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A Feasibility Analysis of Wind Power Project in the Hunza Valley of Pakistan

Muhammad Amjad Khan[1a], Salman Amin[1b], Abdul Rauf Bhatti[2], Sheikh Saaqib Haroon[1c], Intisar Ali Sajjad[1d]

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ABSTRACT

Wind resource potential is strongly influenced by the exposure, orientation of the terrain and the wind direction. In Pakistan, the northern areas have very attractive sites for wind power plants. However, due to non-standardized masts installed, the collected data are not reliable. Due to the unreliable nature of available data, the investors normally avoid the investing in the wind power projects. Various software and tools have been used so far for the feasibility analysis but due to unreliable data, the proper feasibility analysis is still out of sight. To overcome this deficiency, a feasibility study of a wind power project in the Hunza Valley of Pakistan using reliable data is presented in this paper. For this purpose, the RETScreen is used by exploiting the standard NASA's (National Aeronautics and Space Administration) database. Since the developing countries are facing problems in the development of wind projects, it is envisaged that this approach will give an easy way to launch new clean energy projects.

Keywords: Energy, Wind Power, Feasibility Analysis, Renewable Energy, Energy System.

1. INTRODUCTION

The geodesic lines show that Pakistan is situated at a minimum latitude of 23.69°, the maximum latitude of 37.09°, minimum longitude of 60.88° and maximum longitude of 77.84° [1]. Its geographical location is self-blessed with wind power potentials, especially in the northern region. Presently, the oil and gas power plants (which are around 58.9%) are normally used to fulfil the country's energy demand. This percentage is sufficiently high. On the other hand, the renewable and nuclear power generation is around 6% only [2]. The demand for energy is increasing day by day resulting in the increased consumption of fossil fuels. Consequently, another alarming factor i.e. global warming is also increasing day by day due to the emission of Greenhouse Gases (GHG) exhausted by the burning of fossil fuels. These gasses not only the cause of the increase in environmental temperature but also a major cause of shifting of wind energy zones [3]. Therefore, the production of energy through such conventional methods leads to the deficiency of fossil fuels and prove hazardous from an environmental point of view as well. To cope with such forthcoming situations, it is needed to look for renewable sources of energy which are cheaper, reliable and environment-friendly. Since the sun is a great source of energy, solar power is a reliable option. However, the photovoltaic panels cover a huge land area and need battery backup. Similarly, wind power projects use huge land space but due to high pole heights of windmills, the below land can be used for agriculture. Around 70% of the land is useable for crops, which is covered by wind

[1] Department of Electrical Engineering, University of Engineering and Technology, Taxila, Pakistan.
Email: [a]amjaduet10@gmail.com (Corresponding Author), [b]salman.amin@uettaxila.edu.pk, [c]saaqib.haroon@uettaxila.edu.pk, [d]intisar.ali@uettaxila.edu.pk
[2] Department of Electrical Engineering, Government College University Faisalabad, Faisalabad, Pakistan.
Email: bhatti_abdulrauf@gcuf.edu.pk

farms [4]. The reliability of the wind power plant is mainly depending upon the continuous flow of air. Pakistan Metrological Department (PMD) has installed many wind masts to gather airspeed data throughout the year, but these masts were not installed as per IEC Standard (IEC-61400-12-1: 2005). There were many issues of masts installed like installation, quality and instrumentation [5-6]. In the planning and management of a wind power project, reliable data has a vital role [7].

There is another problem with aero profiles of wind in mountainous areas due to the unbalance nature of the land. This results in a false collection of wind data which leads to the unreliable feasibility report. Pakistan also lies in a region of increasing wind speed as simulated with ECHAM5-HAM by an average over 30 years [8]. So, zonal climate change has no significant effect on wind speed in the future.

The site location is Hunza valley, Pakistan. Since the climate of this valley remains very cold, the environment is not good for any kind of wind turbine due to icing. Icing can cause 3-17% of total energy losses per annum [9]. This can be mitigated by heating or pulsating the blades. Now a day's superhydrophobic sprays are available, which repels water, icing, dust and snow rain as well. A thin coating of superhydrophobic spray will also serve the purpose.

Taking into account the above-stated scenarios, a feasibility study of the wind-based power project of 50MW is examined in this paper using RETScreen software. The data used for analysis is fetched through NASA's database. RETScreen is very popular software by NASA which can perform an economic and technical analysis of PV Systems, Wind system and other hybrid clean energy projects through this tool [10].

2. WIND SPEED IN NORTHERN PAKISTAN

The wind Atlas along the Northern side of Pakistan is shown in Fig. 1 which shows the overall wind flow. Although, it is not precise, it maps an overall picture of wind potential. Different wind turbines have different power curves, but most of the windmills show significance power output when wind speed at hub height is around 10 ms^{-1}. A map of wind speed at 50 m height is shown; the dark brown regions in Fig.1 indicate the region with wind speed around 9-10 ms^{-1} [11]. Several belts for good wind speeds are shown in Fig. 1. Although the climate variation changes the wind flow areas this area is so huge that it covers hundreds of kilometers. So sustainability has no issue here.

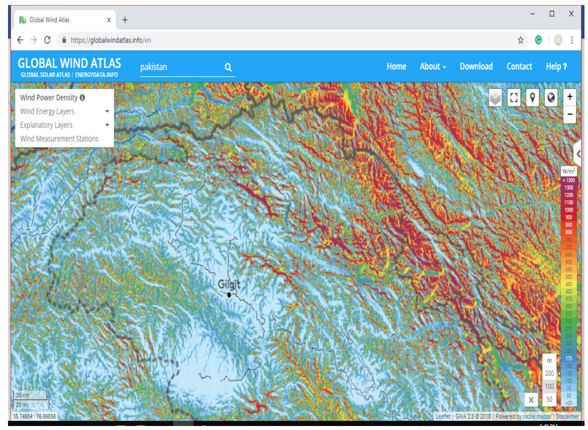

Fig. 1: Wind Atlas along the Northern Side of Pakistan [11]

Engineering of the wind energy distribution is given by using Weibull probability density function. This can be used to observe the mean wind speed over a long range of the area in long term scenarios. The p(v) probability of wind speed v around the year is as (Equation (1)):

$$p(v) = \left(\frac{s}{C}\right)\left(\frac{v}{C}\right)^{s-1} \exp^{\left[-\left(\frac{v}{C}\right)^{s}\right]} \quad (1)$$

where s is the shape factor, ranges from 1-3, is defined by the user. This equation is valid only if s>1, v≥0 and C>0. C is the scale factor and can be defined as (Equations (2-3)):

$$C = \frac{v}{\gamma\left(1+\frac{1}{S}\right)} \quad (2)$$

$$\bar{v} = \sum_{v=0}^{v=25} v\,p(v) \quad (3)$$

where $\bar{v}$ is the average wind speed and γ is the amma function [12]. If ρ is the air density then wpd (Wind power density) is given as (Equation (4)):

$$pd = \sum_{v=0}^{v=25} 0.5\rho v^3 p(v) \quad (4)$$

3. WIND MILL

In the last decade, due to fast success in research and development, wind technology got a mature status. Modern wind energy systems are more efficient, reliable, automatic and less expensive than it was in the past.

The front and side views of a typical horizontal axis wind turbine are shown in Fig. 2. As the wind flows over the cut with the speed usually 4 ms^{-1}, the blades start to move due to aerodynamic upward lift. Blade speed increases with the increase in speed of the wind. When wind speed is high enough then the control system of the modern wind turbine shuts it down to avoid serious damage. Normally, it happens when the wind speed is around 25 ms^{-1}, which is also called a cut out speed.

The main parts are a rotor with blades, gearbox to regulate the speed of the generator, a tall tower to support the whole system at a certain height, to capture the high wind velocity and to sport the heavy nacelle assembly.

There are different configurations in which the wind farms can be established. The optimum gap between the towers should be around 3-5 rotors and 5-9 rotors between the rows [12].

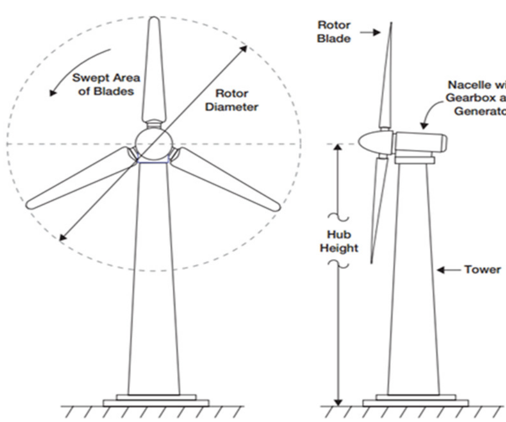

Fig. 2. Front and side views of a wind turbine [13]

The windmills used in this feasibility report are Vesta manufactured, model VESTA V80-2.0 MW-78m of capacity 2MW with a hub height of 78m, the rotor diameter of 80m and the swept area of 5026.55m^2. The energy curve of the above-described model is shown in Fig. 3. The nacelle of the wind turbine contains a shaft, gearbox, fail-safe break, generator, controller, yaw control motor, coupling and a cooling system. The modern turbines are designed for cold areas.

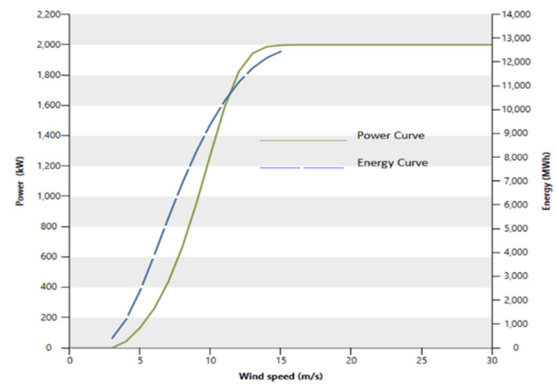

Fig. 3: Energy curve ff Vesta V80-2.0 MW-78M

Since the Hunza Valley's climate is cold, the problem of icing within the nacelle creates a big problem. However, in modern turbines, the chances of icing within the nacelle have been diminished.

4. CLIMATE DATA AT HUNZA VALLEY

RETScreen is a versatile analysis tool which is based on Microsoft Excel. It is used to assess the viability of clean energy projects both technically and financially from a small scale to very large scale. The first step is the selection of location, which is done through google maps. Our desire location is Hunza Valley and its surrounding areas. The climate data is shown in Tables 1-2.

All the data given in the climate are reliable as it is taken from the database of NASA's satellite-derived metrological and solar energy dataset which was recorded for 10 years continuously over the past. An annual average wind speed of 5.6 ms^{-1} at a height of 10 m above ground level can be observed from the table, which indicates that Hunza Valley is a very good location for wind power projects. The wind speed in

Table 1. NASA's Climate Data at Hunza Valley.

	Climate Data Location	Facility Location	Source
Latitude	36.3	36.3	-
Longitude	74.6	74.7	-
Climate Zone	8-Subarctic		NASA
Elevation (m)	4269	4269	
Heating Design Temperature (°C)	-25.0		
Cooling Design Temperature (°C)	12.4		
Earth Temperature Amplitude (°C)	29.5		

Table 2: Monthly NASA's Climate Data at Hunza Valley

Months	Air Temperature (°C)	Relative Humidity (%)	Precipitation (mm)	Daily Solar Radiation Horizontal ($kWh/m^2/d$)	Atmospheric Pressure (kPa)	Wind Speed (m/s)	Earth Temperature (°C) C	Heating Degree-days 18 C (C-d)	Cooling Degree-days 10°C (C-d)
January	-19.0	81.6%	59.37	2.37	60.7	5.8	-20.4	1,147	0
February	-16.7	80.5%	54.11	3.06	60.7	5.7	-17.6	971	0
March	-12.3	80.9%	53.85	4.04	60.9	5.5	-12.9	940	0
April	-8.2	81.3%	65.55	4.83	61.3	5.1	-8.8	785	0
May	-3.0	73.2%	35.10	5.65	61.4	5.0	-1.3	651	0
June	3.4	59.0%	25.93	6.58	61.5	5.3	6.3	440	0
July	7.8	45.8%	33.23	6.68	61.5	5.6	12.4	315	0
August	7.8	46.4%	35.86	5.95	61.6	5.6	12.2	317	0
September	3.4	47.9%	29.66	5.21	61.6	5.8	6.7	437	0
October	-4.1	61.4%	24.35	3.94	61.5	5.9	2.8	684	0
November	-11.0	72.0%	31.23	2.89	61.4	5.7	11.3	871	0
December	-16.3	80.2%	34.65	2.17	61.1	5.7	17.6	1,065	0
Annual	**5.6**	**67.4%**	**482.89**	**4.45**	**61.3**	**5.6**	**-4.5**	**8,621**	**0**

this region is lying in class 4 as per standard wind classification [14]. Apart from Hunza Valley, there are many other wind channels in surrounding areas as well. In these areas, the problem of icing of blades and nacelle can be mitigated by the use of nanoparticle sprays. These sprays fill all Nano or Micro level pits over the blade surface and make it dead smooth. This results in high superhydrophobicity for water and snow. This will also reduce the drag force as well. There are other active and passive methods to mitigate the icing effects including indirect heating and pneumatic or chemically [15].

It is worth mentioning that the class 4 and above are best suited for wind power projects as per Rayleigh statistics. Also due to the cold climate, the air density is high and power is directly related to wind density. The more density of wind will result in more generated power.

5. WIND DATA ANALYSIS

NASA's metrological data is available at 10 m height. To calculate this speed at the hub height we use hub height and wind shear exponent in the following Equation (5) [16].

$$\frac{\overline{v_h}}{v_o} = \left(\frac{H_h}{H_o}\right)^{\alpha} \quad (5)$$

where $\overline{v_h}$ and $\overline{v_o}$ are wind speeds at hub height and at anemometer height and α is the shear constant. The column of wind speed in Table 3 is calculated using Equation (5).

Now by interpolating the energy curve shown in Fig. 3, as per adjusted speed, the energy produced can be calculated. After subtracting the losses (array losses, icing and airfoil soiling losses, downtime and uptime losses and other miscellaneous losses), the net energy exported to the grid is extracted. Array losses are due to closely spaced installations. These losses should be normally less than 5%. For a single turbine, array losses are 0%. Icing and airfoil soiling losses depend on temperature, humidity, altitude, blade design and overall machine design. These losses lie in the range of-10% of total energy generated as is given in Table 4. The losses occur due to maintenance, turbine failures and utility outage which are called downtime losses. These losses vary from 2-7% of the gross output power. Miscellaneous losses include start/stop operation, transmission line losses, high wind cut-outs and off-yaw operation losses. The burden of these losses is from 2-6% of total energy generated. A total of 151263 MWh is annually exported to the grid. The CF (Capacity Factor) of the plant can be calculated as Equation (6) [17]:

$$CF = \frac{\text{Annual Energy Collected}}{\text{Plant Capacity} \times 24 \times 3 \times 365} \times 100 \quad (6)$$

$$CF = \frac{151263}{50 \times 24 \times 365} \times 100 = 34.534\%$$

The range of a CF is from 20-40% and 34.53% be on the upper end of the range, which represents the latest model of a wind turbine with a good wind regime. The various turbine related losses are shown in Table 4.

Table 3: Wind Data Analysis at Hub Height

Month	Wind Speed (m/s)	Atmospheric Pressure (kPa)	Air Temperature (ºC)	Climate Data (m/s)	Climate Data (kPa)	Climate Data (ºC)	Electricity Export Rate (S/MWh)	Electricity Exported to the grid (MWh)
January	13.2	60.7	19.0	5.8	60.7	-19.0	100	13,772
February	13.0	60.7	16.7	5.7	60.7	-16.7		12,228
March	12.5	60.9	12.3	5.5	60.9	-12.3		13,022
April	11.6	61.3	8.2	5.1	61.3	-8.2		11,799
May	11.4	61.4	3.0	5.0	61.4	-3.0		11,800
June	12.0	61.5	3.4	5.3	61.5	3.4		11,677
July	12.7	61.5	7.8	5.6	61.5	7.8		12,346
August	12.7	61.6	7.8	5.6	61.6	7.8		12,362
September	13.2	61.6	3.4	5.8	61.6	3.4		12,419
October	13.4	61.5	4.1	5.9	61.5	-4.1		13,272
November	13.0	61.4	11.0	5.7	61.4	-11.0		12,961
December	13.0	61.1	16.3	5.7	61.1	-16.3		13,604
Annual	**12.6**	**61.3**	**5.6**	**5.6**	**61.3**	**-5.6**	**100**	**151,263**

Table 4: Losses Percentage

Losses	Percentage
Array Losses	7.0
Airfoil Losses	3.0
Miscellaneous Losses	5.0
Availability	94.0

A German Physicist A. Betz claimed that a maximum of 59.3% of wind energy can be converted into mechanical energy by wind turbine blades [17]. The cost estimation of an installed wind turbine is presented in the next section.

6. COST ESTIMATION

There are two types of costs involved in wind turbine cost estimation. One is fixed cost and the other is a variable cost. The detail is shown in Table 5. This cost estimation does not include land cost.

The cost of a wind turbine is usually described in per MW, the normal market rates are ranging from US$ 1,300,000-2,200,000 per MW [18].

The cost per unit has a great significance from a user point of view. Per unit cost can be calculated as [19]:

$$C_{pu} = \frac{\text{Fixed Cost} + \text{Per Annum Varibale Cost} \times \text{Project Life}}{\text{Project Life} \times E(\bar{v})} \times 100$$

where $E(\bar{v})$ is per annum energy in KWh at average wind speed.

$$C_{pu} = \frac{101002440 + (3500000 \times 25)}{24 \times 151263000}$$

C_{pu} =0.0519 US$

In PKR it is 5.2 PAKRS/KWh.

Table 5: Fixed and variable costs details

Name of Item	Unit	Quantity	Unit Cost	Amount (US$D)
Engineering	Cost	1	20000	20000
Wind Turbines	kW	50000	1800	90000000
Contingencies	%	10%	9002000	9002000
Interest During Construction	8%	6 months	99022000	1980440
Grand Total Fixed Cost			101002440	
Salaries	Cost	-	2000000	2000000
Maintenance	Cost	-	1500000	1500000
Grand Total Variable Cost Per Annum			3500000	

This cost can be further reduced by changing the wind turbine model. Also, incentives or grants, if available, make a significant difference in per-unit cost. The profitability of the wind turbine system can be estimated by performing the financial analysis of the system.

7. FINANCIAL ANALYSIS

Financial analysis indicates whether a system is profitable or not. It is the most critical part of feasibility analysis. Financial analysis describes the system stability and viability by analyzing financial parameters, income statement, cash flows and balance sheets. The general parameters' considerations in the financial analysis of wind power project are inflation rate, the debt ratio, debt term, project life and interest rate, as is shown in Fig. 4.

It can be seen that the revenue generated per annum is more than the cumulative costs of the operation and maintenance and annual debt payments. The equity payback is 7.1 years. Project life is 25 years. The cumulative earning with a breakeven point is shown in Fig. 4, according to which the profit will start after 7 years 1 month and 6 days. If the debt ratio is set to 0%, the equity payback will start immediately. Simple payback is 8.7 years which does not matter that whatever the debt ratio will be. Looking at all scenarios, the project is viable, either the investor takes all the money as a loan from the bank or uses capital, in any case, the business is stable and profitable.

Table 6 summarizes the results of the financial analysis. Table 7 shows the yearly cash flow which reveals that after 6 years the cumulative amount has a positive sign. This means after six years, net profit will start.

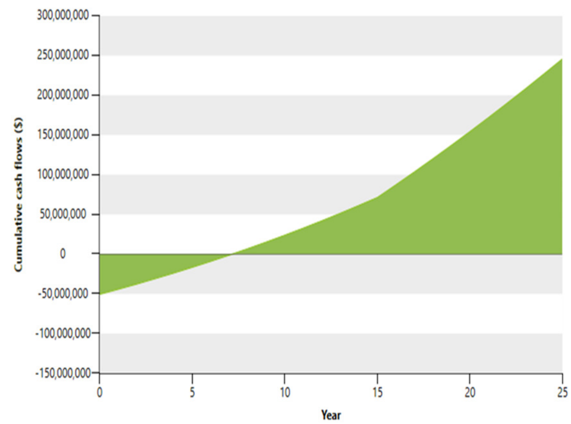

Fig. 4: Breakeven Analysis

Table 6: Financial Analysis

Financial analysis	
Financial Parameters	
Inflation rate	2%
Project life	25 Year
Debt ratio	50%
Debt interest rate	7%
Debt term	15%
Total Initial Costs	101,002,440 (US$)
Incentives and Grants	
Annual Costs and Debt Payments	
Operation & Maintenance	3,500,000 (US$)
Debt payments-15yrs	5,544,762 (US$)
Total Annual Costs	9,044,762
Annual savings and revenue	
Electricity export revenue	15,126,343(US$)
Total Annual Savings and Revenue	
Financial Viability	
Pre-tax IRR-equity	16%
Pre-tax IRR-assets	8.20%
Simply payback	8.7 Year
Equity payback	7.1 Year

8. GHG REDUCTION

GHG can be defined as the mixture of gasses that absorb and emit the infrared radiation which is emitted by the earth and is the main cause of increasing atmospheric temperature. These gasses mainly consist of tiny water droplets, methane, carbon dioxide, ozone, Nitrogen dioxide, hydrofluorocarbons and chlorofluorocarbons. Among these, carbon dioxide has a major role in increasing global warming [20-27]. The airborne fraction of carbon dioxide has been increasing for the last 50 years by 2.5$\pm$ 2.1% for every year. The lifetime (the time during which the gas remains in the atmosphere) of CO_2 is quite high in the order of 30-95 years. In order to keep the balance between GHG and non-GHG gasses, it is needed to reduce the GHG emission. CO_2 emission in the base case is in the order of 71082.6 tons per year but for the proposed case it is just 1421.7 tons per year. It is a significant decrease in GHG emission. The brief summary is shown in Table 8.

Table 7: Yearly Cash Flows

Year	Pre Tax	Cumulative (US$)
0	-50000000	-50000000
1	7470346	-42529654
2	7729548	-34800106
3	7993933	-26806173
4	8263607	-18542566
5	8538673	-10003893
6	8819241	-1184652
7	9105421	7920769
8	9397324	17318093
9	9695065	27013158
10	9998761	37011919
11	10308531	47320450
12	10624496	57944946
13	10946781	68891727
14	11275511	80167238
15	11610816	91778054
16	17442558	109220612
17	17791409	127012021
18	18147237	145159258
19	18510182	163669440
20	18880386	182549826
21	19257993	201807819
22	19643153	221450972
23	20036016	241486988
24	20436736	261923724
25	20845471	282769195

Table 8: GHG Emission Summary

Base Case	Proposed Case	Gross annual GHG emission reduction
tCO_2	tCO_2	tCO_2
71,082 .60	1,421.70	69,66090
100%	2%	98%

The histogram is shown in Fig. 5.

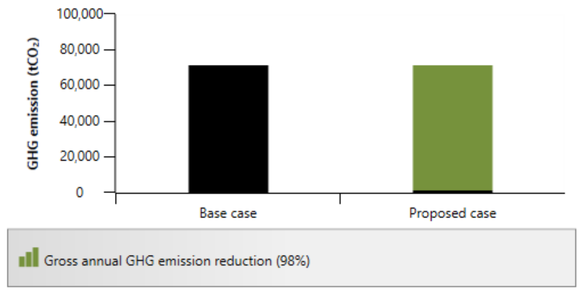

Fig. 5: Histogram of GHG Emission

9. RISK ANALYSIS

The risk analysis shows the probability of the uncertainty of project cash flow. It gives a statistical analysis of project failure or success. Fig. 6 shows the statistical analysis of the overall project by telling the cash flows.

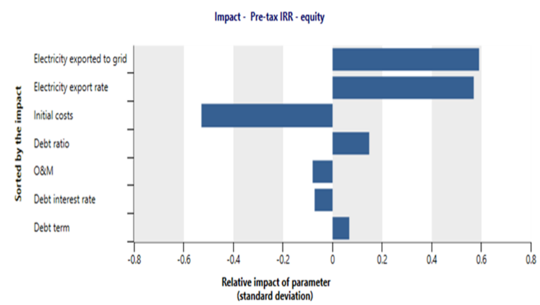

Fig. 6: Risk Analysis

The overall cash flows are to the right side with positive standard deviations that mean a successful project. It uses the variation of all the variables used in this project.

10. CONCLUSION

Pakistan is a country full of natural resources. The northern sides of Pakistan are best for such projects, although the climate is very cold technology has made things feasible. Modern wind turbine design can handle such harsh climates. The wind potential of class 4 is available along the northern sides of Pakistan, which is very productive from the point of view of harvesting of electrical energy. Although the initial cost is very high by suitable planning and estimation can open the gates of profitable business for investors. Good feasibility that incorporates all costs with risk analysis is always required to execute a project.

RETScreen is a very useful tool for an initial estimate of financial analysis. It gives the investors a clear cut image of the economic benefits of the clean energy projects and is useful for making decisions easily. RETScreen is very reliable as it uses the database of NASA. The micro-siting analysis is the key factor for a good feasibility report which leads to a successful business. The author believes that the GHG reduction and risk analysis gives a kick start to such clean energy projects, especially in developing countries. The developing countries are facing problems in the development of such projects. This approach gives an easy way to launch new such clean energy projects.

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