to as gross GHG emissions. The gross annual GHG emissions reduction was calculated for the proposed system as compared to the equivalent quantity of electrical energy produced using oil, coal or natural gas as the power source. The gross annual GHG emission reduction is shown in figure 2. The gross annual GHG emissions reduction is recognized as comparable to hectares of the forest absorbing carbon and barrels of crude oil not consumed.

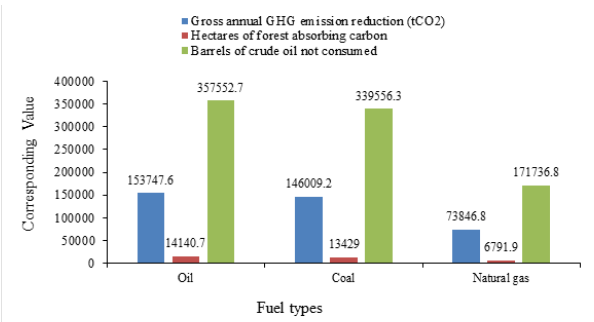

Figure 2. Gross annual GHG emissions reduction for three types of fuels.

3.3. Financial analysis

The worksheet for financial analysis enables the decision-making process of the project to take numerous financial factors into consideration with a fair amount of ease. This includes the input items of financial parameters such as debt ratio and discount rate, and computed the output items of financial viability such as simple payback, IRR and NPV. Below is a summary of these issues, as well as observations on the importance of the preliminary feasibility investigation. The parameters of the financial analysis for the proposed solar system, as shown in Figs. 3-5, clearly demonstrated the impact of GHG emission reduction revenue. The following information was provided as financial input parameters to the RETScreen software, as listed in table 4, to just be able to examine the financial feasibility of the system.

Table 4. Financial input parameters [23].

Parameters	Value
GHG reduction credit rate	$50
Inflation rate	2%
Project life	20 years
Debt ratio	70%
Debt interest rate	7%
Debt term	15 years
Total initial cost	$120,000,000

Figure 3 shows a financial study of the impact of reduced GHG emissions revenue for the proposed system as compared to the equivalent quantity of electrical energy produced using oil as the electrical power source. The total annual savings and revenue are $21,435,485. The equity payback duration is 3.1 years, whereas the simple payback term lasts 5.9 years.

Figure 4 shows a financial study of the impact of reduced GHG emissions revenue for the proposed system as compared to the equivalent quantity of electrical energy produced using coal as the electrical power source. The total annual savings and revenue are $21,048,563. The equity payback duration is 3.2 years, whereas the simple payback term lasts 6 years.

Figure 5 shows a financial study of the impact of reduced GHG emissions revenue for the proposed system as compared to the equivalent quantity of electrical energy produced using natural gas as the energy source. The total annual savings and revenue are $17,440,444. The equity payback duration is 4.5 years, whereas the simple payback term lasts 7.3 years.

The financial analysis results without the price of emission reduction are shown in table 5. The Total annual cost and debt payment are $10,222,748 and the total annual savings and income are $13,748,101. The equity payback duration is 7.7 years, whereas the simple payback term lasts 9.4 years. As a result, the project may therefore be deemed acceptable to be implemented for economic advantage.

Table 5. Financial analysis result without emission reduction price [23].

Parameters	Value
Total annual cost and debt payment	$10,222,748
Total annual savings and income	$13,748,101
Pre-tax IRR – equity	15.4 %
Pre-tax IRR – asset	3 %
Simple payback	9.4 years
Equity payback	7.7 years
Net Present Value (NPV)	$26,164,654
Annual life cycle savings	2,866,246$/yr

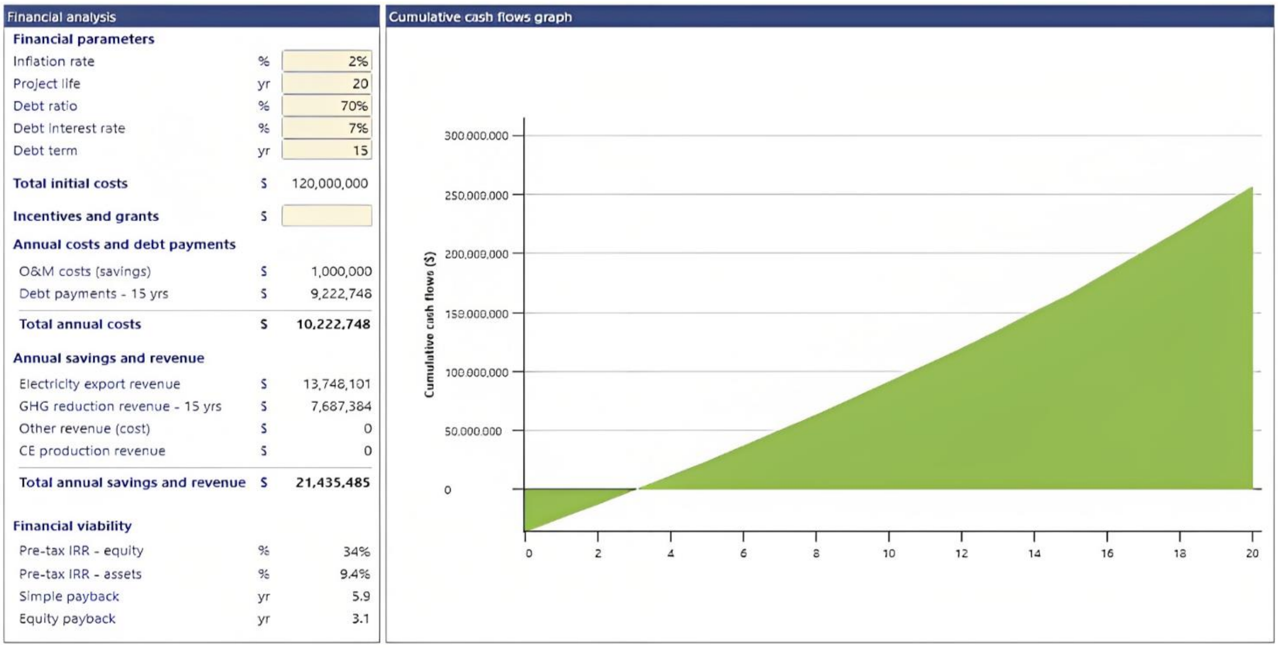

Figure 3. Financial analysis with revenue implications of reducing GHG emissions from oil.

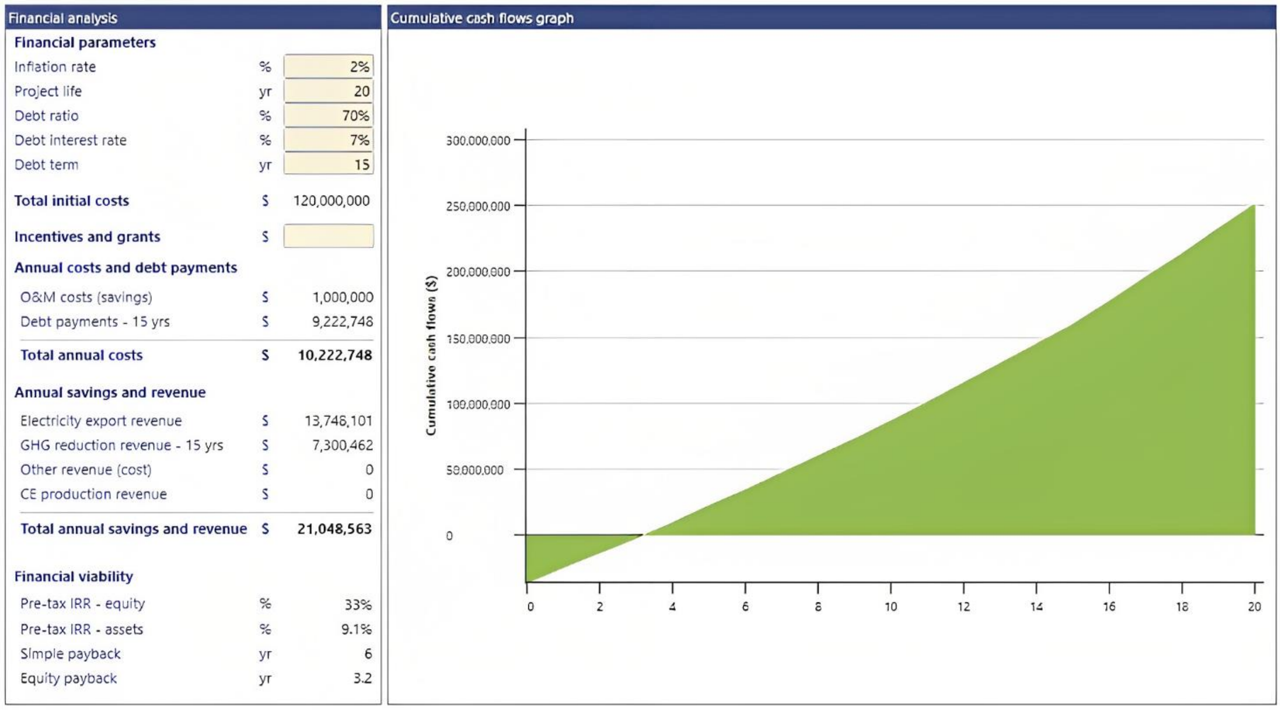

Figure 4. Financial analysis with revenue implications of reducing GHG emissions from coal.

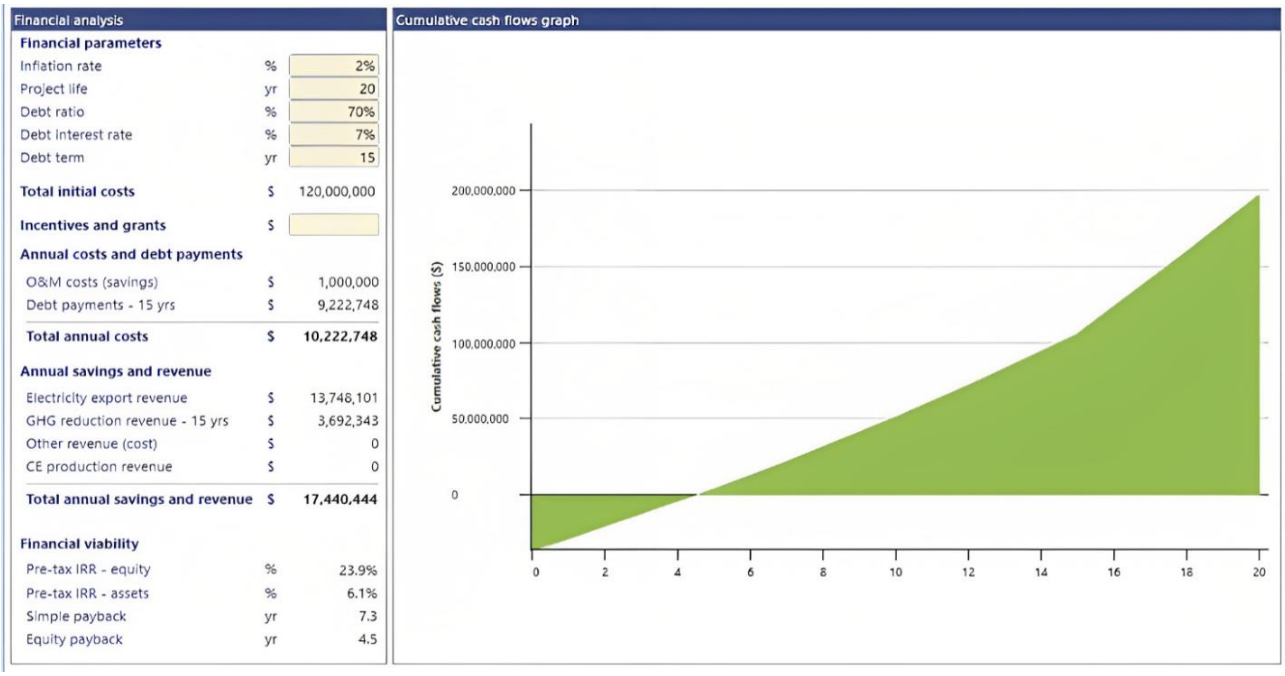

Figure 5. Financial analysis with revenue implications of reducing GHG emissions from natural gas.

3.4. Sensitivity analysis

A financial model is called sensitivity analysis that analyzes the target variables with the input parameters or other variables. Sensitivity analysis is a technique for estimating a result in the presence of a variety of possible factors. An analyst can assess how changes in one variable impact the results by establishing a specified set of parameters. Sensitivity analysis also determines the level of uncertainty that impacts the economic factors that were estimated. The sensitivity analysis of the proposed PV power system is shown in figure 6.

To determine the sensitivity analysis, the Net Present Value (NPV) of the proposed project was assessed. The initial cost was calculated in contradiction of the debt interest rate by ±25% range, which is shown in case 1 and the starting cost was calculated in contradiction of electricity export to the local grid by the equal range shown in case 2. The starting cost in case 1 is predicted to be $120,000,000 with a ±25% discount. The initial costs will be $150,000,000 and $90,000,000, respectively. The original debt interest rate is 7%, but with a ±25% increase, the debt interest rate is 8.75% and 5.25%, separately. The software includes the color orange to indicate NPV values less than zero. The project will be financially unprofitable with a 25% rise in the starting cost and a 25% drop in the debt interest rate since the NPV will be −$1,420,771. Conversely, if the initial price is decreased by 25% and the debt interest rate is raised by 25%, the proposed project will be financially viable because the NPV is significantly more than zero.

Correspondingly, the initial cost is evaluated against the amount of electricity supplied to the local grid in case 2. The project will be financially successful if the initial cost is decreased while increasing the value of the electricity supplied to the local grid.

Sensitivity analysis

Perform analysis on: Net Present Value (NPV)
Sensitivity range: 25%
Threshold: 0 $

Debt interest rate		Initial costs ($): 90,000,000	105,000,000	120,000,000	135,000,000	150,000,000
%		-25.0%	-12.5%	0.0%	12.5%	25.0%
5.25%	-25.0%	59,751,270	46,958,756	34,166,241	21,373,727	8,581,213
6.13%	-12.5%	56,791,571	43,505,774	30,219,977	16,934,179	3,648,382
7.00%	0.0%	53,750,080	39,957,367	**26,164,654**	12,371,941	-1,420,771
7.88%	12.5%	50,629,635	36,316,848	22,004,062	7,691,275	-6,621,512
8.75%	25.0%	47,433,174	32,587,644	17,742,113	2,896,583	-11,948,947

Electricity exported to grid		Initial costs ($): 90,000,000	105,000,000	120,000,000	135,000,000	150,000,000
MWh		-25.0%	-12.5%	0.0%	12.5%	25.0%
103,110.76	-25.0%	16,946,497	3,153,784	-10,638,929	-24,431,642	-38,224,354
120,295.88	-12.5%	35,348,288	21,555,575	7,762,863	-6,029,850	-19,822,563
137,481.01	0.0%	53,750,080	39,957,367	**26,164,654**	12,371,941	-1,420,771
154,666.14	12.5%	72,151,871	58,359,158	44,566,446	30,773,733	16,981,020
171,851.26	25.0%	90,553,662	76,760,950	62,968,237	49,175,524	35,382,811

Figure 6. Sensitivity analysis of the proposed power system.

4. Conclusion

The PV system is an essential strategy for reducing CO_2 emissions due to the reasonable emission reduction potential. This study used RETScreen software to calculate the yearly CO_2 or GHG emission reduction and financial viability of a grid-connected photo-voltaic solar system in the Bogura of Bangladesh. The outcomes are measured as compared to the equivalent quantity of electrical energy produced using oil, coal or natural gas as the electrical energy source. The gross annual GHG emissions reduction was calculated against the equivalent hectares of the forest absorbing carbon and crude oil barrels that are not used. Therefore, if the government offers a sufficient financial incentive, then the usage of solar PV systems will be able to enhance [24]. The government should establish specific laws to simplify the processes used to build generation facilities. These actions will stimulate private investors, leading to a big percentage of PV power production facilities, and the corresponding emissions of CO_2 are significantly reduced. As a result, the project may be regarded appropriate to be installed for the economic and environmentally beneficial.

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