# *The economic prospect of rooftop photovoltaic (PV) system in the commercial buildings in Bangladesh: a case study*

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**Ujjwal Datta[1]. Akhtar Kalam[1]. Juan Shi[1]**

The research investigates the financial and environmental implications of roof-top PV installation in a case study of commercial buildings in Bangladesh. With annual horizontal solar radiation of 4.65 kWh/m$^2$/d, Bangladesh has a great potential to avail sustainable solar energy which would have environmental and economic ramifications. To accomplish this, the simulation has been carried out using the RETScreen software. To perform the calculation, the climatic data from NASA for the selected location has been considered. Numerous economic indices encompassing net present value, payback period, internal rate of return and benefit-cost ratio have been taken into consideration as a measure of performance indicator for the enacted project. The determined economic outcome of the case study points out a net present value of $756,896 with 14.2% internal rate of return, 10.1 years simple payback time, 8.1 years equity payback and 1.5 benefit-cost ratio which implies that the project is remarkably appealing. In addition, the sensitivity analysis of the project highlights that the profitability of the investment is protected in most of the cases for ±30% variation in input parameters. For example, initial and fuel costs of the proposed case may generate a negative net present value beyond 15% variations. However, a positive net present value within the wide sensitivity ranges for fuel costs base case, operation and maintenance costs, fuel cost escalation and discount rate, debt ratio and debt term imply economic feasibility is still obvious. This may encourage the building owner to incorporate solar PV in commercial buildings in Bangladesh.

**Keywords** Commercial buildings · Economic assessment · rooftop PV · Environmental assessment · Sensitivity analysis · Risk analysis.

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## Introduction

The population growth and industrialization are at the forefront in the escalation of global energy demand. Around 74\% of the global energy demand is supplied by fossil fuel (International Energy Agency 2020). As the majority of electricity generation sources, fossil fuels like diesel, coal and natural gas have put significant challenges on greenhouse gas emission (GHG) and global warming. To mitigate these challenges, there is a rise in the exploration and integration of sustainable energy resources to meet the energy requirement (Haldar et al. 2015; Li and Zheng 2016) and likely to be continued in the future (International Energy Agency 2020).

Bangladesh with its large population and rapid industrial growth such as in textiles, pharmaceuticals and other manufacturing industries, electrification is playing a vital role in socio-economic development. Following the current trend of Gross Domestic Product growth, the electricity demand is anticipated to rise by 6.9% per year until 2041 (Ministry of Power, Energy and Mineral Resources 2020). To support this continuing growth, Bangladesh needs to ramp up its generation capacity. However, the faster depleting natural gas, decreased efficiency of the aging power plants and a higher cost of existing coal extraction have resulted in numerous challenges in its endeavors of energy supply expansion. Bangladesh has started importing a large amount of power from India, nearly 5.93% of its total demand, since the last few years in order to satisfy the thriving electricity demand (Bangladesh Power Development Board 2020a). Furthermore, the construction of fossil fuel generated power plants continues to be on the rise in Bangladesh (Bangladesh Power Development Board 2020b). This will likely escalate the GHG emission and resulting in an increased threat to environmental sustainability.

Moving towards the clean energy resources can satisfy the growth in energy demand and the reduction of $CO_2$ at the same

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time. Globally, the current share of renewable energy is 26% (International Energy Agency 2020). On the contrary, the renewable energy sources (RESs) in Bangladesh till date did not get enough attention from the government and stakeholders. This is clearly visible from its present share of renewable energy which is only 0.19% (Bangladesh Power Development Board 2020a). However, the situation has started improving over the last few years with the government's subsidy on RESs related businesses. Bangladesh is geographically located in a suitable place for solar energy which has a very high potential across the country and could be an effective solution if utilized for generating electricity. However, amidst little maintenance cost, straightforward solution and maximum production in typical sunny days, the initial investment of photovoltaic (PV) technology is yet a big challenge for its large-scale implementation (Mirhassani et al. 2015). This is why economic analysis is imperative to identify the economic feasibility and sustainability measure for prospective projects.

To address this challenge, numerous studies are available that have analyzed the economic viability and the environmental impact of PV installation. Lau et al. (2016) carried out an economic analysis in Malaysian residential zone and suggested that the project is economically feasible if the costs of PV array is $1120 per kW or less. A techno-economic analysis by Kazem et al. (2017) analyzed that 1MW PV plant in Oman is highly promising in terms of a reduced cost of energy and 10 years of pay-back time (PBT). A similar study by Shagdar et al. (2020) revealed that solar energy assisted power generation is economically attractive and environmentally sustainable. Li et al. (2018) assessed that grid-connected PV at 5 different climate zones in China is a technically and economically viable solution. Another study in rural areas of Algeria by Nacer et al. (2016) indicated that PV energy systems are viable for all regional farms. On the contrary, a feasibility study for 10MW PV capacity in Saudi Arabia has been carried out by Rehman et al. (2017) and the authors suggested that not all the locations are suitable for PV installation due to the intensity variation of solar radiation at different areas. Elshurafa et al. (2019) suggested that the rooftop PV system in Saudi Arabia is economically feasible and can incur zero electricity bill.

The feasibility study of PV system integration, economic asset and sensitivity analysis are mostly considered indices as a performance indicator. Bakhshi-Jafarabadi et al. (2020) utilized the experimental data of a 120kW grid-connected PV system in Iran and the results suggested that the economic gain is highly appealing. Furthermore, it is also illustrated that with the deterioration in PBT and the internal rate of return (IRR) and generation reduction by 20% than the predicted value is still financially feasible. Authors in (Li and Yu 2016) established that the rise in fuel cost, inflation rates and project life impacts positively on the net present value (NPV), annual life cycle savings (ALCS) and GHG reduction cost whereas the discount rates affect negatively. The sensitivity analysis in another study by Sagani et al. (2017) concluded that the initial PV related costs notably influence the efficiency of PV project in terms of maximum NPV; a lower initial cost implies a higher NPV. In addition to high initial costs, the expected electricity rate i.e. lower energy price is another component that significantly influences the economic viability of the PV project (Edalati et al. 2016). The NPV value decreases with the reduction of the electricity export rate (Salehin et al. 2016). Grant and Hicks (2020) discussed that manufacturing and installation location have a substantial effect on the PBT. On the other hand, the impact of operation and maintenance (O&M), debt interest rate, debt term are much less on NPV and PBT (Salehin et al. 2016). Another study by Njoku and Omeke (2020) identified that high-latitude locations result in lower $CO_2$ emission.

Few researchers have carried out risk analysis while evaluating the feasibility of PV system integration. Owolabi et al. (2019) have shown that with a 20% risk level, the energy production cost is still within the reach which makes the project viable and realistic. However, another risk analysis study by Bustos et al. (2016) argued that the profitability of a project in Chile is very low owing to the dominant impact of high initial investment cost over the rate of electricity export. Another study in (Farias-Rocha et al. 2019) finalized that a grid-tied PV project in the Philippines is not financially attractive anymore if the current electricity price drops by more than 10%.

On the contrary, only few studies are available on the economic feasibility, environmental impact and sensitivity analysis of PV project in Bangladesh. Mondal and Islam (2011) found that the PV project is financially attainable for all the studied sites in Bangladesh. The reduction of $CO_2$ by 10% and 20% constraints are used in Mondal and Islam (2012) which showed a reduction of 4.5-22.37% in the fossil fueled based primary energy sources. The study in (Mandal et al. 2018) investigated a PV/Battery/Diesel system and the result suggested that the configuration is most effective in $CO_2$ reduction but incurs higher cost than the grid electricity price. Nevertheless, it is not clear whether the battery or the solar is the main contributor to having a lower cost than the other hybrid combination. Hybrid mini-grid study by Islam et al. (2018) with PV/Biomass/Battery/Diesel suggested that a renewable project is viable if the price of Biomass resource is controlled within the limit.

The findings from the literature point out that the previous studies in Bangladesh have overlooked the risk involved in PV projects. Furthermore, economic feasibility, environmental sustainability, sensitivity and risk factors analysis are not analyzed thoroughly so far for the same project. In addition, the potential of commercial buildings' roof-top for solar installation is also not explored which can be a worthy case to maximize the generation from renewable sources and thus contribute in improving environmental conditions.

To this end, this paper intends to investigate the feasibility of integrating roof-top PV in commercial buildings in Bangladesh. For this, several influential factors are considered for financial evaluation. The possible environmental benefit of the rooftop solar project is also estimated. A case study is carried out using RETScreen for economic and environmental performance evaluation. Bearing in mind that investors' wiliness to promise capital investment in such projects requires a risk-return outline, a Monte Carlo simulation technique is adopted for sensitivity analysis and to obtain risks associated with the project. Previous works by Mandal et al. (2018) did not consider risk analysis and studies by Salehin et al. (2016), Mondal and Islam (2011), Mondal and Islam (2012) and Islam et al. (2018) focused on grid-connected PV only with or without storages. To the authors' best knowledge, no studies on rooftop PV installation in commercial buildings in Bangladesh are carried out in terms of its economic, environmental, sensitivity and risk perspective. It is envisaged that the provided outcomes can be used as a starting point of exploring the feasibility of PV installation as a part of an energy optimization on commercial buildings in Bangladesh and contribute to environmental sustainability.

# Background information

## The existing energy systems profile in Bangladesh

In the last 12 years, the installed electricity generation capacity has increased by more than 4.5 times from 4130MW in 2017 to 19570MW in 2019 (Bangladesh Power Development Board 2020a, b). Natural gas is the dominant fuel (56.34%) for electricity generation as it is domestically available followed by furnace oil, diesel, power import and coal which are shown in Fig.1 (a). However, the declining supply of natural gas and the rising electricity demand have enforced the government to find alternative energy sources. Primarily, heavy fuel oil (HFO), imported coal and liquefied natural gas (LNG) are on the top of the list.

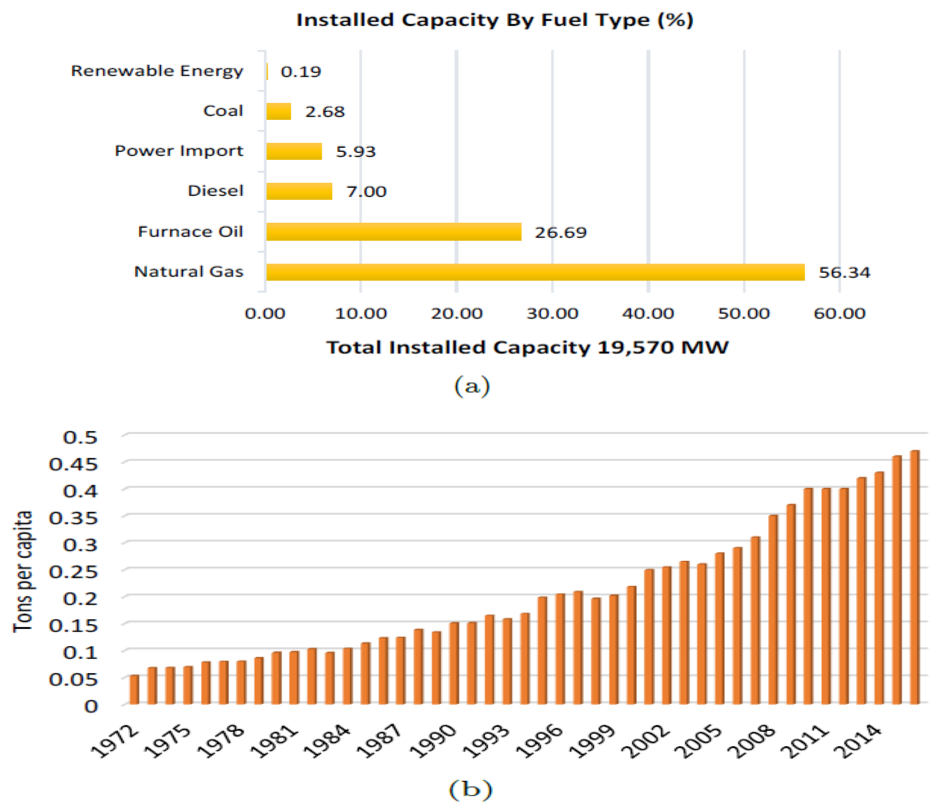



Fig. 1 Installed electricity generation capacity in Bangladesh (by fuel type) (a) $CO_2$ emission in Bangladesh (b)

Fig. 1(b) illustrates the growth in $CO_2$ emission over the decade in Bangladesh (Worldometer 2020). A significant part of the emission is caused by the power industry (41.7%) which indicates that a major upgradation in generation policy is required to reduce carbon emission. Moreover, the rising electricity demand for industrialization and urbanization justify the growth in $CO_2$. In addition, the installed and ongoing generation projects in recent and upcoming years are mostly based on fossil fuel which is likely to escalate emission in the next decade. The current share of renewable is mostly coming from solar (~63%) and hydro (~37%) as shown in Table 1 (SREDA 2020). However, it can be seen that the major portion of the total PV share is in off-grid mode (~80%). Nevertheless, a total of 664MW ongoing PV plant projects are estimated to be in operation by the end of 2020 (Bangladesh Power Development Board 2020a) which indicates the conclusive actions by the government for RES based generation. Nonetheless, the percentage of RES generation is not yet significant.

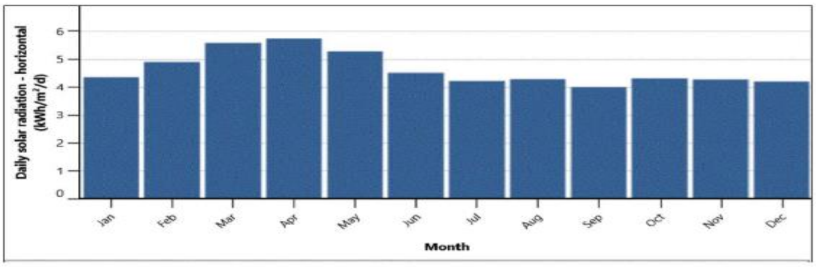
Table 1 Installed renewable energy capacity in Bangladesh (SREDA 2020)

| RES sources Share | Off-grid | Share | On-grid | Share | Total | Share |
|---|---|---|---|---|---|---|
| PV | 326.74 | 50.39 | 87.74 | 13.53 | 414.48 | 62.92 |
| Wind | 2 | 0.31 | 0.9 | 0.14 | 2.9 | 0.45 |
| Hydro | 0 | 0 | 230 | 35.47 | 230 | 36.47 |
| Biogas to Electricity | 0.63 | 0.1 | 0 | 0 | 0.63 | 0.10 |
| Biomass to Electricity | 0.4 | 0.06 | 0 | 0 | 0.4 | 0.06 |
| Total | 329.77 | 50.86 | 318.64 | 49.14 | 648.41 | 100 |

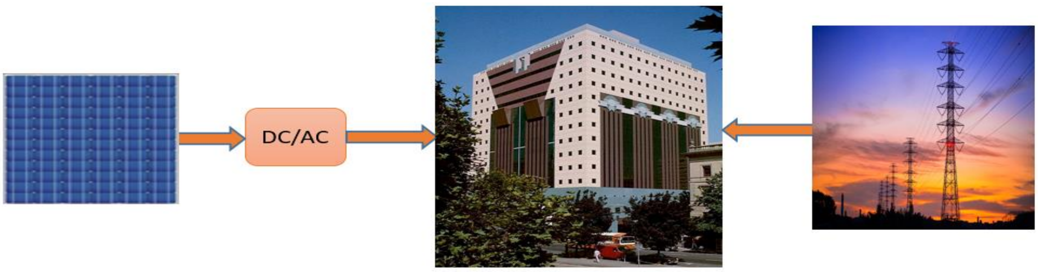
## Project description and meteorological data

Bangladesh is in South Asia and its latitude and longitude extend from 20º 34 N to 26º 38 N and from 88º 01 E to 92.41º E. For a successful PV project, one of the essential elements is the available solar radiation at the selected location as illustrated in Fig. 2(a). The climate data of the studied location (Dhaka) is situated at 23.7º N (latitude) and 90.4º E (longitude). The solar radiation data is collected from the NASA Surface Meteorology and Solar Energy (SSE) Data set via RETScreen software which is presented in Fig. 2(b). From the data, daily/monthly/annual horizontal and tilted solar radiation is calculated and from this value, electricity production is calculated. The annual data is then used to estimate the total electricity production in the project's lifetime. The data reveals that solar radiation is nearly flat throughout the year and typically ranges between 4-5.76 kWh/m$^2$ per day.


(a)




(b)




(c)

Fig. 2 Geographical layout of the study location- Google Map 2020 Edited (a), solar radiation data at Dhaka, Bangladesh (b) and structure of the project rooftop integrated building energy system

The solar data provided by the National Renewable Energy Laboratory in other major cities of Bangladesh shows that solar radiation varies between 4-5 kWh/$m^2$ per day (REexplorer 2020). This resembles that the benefit of rooftop solar installation in other cities is reasonably comparable with the studied location. However, the building sizes differ in each city depending on their economic importance and growth. To realize the precise benefit of solar installation in other locations, a detailed study of each location needs to be investigated which would be a future study scope.

This project comprises rooftop solar units in a generic commercial building in Bangladesh as shown in Fig. 3(c). It is assumed that the integrated solar output is less than the total power demand of the building at any given time and hence the system consumes deficit power from the grid. The daily load demand in a commercial university building in Bangladesh is approximately 122.3kWh (Rayhana et al. 2015). On the other hand, the daily energy output of the installed solar modules is 19.54kWh (4,280,058 kWh in its project lifetime) which is only a fraction of the total load demand of the building. Due to lower capacity than the building load profile, PV is only being utilized to power the building and does not inject any power to the grid. As the building system is grid-connected and the shortfall power is fed from the grid, no storage is designed in the proposed scheme. However, this could be a potential area to be explored in future study.

# Materials and methods

For economic analysis, first, the initial financial parameters inputs are taken from the existing literature on the economic study of PV installation in Bangladesh, the power generation and transmission company websites in Bangladesh, other literature and RETScreen software (Mandal et al. 2018; GlobalPetrolPrices 2020; PowerCell 2020; RETScreen). Second, the economic sustainability of the proposed project has been calculated. Third, the sensible attributes to NPV with respect to the input values have been evaluated. Finally, the risks involved in the project have been derived. The approach and information on parameter selection for each of the cases has been explained in the subsequent subsections.

## Calculation of hourly irradiance in the plane of the PV array

The detail of the hourly irradiance calculation is presented in Engineering and Cases textbook by RETScreen (RETScreen 2005). A brief calculation method is presented below and for details please consult the referred book. There are three basic steps in calculating the tilted solar radiation. First, the calculation of hourly global and diffuse irradiance on the horizontal surface for total hours on an average day. This daily global radiation is the same as the monthly average. Second, the calculation of hourly data of global irradiance on the tilted surface for the complete day. Finally, the calculation of an average daily irradiance on the plane of PV array by summing up the hourly tilted data. The hourly irradiance in the plane of PV array $H_t$ can be calculated from the isotropic model presented by Duffie and Beckman (1991) which is considered as a sufficient model at the pre-feasibility studies (RETScreen 2005).

$$H_t = H_b + R_b + H_d\left(\frac{1+cos\beta}{2}\right) + H\rho\left(\frac{1-cos\beta}{2}\right) \qquad (1)$$

Where $H_b$ and $H_d$ are the beam and diffuse components, H represents the global horizontal irradiance, $\rho$ denotes the diffuse reflectance of the ground, $\beta$ denotes the slope of PV array. Rb represents the ratio of beam radiation on the PV array ($cos\theta$) and horizontal ($cos\theta_z$) where $\theta$ represents the incidence angle of beam irradiance on the array and $\theta_z$ represents the zenith angle of the sun.

## Area calculation

The estimation of the useful roof area in Geneva, Switzerland by Mohajeri et al. showed that commercial buildings have huge potential for PV energy (Mohajeri et al. 2018). In contrast to the previous study, Bangladesh has mostly flat-roofed buildings. The dimension of the selected building is 38.14m (length) and 20.1m (width) as highlighted in Fig. 3(a). In practice, the entire area cannot be used for PV installation due to water tank, air conditioning equipment, etc. Therefore, to calculate the available area of a PV installation, a formula has been derived which is as follows:

$$Ac = N_B \cdot A_T \cdot A_{aa} \qquad (2)$$

where Ac is the area calculation (≈406.3$m^2$/building), $N_B$ is the number of buildings participating in PV installation (50), $A_T$ is the total area of a building (766.62$m^2$) and $A_{aa}$ is the actual available area for PV installation (≈53%). The selected building has an installed air conditioning system, telecommunication towers and staircase as shown in Fig 3(b). Therefore, the value of $A_{aa}$ is approximately estimated as 53%. However, not all the buildings have telecommunication towers but they may have other arrangements such as a coffee shop, small garden, office party space, etc. and hence the selected value is roughly an approximation. An accurate measurement would require an on-field visit that can be considered in the future study.


(a) (b)

Fig. 3 Selected commercial building location (Gulshan-2) in Bangladesh.

## Selection of solar PV components and other parameters

There are various categories of PV modules accessible in the market. In this study, Monocrystalline silicon (mono-Si) type PV panels have been selected. The efficiency of the module and inverter is 15.75% and 95% respectively (Rehman et al. 2017) as illustrated in Table 2. For 64kW capacity per building, the total required solar collector area is 20317 m$^2$. In this analysis, a fixed type of solar tracking method has been used for simplicity.

Table 2 The technical parameter details of mono-Si type PV

| PV parameters | |
|---|---|
| PV type | mono-Si |
| Solar tracking mode | Fixed |
| Nominal operating cell temperature ºC | 45 |
| Efficiency | 15.75% |
| Solar collector area m$^2$ | ~85.3 per 15kW panel and<br>~28.4 per 5kW panel (Enerysage 2020) |
| Inverter efficiency | 95% |

The capacity factor (CF) of the PV plant has been determined by the proportion of energy generated in a year with respect to its installed capacity in that entire year which can be written as in (2).

$$\mathrm{CF} = \frac{\text{Energy } generated/annum\text{(kWh)}}{\text{8760 (hours in a year) x Installed capacity (kW)}} \quad (2)$$

The value of CF has been found as 15.3% from RETScreen and other technical parameters are highlighted in Table 2. The total energy saved due to PV installation is 4280058 kWh annually.

## Economic analysis of rooftop PV

The fuel and PV related costs are summarized in Table 3. The cost breakdown of initial financial parameters is outlined in Table 4. Life cycle emission (LCE-kg $CO_2$-eq/yr) is the sum of emissions from the raw material extraction, manufacturing, processing, operation and disposal of the components which is epitomized in Table 5 (includes other correlated emission inputs). The investigated critical factors for substantiating the economic feasibility are NPV, IRR, simple payback, year-to-positive cash flow, annual life cycle savings, benefit-to-cost ratio and debt service coverage.

Table 3 The fuel and PV related cost parameters for economic analysis

| Fuel generation related cost | |
|---|---|
| Fuel cost ($/l) | 0.91(Mandal et al. 2018) |
| PV module initial cost ($) | 1300 (Mandal et al. 2018) |
| PV module O&M cost ($/kW-year) | 20 (Mandal et al. 2018) |
| Electricity rate (kWh) | 0.101 (GlobalPetrolPrices 2020) |
| T&D loss | 11.96 (PowerCell 2020) |

Table 4 The cost parameters for economic analysis

| Financial parameters | |
|---|---|
| Fuel cost escalation rate (FCER) (%) | 2 |
| Inflation rate (IFR) (%) | 2 |
| Discount rate (DR) (%) | 10 (Mandal et al. 2018) |
| Reinvestment rate (%) | 9 |
| Project lifetime (years) | 25 |
| Debt ratio (%) | 60 |
| Debt interest rate (%) | 5 |
| Debt term (yr) | 15 |

Table 5 The parameters for emission analysis

| Emission analysis | |
|---|---|
| Diesel LCE (kg CO2-eq/kWh) | 1.054 (RETScreen) |
| PV module LCE (kg CO2-eq/kWh) | 0.045(Mandal et al. 2018) |
| GHG reduction credit rate ($/tCO2) | 10 |
| GHG reduction credit duration (yr) | 10 |

## Net present value

NPV defines the profitability of an envisaged project which is determined as the variation between the net cash inflows and outflows during a specified period. To calculate NPV, all cash flows have been discounted at a rate available for alternative investments which are as follows:

$$NPV = \sum_{k=0}^{N} \frac{\widehat{C_k}}{(1+i)^k} \quad (3)$$

$\widehat{C_k}$: Net cash inflows and outflows in a period of $k$ years

*i*: Discount rate which is 10\% in this project.

## Internal rate of return

IRR is meticulously related to NPV which provides the exact rate of return on the original investment. It is the discount rate (weighted average cost of capital) after which project NPV is exactly zero and can be computed from the following formula (Rehman et al. 2017; Himri et al. 2020):

$$0 = \sum_{k=0}^{N} \frac{C_k}{(1+IRR)^k} \quad (4)$$

$C_k$: Cash flow in a period of $k$ years

N: Project life in years which is 25 years in this project.

IRR elucidates whether the project will be viable or should be abandoned.

## Simple payback time (SPT)

The SPT is the minimum period required for the cash flow (without debt payments) to generate savings to be proportionate with the total investment which can be calculated as follows:

$$SPT = \frac{C_{tic} - I\&G}{C_{inc} - C_{cost}} \quad (5)$$

where, $C_{inc} = C_{yens} + C_{ycas} + C_{yrei} + C_{GHGri}$ and
$C_{cost} = C_{O\&M} + C_{fuel}$

$C_{tic}$: Total project initial cost
I&G: Incentives and grants for the project
$C_{yens}$: Yearly energy savings
$C_{ycas}$: Yearly capacity savings
$C_{yrei}$: Yearly renewable energy generation credit income
$C_{GHGri}$: GHG reduction income

## Equity payback (EP)

The EP or year-to-positive cash flow ($N_{YPCF}$) is the first year that the accumulated cash flows are positive for that project and can be expressed as:

$$0 = \sum_{k=0}^{N_{YPCF}} C_k \quad (6)$$

## Annual life cycle savings (ALCS)

The ALCS is the levelised nominal annual savings that have precisely the equal life and NPV as the project and can be determined from the following expression:

$$\text{ALCS} = \frac{NPV}{\frac{1}{i}\left(1 - \frac{1}{(1+i)^k}\right)} \quad (7)$$

## Benefit cost ratio (BCR)

The BCR can be defined as profitability measurement for the proposed project. It is computed from the ratio of net benefits and cost of the project as follows:

$$\text{BCR} = \frac{NPV + (1 - D_r)\, C_{tic}}{(1 - D_r)\, C_{tic}} \quad (8)$$

where, $D_r$: Debt ratio

## Debt service coverage (DSC)

The DSC is expressed as the proportion of operating income of the project and debt payments. It is a measure of the project's capacity to generate adequate cash flow to pay current debt payments. The DSC for $k$ years can be calculated from the ratio of net operating income and debt payments as expressed in here:

$$\text{DSC}_k = \frac{\max(C_k + D, AOI_k) - \widehat{C_0}}{D} \quad (9)$$

$AOI_k$= Accumulated operating income for $k$ years

# GHG emission reduction assessment

The potential of GHG emission rebate can be realized through the RETScreen emission model for this project. The RETScreen emission model can estimate the amount of emission reduction from the proposed case compared to the base case. The base case in this study is referred to as the situation without a rooftop solar PV installation scenario. The emission reduction $\Delta_{GHG}$ can be determined as follows:

$$\Delta_{GHG} = (e_{bc} - e_{pc})\, E_{pc}\, (1 - \lambda_{fel})\, (1 - e_{ctf}) \quad (10)$$

$e_{bc}$ = GHG emission factor for the base case

$e_{pc}$= GHG emission factor for the proposed case

$E_{pc}$= Yearly electricity production for the proposed case

$\lambda_{fel}$= Portion of electricity loss in transmission and \indent distribution (T&D)

$e_{ctf}$= Credit transaction fee for GHG emission reduction

The base emission factor for the base electricity case can be computed as follows:

$$\Delta_{GHG} = (e_{CO_2} GWP_{CO_2} - e_{CH_4} GWP_{CH_4} + e_{N_2O}\ GWP_{N_2O}) \frac{1}{\eta} \frac{1}{1-\lambda_{fel}} \quad (11)$$

where,

$e_{CO_2}$= $CO_2$ emission factor for the fuel

$e_{CH_4}$= $CH_4$ emission factor for the fuel

$e_{N_2O}$= $N_2O$ emission factor for the fuel

Global warming potentials for $CO_2$, $CH_4$ and $N_2O$ are $GWP_{CO_2}$, $GWP_{CH_4}$ and $GWP_{N_2O}$ respectively.

$\eta$ = Fuel conversion efficiency

Since the PV is onsite generation, there is no T&D losses. The calculation of GHG emission reduction cost (GRC) is the levelized nominal cost to avoid each tonne of GHG and can be expressed from (7) and (11) as:

$$GRC = \frac{ALCS}{\Delta_{GHG}} \quad (12)$$

## Sensitivity analysis

Once the financial results are obtained, a sensitivity analysis has been investigated to realize the dynamic outcomes, similar to other studies (Bustos et al. 2016; Farias-Rocha et al. 2019; Salehin et al. 2016). The objective is to scrutinize the effect of key financial parameters that could potentially influence the key financial parameters, NPV and IRR. The parameters are progressively altered one at a time to observe the impact on other output variables (Cheng et al. 2014; Hemsath and Bandhosseini 2015) and the range is ±30% (Bustos et al. 2016). The considered parameters are the initial cost, O&M cost, fuel cost base case and proposed case, debt ratio, debt interest rate and debt term.

## Risk analysis

A risk analysis has been investigated to reveal the amount of uncertainty in the output variables for the variation in input parameters. The risk analysis in RETScreen has been performed using the Monte Carlo technique in which financial simulation values are generated 500 times and all the parameters alter at the same time with the range of ±20% but independently through a normal (Guassian) distribution (Owolabi et al. 2019).

# Financial interest of PV installation in commercial buildings

Various studies have explored the economic feasibility, sensitivity and risk analysis of PV installation using RETScreen software (Azerefegn et al. 2020; Pan et al. 2017). The study of technical benefits of rooftop PV in buildings is already an established area of research in recent times in terms of energy potential, surface suitability (Srekovi et al. 2016; Thotakura et al. 2020; Jahanfar et al. 2019). Few other studies have concluded the economic potential of PV installation in the building roof (Quansah et al. 2017; Salimzadeh et al. 2020; Ali et al. 2018).

For the given initial financial parameters of the project, the simulation studies have resulted in NPV value of $756,896. This positive NPV which is the difference of cash inflows and outflows defines that the proposed project is economically viable.

The IRR analysis provides both the pre-tax and after-tax IRR on equity (IRR-E). As the energy is not selling back to the grid hence there is no income tax available and pre-tax IRR-E is equivalent to the after-tax IRR-E which is 14.2% for this project. A project is said to be financially acceptable when the IRR surpasses the discount rate (10%) (Bakhshi-Jafarabadi et al. 2020). In this project, an IRR-E of 14.2% defines that the project investment is economically viable.

A shorter payback period delineates the desirable speedy recovery of the initial investment. In the proposed project, the SPT is calculated as 10.1 years which indicates the economic viability of the PV installation in commercial buildings. The EP in this project is found to be 8.1 years.

The ALCS can be calculated from the NPV, discount rate and project lifetime which is determined as $83,386. When the BCR in a project is higher than 1, the project is considered as a profitable project. In the presented case, BCR is estimated as 1.5 which indicates a worthwhile project.

The value of DSC must be greater than one to be able to pay back the debts incurred in this project. The DSC values of 1.7 point out that the borrower will be able to pay current debts.

## Effect in reducing GHG emission and revenue

The annual environmental performance has been performed to calculate the amount of GHG reduction and revenue that is possible to acquire from carbon trading (GHG emission reduction). As the generated energy is consumed directly by the prosumer, there will be no T&D losses involved. The software generated GHG emission for the base case and proposed case are found to be 4524.1493 $tCO_2$/yr and 206.372 $tCO_2$/yr respectively. The subtracted value of 4318 $tCO_2$/yr clearly demonstrates the environmental contribution of green solar energy. This implies a total of 107,944 $tCO_2$ GHG emission reduction in its 25 years of the project lifetime.

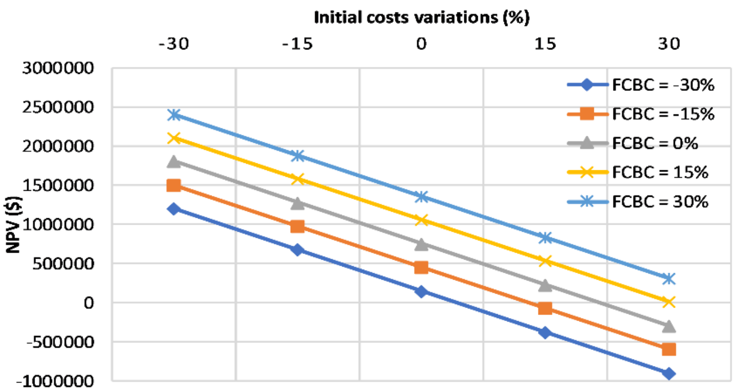
The achievable GHG reduction revenue through carbon trading for the proposed case is determined as $43,178. The imposed GHG reduction credit rate is $10/$tCO_2$ for a credit duration of 10 years. Nevertheless, the credit escalation rate for GHG reduction is considered as 0.

## Effects of diversity in financial input parameters on financial viability

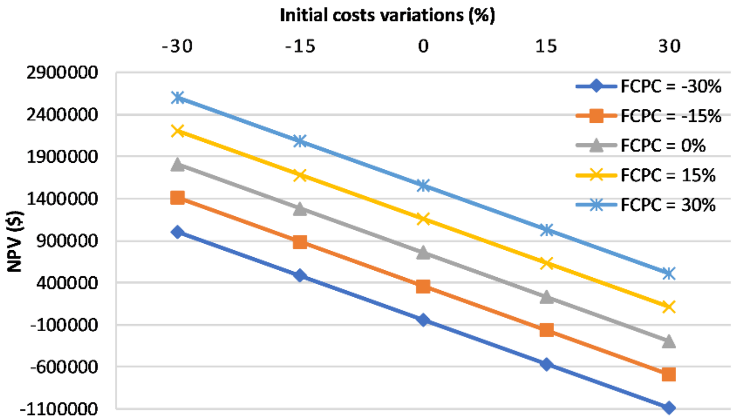
As a result of unforeseen circumstances, the project is seldom static in practice. Consequently, it is imperative to develop an understanding of how the target variable i.e. NPV reacts with the variations in financial inputs. For in-depth analysis purposes, deliberate attention is given to several input variables i.e. initial costs, fuel cost escalation rate, inflation rate, discount rate O&M costs, fuel cost for the base and proposed cases, GHG reduction credit rate and reduction duration, debt ratio, debt term and debt interest rate. The sensitivity analysis is carried out for a variation of ±30% of other parameters.

### Effects of variations in initial costs and fuel cost for the base and proposed case on NPV

To begin with, Fig. 4(a) points out that the project is financially in a better position if the fuel cost of the base case increases. A 15% increment in fuel cost for base case results in a nearly 40% hike rise in project NPV whereas it shows a reduction by the same percentage for a 15% decline in fuel cost. However, the initial cost has the utmost impact on NPV as opposed to fuel cost. This subtlety signifies that to accomplish an economically viable project, the shrinkage of initial costs is the prime requisite. In contrast, the impact of fuel cost for the proposed case can be observed as negative on NPV as illustrated in Fig. 4(b). A 15% rise in the base value of $-246,023 leads to $-282,926 which results in a 15% increment in project NPV. The analysis clearly pinpoints that the initial costs of PV are yet the main impediment for project viability. Given the fact of price slashes in the PV module and converter technology, it implies a positive return of investment environment. In consequence, this would encourage policymakers and investors to finance PV projects.




(a)




(b)

Fig. 4 NPV of the project with variations in financial input parameters; Fuel cost- base case (FCBC) (a), fuel cost- proposed case (FCPC) (b)

## Effects of variations in initial and O&M costs on NPV

In regard to variations in O&M costs, a 15% growth calculates the drop in NPV to $653,030 which is a 13.7% reduction in contrast to the base case (Fig. 5). Likewise, the same rate of variations in either direction is estimated for NPV as O&M costs vary. Despite this, the results reveal that initial costs have massive impacts on NPV as opposed to O&M costs.

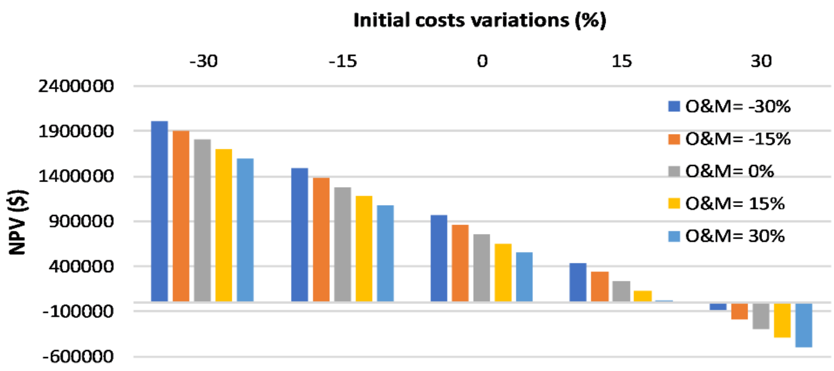



Fig. 5 NPV of the project with variations in O&M cost

## Effects of variation in escalation rate on EBT, IRR Equity and NPV

In view of the impact of escalation rate, it can be observed that NPV changes remarkably throughout the sensitivity ranges which implies a strong relationship between the escalation rate and project NPV as demonstrated in Fig. 6. In the case of IRR-Equity, ±30% alterations in escalation result in a 7.58% surge and an 8.45% downturn in IRR-Equity, respectively. Nonetheless, 13% of IRR-Equity entails that the project is financially viable even with a 30% cutback in the escalation rate. Notwithstanding, EBT is moderately impacted by the diversities in fuel cost escalation rate.

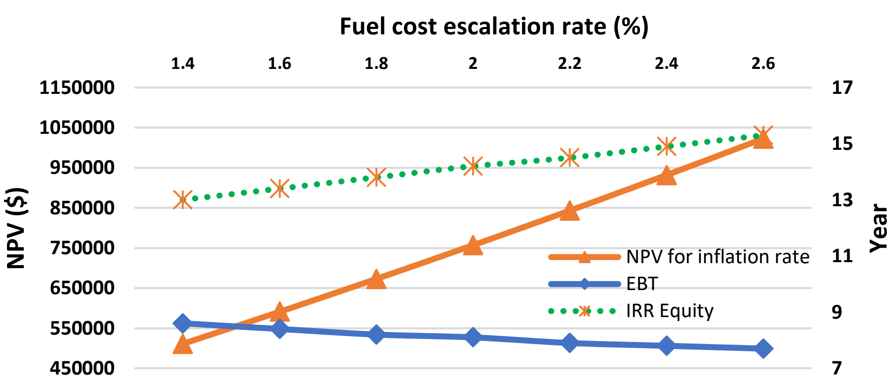


Fig. 6 NPV, EBT and IRR-Equity of the project with variations in fuel cost escalation rate

## Effects of variation in discount rate on NPV

In practice, discount rates are not risk-free. Fig. 7 suggests that NPV dwindles as the inflation rate increases. Though, the discrepancies are not much prominent. The response of NPV affirms a significant reduction with the upsurge in discount rate. For instance, a 10% rise in the discount rate leads to an approximate 30% reduction of NPV. Ideally, this phenomenon is the result of surpassing the cost of funds and thus returns will be less than the expectation.

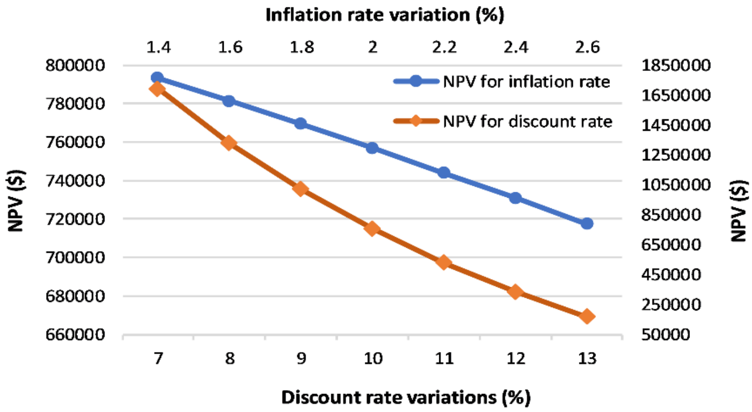



Fig. 7 NPV of the project with variations in discount (secondary axis) and inflation rate (primary axis)

## Effects of variations in initial costs and debt ratio on NPV

By definition, the debt ratio specifies the financial interest of the project which is positively linked to each other as illustrated in Fig. 8. With the fixed initial costs for the base case, a 15% drop/rise in debt ratio reflects a 13.21% slash/growth in NPV. What is more, the deviations in NPV is not significant in the case of the decreased initial cost. In contrast, project NPV nearly doubles with a varying debt ratio of 15% when the initial costs rise by 15%. It is worth noticing that project NPV becomes negative when the initial cost rise reaches 30% and thus the project seems to be financially impracticable.

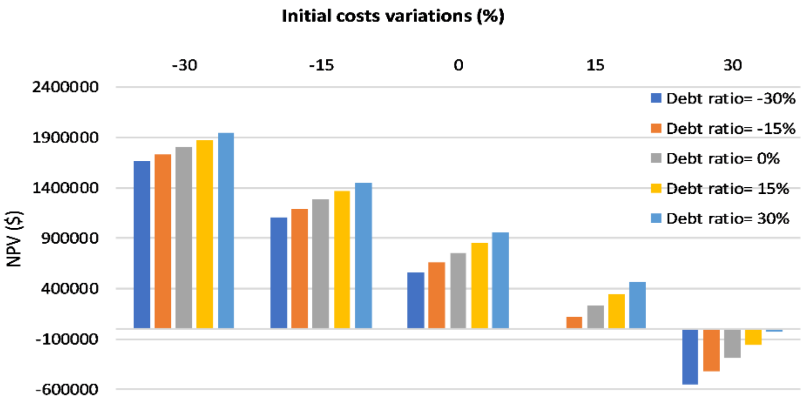



Fig. 8 NPV of the project with variations in the debt ratio

## Effects of variation in debt term on NPV

Principally, a longer debt term exemplifies an improved financial circumstance. When the debt term deviates by 15%, the NPV value of $793,326 increases by 6.27% whereas it diminishes by 7.36% for the reduced debt term of 15% as illustrated in Fig. 9. On the contrary, an escalated debt interest rate (DIR) corresponds to vary NPV by roughly 11% for 15% deviation in each direction which becomes approximately 22% rise/drop in NPV when DIR increases/cuts down by 30%.

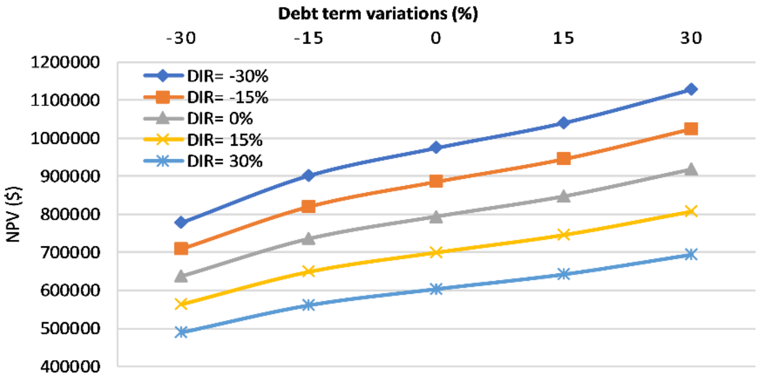



Fig. 9 NPV of the project with variations in debt term and debt interest rate (DIR)

## Effects of variations in GHG reduction duration and credit rate on NPV

To realize the impact of GHG reduction duration (GHGRD), a comparison between 0% and 15% variance for the base GHG reduction credit rate (GHGRCR) as shown in Fig. 10 depicts that NPV value alters by 5.26% in each direction for 15% deviation of GHGRD from the base case. A similar percentage of variations are visible with associated changes in GHGCRR. Conversely, GHGCRR variances demonstrate a 4.11% and 4.28% decline in NPV for GHGRD variations of ±15% and 30%, respectively. On the other hand, NPV surges by 8.58% for GHGRD of 30% which is nearly doubled than that of the 30% reduction case and follows the same trend for all other GHGRD cases.

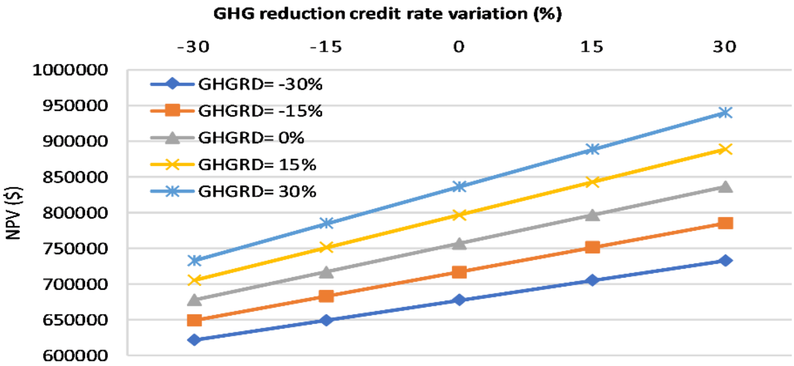
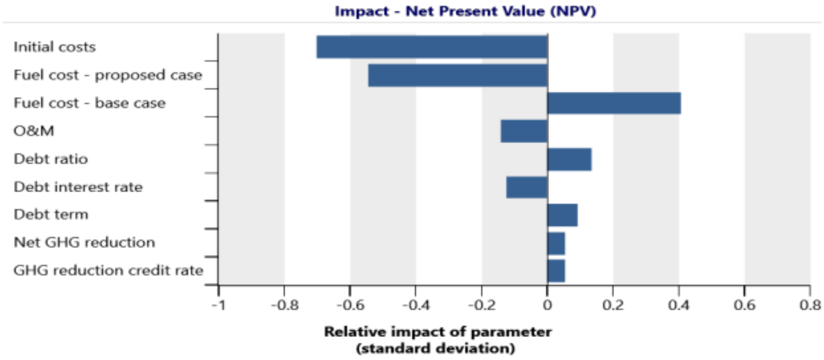



Fig. 10 NPV of the project with variations in financial input parameters; GHG reduction duration (GHGRD) and credit rate

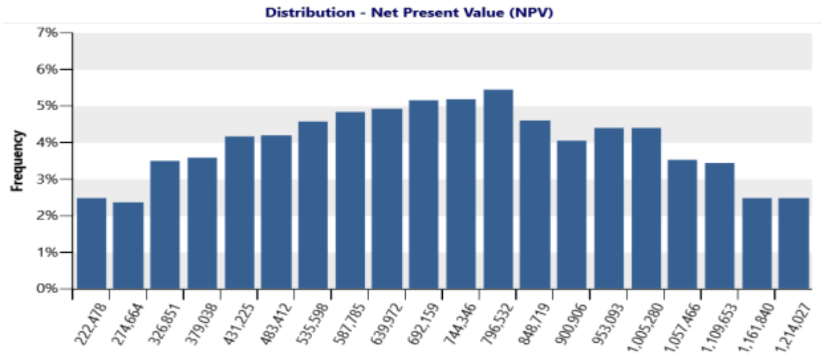
## Relevant risks of the project

In risk analysis, all the parameters are varied with each other within the definite range. The NPV is considered as a financial index and the selected level for risk analysis is ±25\%. The results of risk analysis are outlined in Table 6. The impact graph as shown in Fig. 11 indicates that initial costs followed by the fuel cost for the proposed case have the highest footprint on project NPV which is elaborately described in Fig. 4(b). The O&M costs and debt interest rates have an adverse footprint on the NPV through their footprint is not as significant as initial costs and fuel costs-the proposed case. On the contrary, the fuel cost of the base case has a positive impression on NPV as pointed out through sensitivity studies as depicted in Fig. 4(a). The results also expose that debt ratio, debt term, Net GHGRD and GHGRCR have a positive influence on NPV.

In the distribution graph, the applied risk level is 25% to represent a 90% confidence level. A positive NPV with the level of studied risk implies that the project is financially viable and realistic.




**(a)**




**(b)**

Fig. 10 Impact graph (a) and distribution graph (b) of risk analysis

Table 6 Impact data of risk analysis

| Parameter | Unit | Value | Range (+/-) | Minimum | Maximum |
|---|---|---|---|---|---|
| Initial costs | $ | 4,160,000 | 25% | 3,120,000 | 5,200,000 |
| O&M | $ | 64,000 | 25% | 48,000 | 80,000 |
| Fuel cost - proposed case | $ | -246,023 | 25% | -184,517 | -307,529 |
| Fuel cost - base case | $ | 186,263 | 25% | 139,697 | 232,829 |
| Net GHG reduction – credit duration | $tCO_2$ | 43,178 | 25% | 32,383 | 53,972 |
| GHG reduction credit rate | $tCO_2$ | 10.00 | 25% | 7.50 | 12.50 |
| Debt ratio | % | 60.0% | 25% | 45.0% | 75.0% |
| Debt interest rate | % | 5.00% | 25% | 3.75% | 6.25% |
| Debt term | yr | 15 | 25% | 11 | 1 |

## Conclusion

An in-depth analysis of rooftop PV in commercial buildings in Bangladesh has not been explored in earlier studies.In this study, an in-depth feasibility analysis is carried out to assess the profitability of roof-top PV installation in commercial buildings and simulation with a case study is conducted through RETScreen software. Specifically, the article is meant to determine: (a) the economic feasibility of rooftop solar in commercial buildings and (b) sensitivity and risks involved in the project. The selected area calculation for PV installation and the impact of various financial parameters on project NPV is presented and discussed. Besides, sensitivity and risk analysis are also given careful consideration for viability assessment.

The rigorous economic analysis of the project shows a NPV value of $756,896 and an IRR-E value of 14% which is greater than the discount rate and this implies that the project is economically viable. Additionally, a shorter recovery of the project investment further embodies the financial viability of the project. Moreover, it is found that the suggested project not only incurs financial gain but also ensures a convincing amount of GHG emission reduction which is estimated to be 206.372 $tCO_2$/yr in the project's lifetime. These findings could serve as a motivator to the public or government buildings for such commercial deployment.

Additionally, the performed sensitivity and risk analysis symbolize that the initial costs and fuel cost are the dominant factors to achieve a profitable outcome from this type of project. An increase in the overall NPV can be achieved by decreasing the initial costs and increasing the selling price of solar-generated electricity. Hence, high initial costs may discourage building owners and this will impede the possibility of utilizing commercial buildings and obtaining greener energy in the city area. Nonetheless, considering a competitive market, initial cost reduction is the most viable option which depends on the manufacturing and production of components. In this circumstance, government incentives and tax deductions in RES equipment would play a key role in developing countries like Bangladesh. Other factors also seem to have an impact on NPV but not as significant as the initial and fuel costs. The results point out that PV installation in the commercial building in Bangladesh has enormous financial implications that would have far-reaching economic and environmental benefits and may motivate building owners in investing in rooftop PV in the country. Although this study is focused on Bangladesh and the capital city, this can be easily considered in other cities and countries too.

Despite the contribution of economic and environmental analysis, the study has the following limitations: (i) Inclusion of battery storage, PV output variation and load balancing to minimize the impact on the grid is not considered in this study (ii) Solar data of Dhaka is used to reasonably estimate the financial and atmospheric performances across Bangladesh. However, building sizes, numbers and available space for rooftop PV installation differ in other cities due to their geographical and economic importance and hence a detailed study for each location must be carried out to find the precise economic and environmental advantages and (iii) Bangladesh with a subtropical monsoon climate has variation in solar output throughout the seasons especially in the rainy season and in winter when PV system will face its extreme situation i.e. no or very limited power output. Hence, it would require a detailed study of weather data for deploying such projects. These limitations will be taken into consideration in future work.

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