Foundation Wind Energy: Wind Turbine Project in Pakistan

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ABSTRACT

The paper examines the startup of a wind energy project in Pakistan. Treating it as a case study, the article discusses the background of conversion of wind energy into electric energy in an efficient manner. It then develops the technical and economic factors that make it a viable source of energy. Considering the actual costs and expected revenues, it determines the profitability of the project.

1. INTRODUCTION

There is chronic power shortage in Pakistan. The country has scarce resources of coal and oil. Although some gas reserves are available, they are earmarked primarily for household use. The increase in demand for electricity has stretched the present power system beyond its capacity. This has resulted in "load shedding," meaning the electricity is on for one hour and off for another hour. At present, hydroelectric power is the backbone of the power supply in Pakistan. The two major dams in Pakistan are at Tarbela and Mangla. If there is not enough rainfall in the monsoon season, the dams remain partially filled. Occasionally, the problem is exacerbated by the lack of snowfall in the Hindu Kush Mountains in the winter. The government is constantly under pressure to expand the power capacity in the national grid.

Set up in 2012, Foundation Wind Energy is a quasi-government agency in Pakistan that in in the process of installing a 50-megawatt capacity wind turbine farm in Sindh, Pakistan. The financing for the project will come from international financing, government subsidy, and private investment. The financing for the project will be 75% debt and 25% equity, with most of the money coming from foreign investment. The interest rate for local debt is set at KIBOR + 2.95%, whereas the internal loan will be at LIBOR + 4.60%. The return on equity is estimated to be 17%. The total cost of the project is approximately $128.7 million. The projected income depends on selling the electrical energy at the rate of 16.2972 cents per kWh in the national grid.

This is an interesting case study in several respects. The students get to understand the benefits of wind as a renewable energy source. They learn some of the technical details of wind turbines. They are required to do a NPV analysis of the feasibility of the project in an international setting. They should be able to apply the concept of hedging in foreign exchange markets.

There is a steady increase in the use of wind energy as a source of electrical power. On a global scale, we can see the development of wind energy in Figure 1.

There are several reasons for this growth. The coal-burning power plants are responsible for large amount of CO_2 emissions. Their negative impact on the environment is well documented. The sulfur in the coal becomes sulfur dioxide after combustion. It then combines with water to form sulfuric acid, which produces acid rain. The steady accumulation of CO_2 in the atmosphere causes greenhouse effect. There is considerable evidence to suggest that it causes global warming.

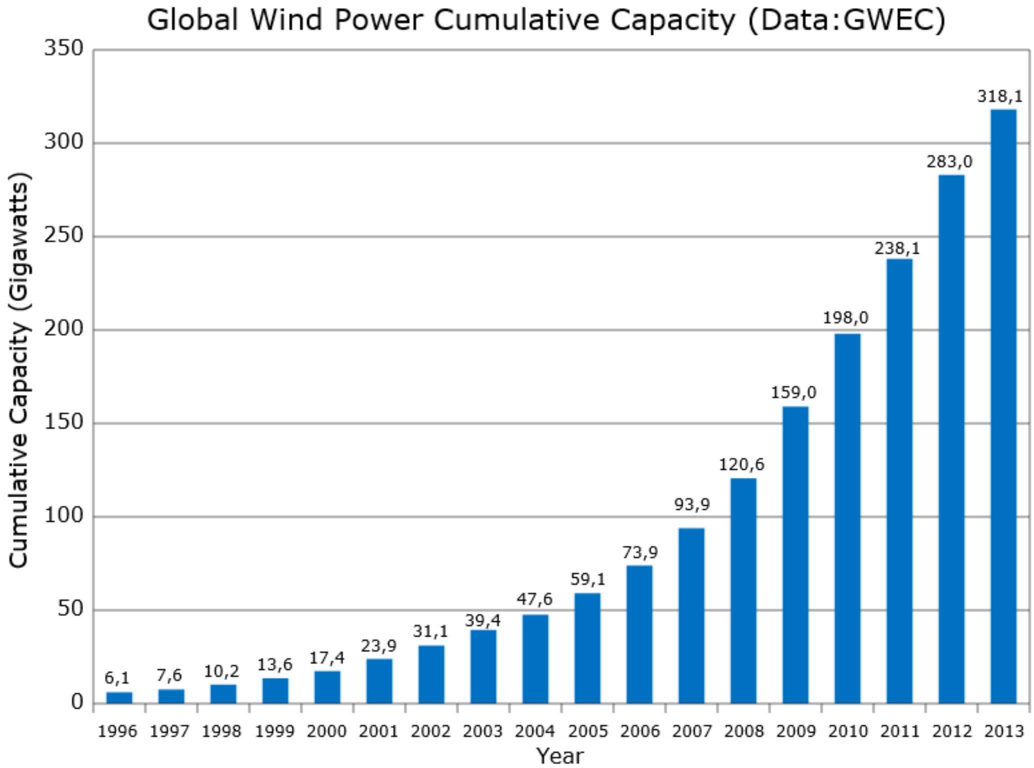

Figure 1: Wind power: worldwide installed capacity (Wikipedia)

Nuclear power is clean and cost effective. However, it is not without its negative effects. The safety of nuclear facilities has always been a concern. The accident at Chernobyl and a more serious disaster at Fukushima have highlighted their vulnerability to natural disasters. In USA, about 100 nuclear reactors are in operation supplying 19% of the electricity consumed.

Type	**Percentage**
Coal	39.1%
Natural gas	27.4%
Nuclear	19.4%
Renewables	12.9%
Other	1.2%

Table 1: Source of energy for the electric power plants in USA.

Natural gas has recently emerged as an important source of electric energy. The gas turbines are clean and efficient, emitting lower levels of CO_2. However, the fuel itself is relatively expensive. Table 1 shows the source of energy in the electrical power plants in USA. Notwithstanding its drawbacks, coal remains the backbone of the energy supply. The renewables include hydroelectric power plants, solar energy, and wind power. Wind power accounts for roughly 4.25% of the total energy generated in USA, where the total wind turbine capacity is 61,108 MW, exceeded only by China. It is difficult to develop additional hydroelectric power plants, thus the growth in the renewable sources will come primarily from wind and solar power.

2. TECHNICAL DETAILS

We define power as the energy generated per unit of time. A convenient unit of power is a watt, which is equivalent to one joule of energy per second. A flashlight bulb has a power of a watt. The human body has the power output of about a hundred watts.

To understand the process of extracting electrical energy from moving air, we start by defining the kinetic energy of a moving object. It is equal to ½ mv^2, where *m* is he mass of the object and *v* is its velocity. The mass of air passing through a windmill per second equals the area of rotor blades *times* the density of air *times* the wind velocity. Using these concepts, we can find the power output as follows.

Power output capacity (Watts) = ½ (Area of the rotor blades, m^2) (wind velocity, m/sec) (density of air, kg/m^3) (wind velocity, m/sec)^2 (efficiency of turbine)

The efficiency of the turbine is the fraction of the wind energy converted into electrical energy. Writing it in symbols, we get

$$P = \tfrac{1}{2} (\pi r^2) (v) (d) (v)^2 (e) = \tfrac{1}{2} (\pi r^2) (v^3) (d) (e)$$

The important feature of this equation is that the power generated by a wind turbine is proportional to the square of the length of the rotor blades and proportional to the cube of the wind velocity. The size of the rotor blades for a large turbine is about 50 meters.

The density of air varies with the temperature: hot air is lighter relative to cold air. The Table 2 shows the density of air at various temperatures.

Temperature *T* in °C	**Density of air *d* in kg·m^{-3}**
+30	1.1644
+20	1.2041
+10	1.2466
0	1.2922
−10	1.3413

Table 2: Variation of the density of air with temperature.

No machine is one hundred percent efficient in converting one form of energy into another form. In a wind turbine, the wind energy is first converted into the mechanical energy of the windmill and then the mechanical energy is converted into electrical energy.

In 1919, a German physicist, Albert Betz proved that the maximum efficiency of a wind turbine is 16/27, or about 59%. This means that no matter how well designed a windmill is, it cannot extract more than 59% of the energy of the wind. After passing through the turbine, the wind slows down, its pressure drops, it occupies a greater volume, and creates considerable turbulence. The maximum extraction of energy occurs when the wind leaves the turbine with velocity that is one-third of its initial velocity. The actual efficiency of a turbine is around 75% of its theoretical maximum.

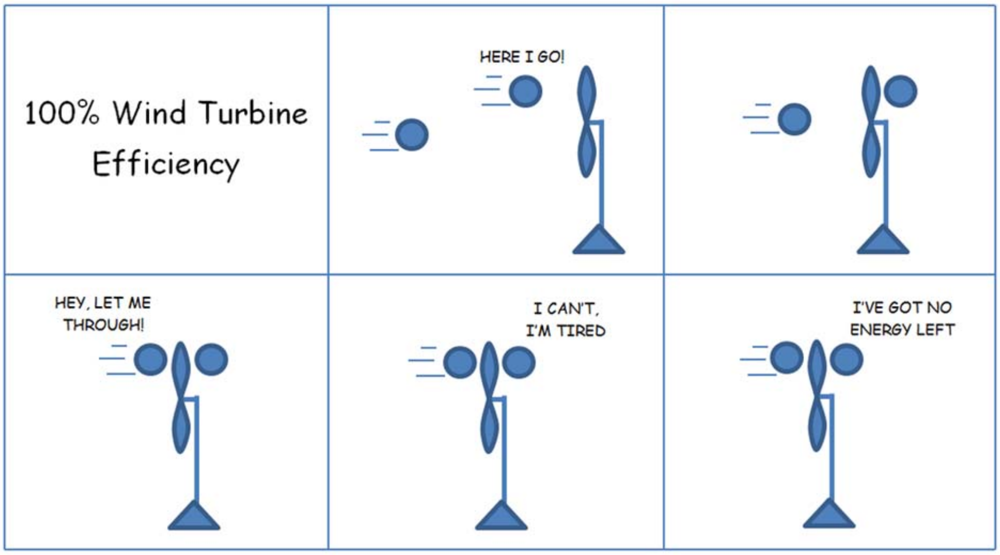

Figure 2: A visual explanation of the efficiency of the windmill. (Wikipedia)

To get an idea of the power output of a wind turbine, we can assume r = 50 meters, v = 12 m/sec, d = 1.22 kg/m^3, e = .4. This gives the electrical power output as

$$P = \tfrac{1}{2}\,\pi(50^2)\,(12^3)\,(1.22)\,(.4) = 3.31 \text{ MW}$$

The wind speed at a given location varies considerably over a 24-hour period. It is never stationary. Most of the time, it is moving at a steady speed with occasional gusts. The usual way to model it is to use Weibull distribution. The probability density function of the distribution is as follows:

$$f(x) = \begin{cases} \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-(x/\lambda)^k}, & x \geq 0 \\ 0, & x < 0 \end{cases}$$

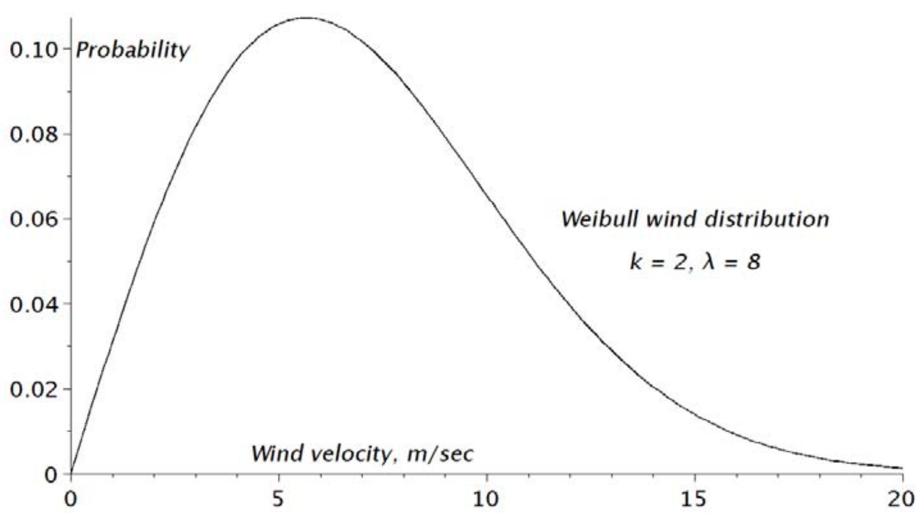

Figure 3: Weibull distribution as a model for the wind velocity, with parameters k = 2 and λ = 8.

In essence, it resembles the log-normal distribution. It too has two parameters, λ and *k* that describe the shape of the distribution curve. One can estimate the parameters by continuously measuring the wind speed over a period of 24 hours. Figure 3 represents the distribution when $\lambda = 8$ and $k = 2$.

3. ENGINEERING

Let us consider the cost of commercially available wind turbines shown in Table 3. These units are suitable for remote locations, such as a farm or a hunting cabin. The electrical power is low voltage, direct current, which is stored in batteries. An inverter delivers the electrical energy as common household 110 volt AC.

Coleman	400 W	$500
Sunforce	800 W	$900
Sunforce	1500 W	$3800
Nature Power	2000 W	$2500
Powermax	5000 W	$11,000
Powermax	7500 W	$13,000

Table 3: Commercially available wind turbines.

Large windmills have power in the megawatt range. A small turbine may have power output of about 2.5 MW. The largest wind turbines have a capacity of over 8 MW. A new generation turbines with capacity of up to 10 MW are under development. Some of the leading manufacturers of large wind turbines are Vestas (Denmark), Nordex and Enercon (Germany), and Goldwind (China).

4. HARNESSING WIND ENERGY IN PAKISTAN

Pakistan has an installed electricity generation capacity of 22,797 MW. It ranks 35th in the world. It is worthwhile to compare it with India, which has a capacity of 199,990 MW, ranking sixth in the world. The two countries have similar physical resources.

	Pakistan	**India**
Total production	94.65 billion KWh	871 billion KWh
Fossil fuels	68.3%	65.8%
Hydroelectric power plants	29.6%	19.5%
Nuclear power plant	2.1%	2.4%
Renewable resources	0.0%	12.3%
Total	**100%**	**100%**

Table 4: Comparison of electric power sources in Pakistan and India.

It is obvious from Table 4 that Pakistan has strong reason to develop renewable sources of electrical power, namely wind power and solar energy. A map of Pakistan showing the availability of prevailing winds in the country is shown in Figure 4.

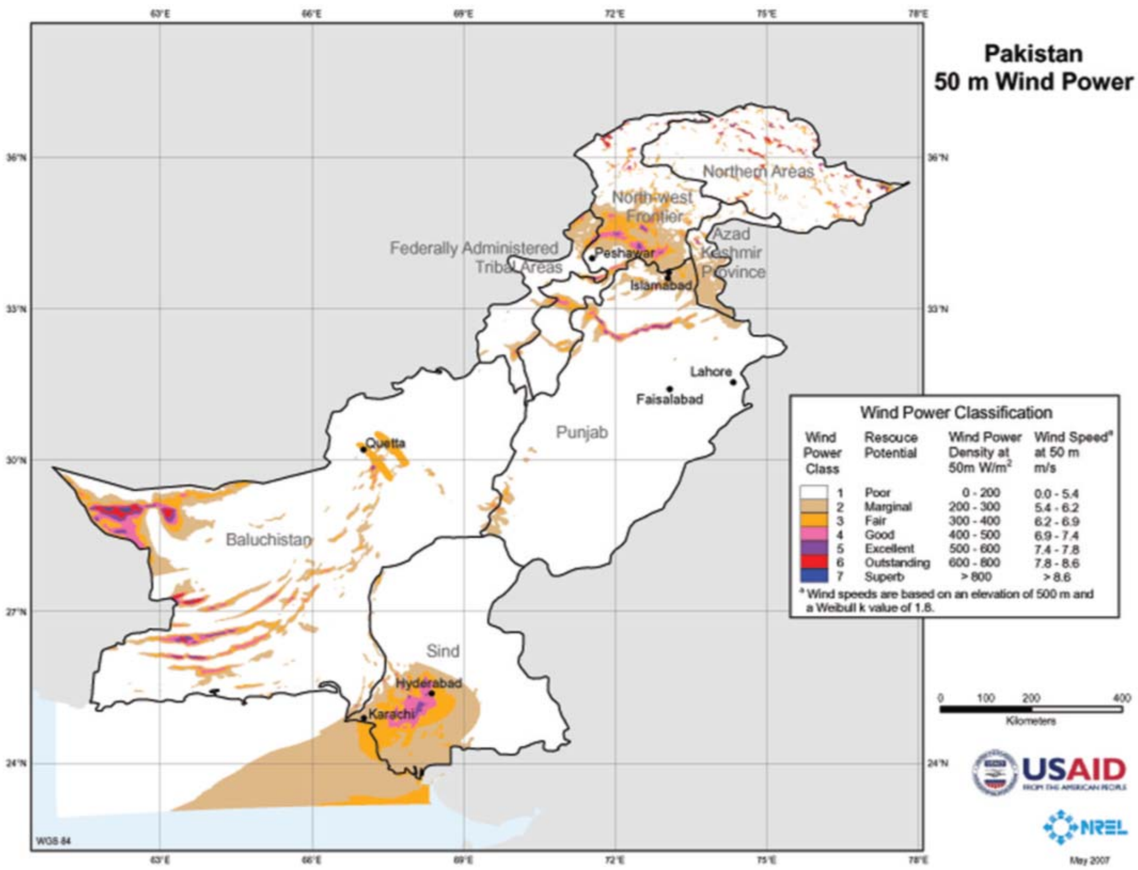

Figure 4: Map of Pakistan showing regions of steady winds.

The map shows the data from the National Renewable Energy Laboratory (NREL), the U.S. Department of Energy's primary national laboratory for renewable energy development, located in Golden, CO. It shows the potential of wind energy in Karachi-Hyderabad area in south Sindh, Quetta in Baluchistan and Peshawar-Islamabad region in northern Pakistan.

Fauji Foundation is a quasi-government organization in Pakistan. It has invested in several manufacturing facilities. In March 2012, it was developing two wind projects, 50 MW each, in Thatta District, in Sindh. The electrical power contractors were Nordex and Descon with Nordex as the lead contractor. Nordex is a German manufacturer of wind turbines, while DESCON is a private Pakistani firm specializing in the construction of manufacturing and power plants.

5. GHARO PROJECT

In March 2012, Safdar Hameed looked out of the window of his third floor office at the Ministry of Water and Power in Islamabad. The spring was in the air, with the flowers already blooming. Safdar had been working for a long time analyzing the problem confronting him: whether to approve the electricity rate requested by Fauji Foundation for its new wind power facility in Gharo, in the south of Sindh.

The problem was complicated by the fact that this was the first wind power project in Pakistan. He felt that he should encourage the development of the new project because of the power shortage in Pakistan. He was concerned with the high tariff for electricity requested by the Foundation, PKR 14.0481 per KWh. Converting it in US currency, with US$1 = PKR 86.20, it was 16.2972 cents per KWh. The electricity would be fed into the national grid through the purchaser of power, National Transmission and Dispatch Company Ltd.

Safdar was aware of the advantages of wind power as a clean, renewable source of energy. He knew that in neighboring India, it was already a major component of the electrical output. He was afraid that the rate was too high, and the government would have to subsidize the cost of electricity. He also wanted to know if the project was economically feasible for the Foundation.

Fauji Foundation had already leased a 1210-acre parcel of land. The lease was in effect for the next 20 years. The location of the site was excellent in terms of steady wind flow.

Safdar was impressed by the technical details of the project. Nordex, a German firm with considerable experience in the design and construction of windmills, was the manufacturer of the turbines. They planned to install 20 Model N-100/2500 turbines. Each turbine had a hub height of 80 meters and provided 2.5 MW of power. The overall efficiency of the turbines, depending primarily on the wind-flow patterns, was 29.47%. The net total annual output of the wind farm was estimated to be 129.1 GWh. DESCON, a Pakistani engineering firm would provide the support and other services during the 18-month construction period.

Fauji Foundation had proposed the capital requirements of the project with 75% debt and 25% equity. Two-thirds of the debt would come from foreign sources and the remaining one-third from the domestic sources. The interest on the debt would be entirely at the floating rate as follows: the foreign debt, six month LIBOR + 4.60% and the domestic debt, KIBOR + 2.95%

Safdar noted in the proposal that the debt would be repaid over a period of 12 years plus up to 24 months grace period, with level semiannual payments. The cost of equity for Foundation was 17% and its income tax rate, 34%.

The initial cost of the project stated in the proposal was as follows.

Cost	**$ million**
International cost of equipment	$83.595
Domestic cost of construction	$27.611
Letter of credit confirmation charge	$0.733
Total EPC cost	$111.939
Non-EPC costs	$1.188
Project development cost	$3.040
Land cost	$0.099
Duties and taxes	$0.711
Pre-COD insurance	$1.511
Financial charges	$3.519
Working capital	$1.037
Interest during construction	$5.658
Total project cost	**$128.703**

Table 5: Project initial cost, in US$ million

The operating and maintenance cost of the project during its twenty-year life was proposed as follows.

	Year 1-2	Year 3-5	Year 6-10	Year 11-20
O&M costs	1.850	3.128	3.395	3.280
Insurance	1.112	1.112	1.112	1.112
Total	**$2.927**	**$4.240**	**$4.507**	**$4.392**

Table 6: Annual project operating cost, in US$ millions

6. ANALYSIS

Initial investment = $128.703 million Life of the project = 20 years
Estimated annual net plant capacity factor (overall efficiency): 29.47%
Estimated net annual benchmark energy: $2.5*10^6*20*24*365*.2947 = 129.1$ GWh
Energy production per year = 129.1 GWh/year = 129.1 million KWh/year
Revenue per KWh = 16.2972 cents/KWh
Annual revenue = .162972*129.1 = $21.0396852 million
Income tax rate in Pakistan= 34%
After-tax annual revenue = $(1 – t)R$ = .66*21.0396852 = $13.886 million
6-month LIBOR (2014) 0.33% + 4.6%
6-month KIBOR (2014) 10.05% + 2.95%
Cost of international debt, $r_1 = .0033 + .046 = 0.0493$, its weight $w_1 = 2/3$
Cost of domestic debt, $r_2 = .105 + .0295 = 0.1345$, its weight $w_2 = 1/3$
Overall cost of debt, $r = 0.0493*2/3 + 0.1345/3 = .0777$
WACC = .0777(.75)(1 − .34) + .17(.25) = .08096150 ≈ .08

The following table summarizes the calculation of the net present value of the project.

	Action	PV of cash flows	Equal to
1	Initial investment	−128.703	−128.703
2	PV of tax benefit of depreciation, tD for 20 years, $t = .34$, $D = 128.703/20$	$+\sum_{i=1}^{20} \frac{.34(128.703/20)}{1.08^i}$	+21.482
3	PV of after-tax operating cost for 20 years	$-(1-.34)\left[\sum_{i=1}^{2} \frac{2.927}{1.08^i} + \sum_{i=3}^{5} \frac{4.240}{1.08^i} + \sum_{i=6}^{10} \frac{4.507}{1.08^i} + \sum_{i=11}^{20} \frac{4.392}{1.08^i}\right]$	−26.720
4	PV of after-tax annual revenue, $13.886 million for 20 years	$+\sum_{i=1}^{20} \frac{13.886}{1.08^i}$	+136.335
5	PV of after-tax terminal value ≈ 10% of initial investment	$+\frac{.1(128.703)}{1.08^{20}}$	+2.761
6	NPV of this project	Sum of the above	5.154

Table 7: Calculation of NPV

With a positive NPV of $5.154 million, it is a viable project.

There are many sources of uncertainty in this analysis. One can embed the uncertainty in the discount rate. Therefore, it is desirable to examine the impact of discount rate on the NPV of the project. This is given in Figure 5. This shows the internal rate of return of the project as 8.524%.

The inflation rate in Pakistan is quite high as reflected by the six-month KIBOR, which was 10.05% in August 2014. This affects the exchange rate of Pakistani rupee against the US dollar. In March 2012, one dollar equaled PKR 86.20. In August 2014, the dollar was worth PKR101.1. Foundation Wind Energy will have to file a petition with National Electric Power Regulatory Authority (NEPRA) for an upward adjustment in the price of electricity delivered.

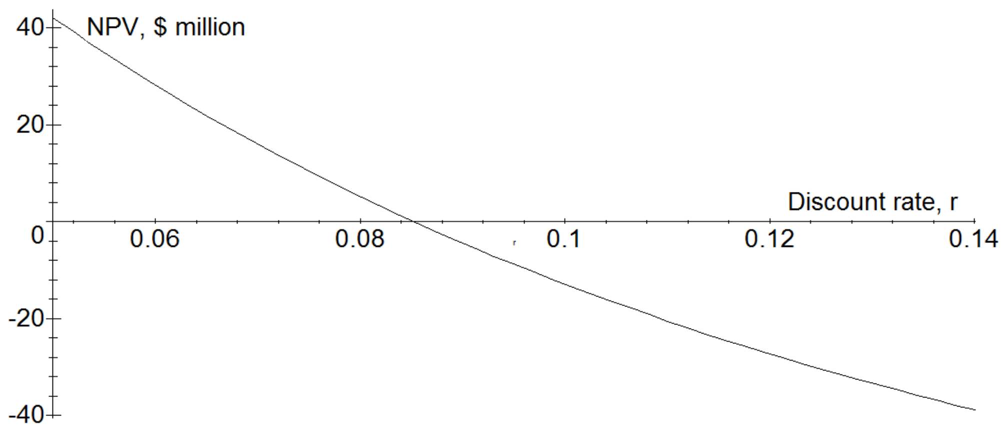

Figure 5: The variation of NPV of the project due to the change in discount rate.

7. CONCLUSIONS AND ACKNOWLEDGMENTS

The analysis of the case shows that it is viable project with a modest positive NPV. The project was completed in 2013. At present, it is supplying electrical energy into the national grid.

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