FEASIBILITY STUDY OF TOWER MOUNTED SMALL SCALE WIND ENERGY GENERATION IN ADIGRAT TOWN CONDOMINIUMS

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***Abstract:** climate change and global warming have urged the world to shift to low carbon emission energy potentials while ensuring the economic feasibility. This research aimed at investigating wind power potential at condominium building planted in Adigrat town. The technical and economic feasibility of tower-mounted small scale standalone wind turbine installation was conducted. The potential for wind power production was statistically analyzed. The data regarding the speed of the wind through the four seasons of the year 2017 were obtained from NASA and Ethiopian Metrological Agency. These were used so as to find out the availability and potential of wind power. The Rayleigh distribution probability was applied to calculate the wind speed distribution. By doing so, the annual wind power potential at the area and the possible annual energy production of the chosen wind turbine was estimated, after the selection of a proper wind turbine has been made upon the site condition. Accordingly, the study 's result shows that installation of the wind turbine at averagely 24 meters hub height in the target areas have a better performance of annual energy production, capacity factor, and economic efficiencies. The economic feasibility evaluation shows that the turbine can save an electricity bill of 52085.597 USD (52139.93 Birr) a year and covers above 100% of the electricity consumption of the condominiums. Moreover, the payback periods for the turbine installations are approximately 13 years which is more feasible if it is considered for small wind turbines too.*

***Keywords:** Adigrat town, Wind speed, Rayleigh distribution, small scale wind turbine, annual energy production, feasibility study.*

I. INTRODUCTION

Ethiopia plans to reach medium income in the coming 5 to 10 years. Researchers agree that Ethiopia has a huge energy potential in hydropower, geothermal, solar and wind energies. And this plan clearly states that generating this large amount of energy will be backbone for the economy. Hence, we are building mega-energy sources for instance renaissance dam and gilgel-gibe III to produce 10,000 Megawatt in the second Growth and transformation plan (GTP 2). And assisting this megaproject by generating energy from alternative source of energy such as different and large amount of distributed micro energy source will be essential (MoFED, 2010).

Distributed generation (DG) are small-scale (typically 1 kW – 50 MW) electric power generators that produce electricity at a site close to customers or that are tied to an electric distribution system [4]. And advantages of these systems are needs a lower capital cost because of the small size, reduce the need for large infrastructure construction, reduce pressure on distribution and transmission lines, increase power reliability as back-up or stand-by power to customers (Mostafaeipour, 2010)..

Therefore, distributed energy generation is widely seen as a beneficial development in terms of both energy security and environment friendly for the electricity production. In an urban environment, micro-generation systems represent an opportunity in terms of development for renewable energy sources, research, technological innovation, and resource efficiency. It is current opinion that governments' policies should promote the adoption of widespread micro-scale power generation in the urban environments. Furthermore, the integration of energy and environmental models in urban planning tools is strongly recommended for the development of sustainable communities. Currently, micro-wind energy is a well known technology for energy generation in urban area of developed countries, but there is relatively little knowledge in Ethiopia concerning their performance and the corresponding energy yield potential, particularly in buildings (EEPU, 2015.).

But in Ethiopia electricity is mostly generated in large centralized power stations, which can be a long way from where the electricity is used. It is then moved around the country through the national grid and then to local distribution networks as a result it suffered with large energy loses in transmission and distribution stations.

Energy services for household in Ethiopia are not exceptional from developing countries. In the case of electricity, which has the potential to improve productivity and provide considerable welfare benefits (lighting, cooking, baking, milling, information, entertainment, etc.), traditional grid extension will not be as the only solution. As researchers agree that decentralized supplies, whether at an individual household level or at community level, are cost-effective for urban cities.

Wind energy generator, an ingenious product, which works on the principle of three stage conversion wind energy in to mechanical Energy, mechanical Energy finally in to useful alternative current electrical energy with optimum efficiency.

Accordingly, this research project will study feasibility of tower mounted small scale wind energy generation in Adigrat town condominiums and to support grid energy supply from micro renewable energy sources. And the reasons for this sampling are one this region has relatively higher wind potential and it is government policy to expand condominium buildings. In addition exploring this technology will led to new approaches generating alternative source of energy, based on self-help for consumers in addition to megaproject.

Objective of the study:

General objective:

The general objective is to study technically and economically feasibility of tower mounted small scale wind energy generation in Adigrat town condominiums.

Specific objectives:

- To assess potential of wind energy
- To identify suitable small standalone wind turbines
- To estimate annual energy productions and performance coefficient of the chosen turbine
- To analyze the payback period

Methodology

The central element of the approach is the technically and economically feasibility study of wind energy generation with tower mounted standalone wind turbine at Adigrat town condominiums. Thus, to provide the necessary input data, different literatures were studied carefully. With this, the analysis were made via excel. Basically, the assessment was based on the available wind potential and economic on an annual basis. There were also three main stages to determine the feasibility and viability of the system.

These include:

1. The methods of data collection: For this study secondary data has been collected. From the website of NASA no of hours with given wind speed bin and direction obtained for a period of one year from January 2017 to December 2017. Selected condominium built electric demand for a period of one year and Electric price per kWh collected from Adigrat branch Ethiopia Electric power utility.
2. The Analysis: Data organization and analysis using excel
3. The main results of the analysis:
   - Annual energy production(AEP)
   - Performance coefficients
   - Electricity bill saved
   - Payback period

Theoretical framework

Wind in atmospheric boundary layer

For a given wind data at a height Z and a roughness height Z_O the velocity at height of Z_R can be found using this logarithmic profile (log law) as:(Mathew, 2006).

$$V(Z_R) = V(z)\frac{\ln(Z_R/Z_0)}{\ln(Z/Z_o)} \qquad \text{Eq. 1}$$

Rayleigh frequency distribution of wind speed

For wind data analysis, the Rayleigh distribution is a simplified case of the Weibull distribution function in which the shape parameter k is approximated as 2.0 (Mathew, 2006; Tong, 2010) and mathematically it is expressed as:

$$f(V) = \frac{\pi}{c}\frac{V}{V_m^2}e^{\left[\pi/4\left(\frac{V}{V_m}\right)^2\right]}$$

or

$$f(V) = \frac{k}{c}\left(\frac{V}{c}\right)^{k-1} e^{-\left(\frac{V}{c}\right)} \qquad (K = 2, V > 0, C > 0) \qquad \text{Eq. 2}$$

The cumulative Rayleigh distribution can be given by .

$$F(V) = 1 - e^{\left[-\pi/4\left(\frac{V}{V_m}\right)^2\right]} \qquad \text{Eq. 3}$$

Furthermore, According (Mostafaeipour et al., 2011) the scale factor (parameter) represented by c (m/s) can be found with more accuracy using an expression

$$c = \frac{V_m k^{2.6674}}{0.184 + 0.816k^{2.73855}} \qquad \text{Eq. 4}$$

Wind power and energy density calculations

The power density is the best way to evaluate the wind resource existing at a comparative site; this indicates how much energy will be available at the site to be converted to electricity by the wind turbine (Mirhosseini et al., 2011). It is expressed as:

$$\frac{P}{A} = \frac{1}{2}\rho\int_c^{\infty} V^3 f(V)dV = \frac{1}{2}\rho c^3(1 + 3/k) \approx \frac{1}{2}\rho V^3 \qquad \text{Eq. 5}$$

And the wind energy density is

$$\frac{E}{A} = \left(\frac{P}{A}\right)(n\Delta t) \qquad \text{Eq. 6}$$

Where: n - is the number of measurement periods, Δt.

Moreover, if the elevation above sea level is given but the temperature and pressure data are not available, the following correlation can be used to estimate the air density (Hughes, 2000).

$$\rho_a = 1.225 - (1.194 \times 10^{-4}) \times z \qquad \text{Eq. 7}$$

Wind Turbine Selection

The important aspects that should be taken under consideration for the installation of the wind turbine are: the hub height, low cut-in speed and diameter (Stankovic et al., 2009).

Wind Turbine's Performance Assessment

The wind turbines performance were analyzed in terms of AEP and capacity factor but the payback period were analyzed only for the chosen wind turbine from potential turbines.

Estimation of annual energy production

To compute the annual energy production (AEP) for given wind turbine at a known location, the power curve method can be used as this technique gives the most realistic results (Gipe, 2004).

$$AEP = T\int_{V_{c1}}^{V_{co}} P_T(v)\, f(v)\, dv \qquad \text{Eq. 8}$$

Estimation of capacity factor

The capacity factor of the potential wind turbines are calculated using Eq.9. As this is one of the important indices for wind turbines to measure their performance of power production facility (Mathew, 2006).

$$C_F = \frac{AEP}{P_R T} \qquad \text{Eq. 9}$$

Power coefficient

Power coefficient can be expressed as percentage of actual power produced by the rotor (P_T) from power in the wind (KE)

$$Cp = \frac{KE}{P_T} \qquad \text{Eq. 10}$$

Where

$$KE = \frac{1}{2}\rho_a A V^3 \qquad \text{Eq. 11}$$

And

$$P_T = \tfrac{1}{2} C_P \rho_a A V^3 \qquad \text{Eq. 12}$$

Economic analysis

The payback method is used on this study to estimate the economic aspect as this is the most common method used for urban wind turbines (Stankovic et al., 2009). The simple payback method is used to assess the economic feasibility of the potential turbines installation using Eq.12 (Wizelius, 2007) and the following financial indicators in (i) and (ii) below:

$$Payback(T) = \frac{\text{Investment}}{\text{Annual net income}} \qquad \text{Eq.12}$$

i. Annual income saving in USD = AEP x electricity tariff (USD/kWh)
ii. Total annual income saving in USD = Annual income saving in USD + (AEP x incentives given USD/kWh)

Sensitivity analysis

All calculations used for the economic feasibility study are fairly uncertain. Therefore, the economic analysis should be followed with a sensitivity analysis to show the risks and opportunities of the investment (Wizelius, 2007). Based on the economic feasibility study that has been conducted, the revenue derived from the wind turbine is affected by two essential factors, the AEP due to wind speed variation and the Tariff variation due to *cost of electricity generated.*

Results, Discussion and Analysis

Wind Resource Assessment

Table 1 illustrates the seasonal average wind speed data together with annual mean wind speed at 17 meter height and their main respective directions and frequencies. As they are indicated in (table 1) summer season had the lowest wind speeds whereas the highest in during autumn seasons for study area.

Period	Average wind speed (m/s)	main direction
autumn	4.47	SW
winter	4.27	SSW
Spring	4.03	SW
Summer	2.83	SW
annual	3.9	SW

Table 1: Statistical data for annual and seasonal average wind speed and their respective main wind directions of Adigrat

Estimation of wind speeds at different heights

Since the given wind speed data is at 17 meters above the ground, these values were inserted into Eq.1 to estimate the wind speed at the desired heights of 20, 24 and 30 meters. For instance, the annual average wind speed of 3.9 m/s^2 results to give the wind speed calculation at 24 meters as:

$$v = \frac{3.9 \times \ln(\frac{24}{0.4})}{\ln(\frac{17}{0.4})} \approx 4.26$$

The rest of the estimated wind speeds were also calculated in the same way as shown in tables 2

Adigrat			
Season	20m	24m	30m
Autumn	4.66027	4.877464	5.143288
Winter	4.451602	4.65907	4.912992
Spring	4.208155	4.404277	4.644313
Summer	2.956142	3.093914	3.262534

Table 2: Seasonal estimated average wind speeds at various heights in Adigrat condominium

The maximums and minimums of the seasonal average wind speeds and their respective annual averages at the estimated positions are summarized in table 3.

Adigrat			
	20m	24m	30m
Minimum seasonal Average speed (m/s)	2.956142	3.093914	3.262534
Maximum seasonal average speed (m/s)	4.66027	4.877464	5.143288
Annual average speed (m/s)	4.069042	4.258682	4.490782

Table 3: Maximums seasonal, minimums seasonal and annual average wind speeds at different heights levels above the ground at Adigrat condominium

Both tables 2 and 3 above prove that with increase in height the wind speed increases. The maximum seasonal average wind speeds at the selected heights in Adigrat range between 4.66 – 5.14 m/s and the annual mean wind speeds at these different heights range between 4.07 – 4.49 m/s. Thus, this wind speed can be classified as low to moderate wind speed class according to the Beaufort scale of wind force.

Rayleigh frequency distribution of wind speed

The annual values for the scale parameter c (m/s) at measurement height (17 meters) and selected height (24 meters) are presented in table 4 which were calculated from the one year wind data. Eq 4 were used for the calculation of c values.

Adigrat		
parameter	value	Hub height
K	2	17
c (m/s)	4.400736	
K	2	24
c (m/s)	4.80547	

Table 4: Wind distribution parameters at hub heights of 17 and 24 m

The wind speed distribution is very crucial in assessing the wind potential and feasibility for the installation of a turbine (Celik, 2003; and Gipe, 2004). Therefore, estimating the wind speed frequency distribution has been conducted using Rayleigh distribution at the measurement height (17m) and at the estimated hub height (24m). Calculating Rayleigh frequency wind speed distribution at each wind speed interval (or bin) are established using Eq.2 via excel as depicted in figure 1, this figure shows that the distribution at 24m height have a higher scale factor as shown in table 4 and results the distribution to have a better distribution spread over a wider range with better probabilistic average wind velocity values than the distribution at 17m height. The cumulative distribution is also illustrated in figure 2 using equation Eq.3.

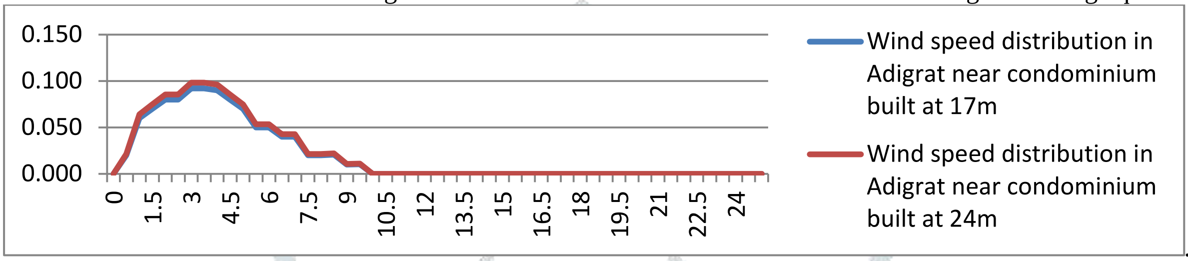

Figure 1: Wind speed distribution at hub heights of 17 and 24 m

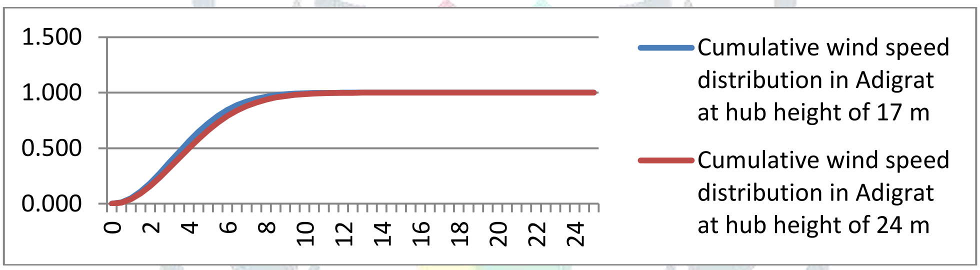

Figure 2: Cumulative wind speed distribution at hub height of 17 m and 24 m

Wind power and energy density calculations

The formula used for calculating wind power per unit area (P/A) or wind power density and the energy density are given in Eq.5 and 6. Estimating the air density at these heights can be done using Eq.7 but as the change from the standard density of air (ρ =1.225kg/m3) is so small for the chosen area, therefore the air standard density in this study was presumed to be1.225kg/m3 for most of the practical cases.

Height	17m	24m
Total annual Power density (W/m2)(Adigrat)	9023.11	17328.52
Total annual Energy density (Wh/m2)(Adigrat)	913287.69	1102721.36

Table 5: The total annual wind power density and energy density at 17m and 24m height

As the result, table 5 indicates the wind power density and energy density at 24 meter height have better energy density potential compared to the 17 meter height, which are approximately 20.74% higher. The next section will discuss the selection (identification) process of the most suitable small scale wind turbines to be tower mounted in the condominium built at a height of 24 meters above the ground.

Wind Turbine Selection

From the catalogue of the Nordic Folkecenter for Renewable Energy 2017, there are 327 small wind turbines available on the current market from 32 different countries all over the world. However, for this study only turbines with 24 meter hub height, low cut in speeds between 2m/s and 2.5 m/s, a rotor diameter of 7 to 8 meters, and rated power capacity between 10kW to 20 kW are considered.

Next to the selection of wind turbines with rated power capacity of 10kW to 20kW, their suitability were assessed further based on product design, maintenance requirements, life span, operating temperatures and the wind turbine manufacturing standards. Finally, only four most qualified turbines namely Aircon (10kw), Hummer (15kw), Windon (10kw) and JonicaImpianti (20kw) were chosen from urban wind turbine manufacturers (urbanwind.org, 2017).

Wind Turbine's Performance Assessment

Estimation of annual energy production

Figure 3 illustrates the existing power within the distribution of the wind speed and the power curves of the potential turbines. The intersection of these highlights the existing power beneath the intersection of the curves for each wind speed bin. Since energy is expressed as the product of power and time, so the percentage of occurrence of each wind speed interval in the wind speed distribution curve of the site multiplied by the number of hours in a year (8760 hr) will give the number of hours at that wind speed bin throughout the year. Therefore, using Eq.11, the annual energy production from a given machine at condominium built is calculated by the sum of the product of power output that the wind turbines generate at that wind speed interval multiplied by the number of hours in a year with the wind speed bin. With this, the performance of the potential wind turbines is summarized as shown in table 6.

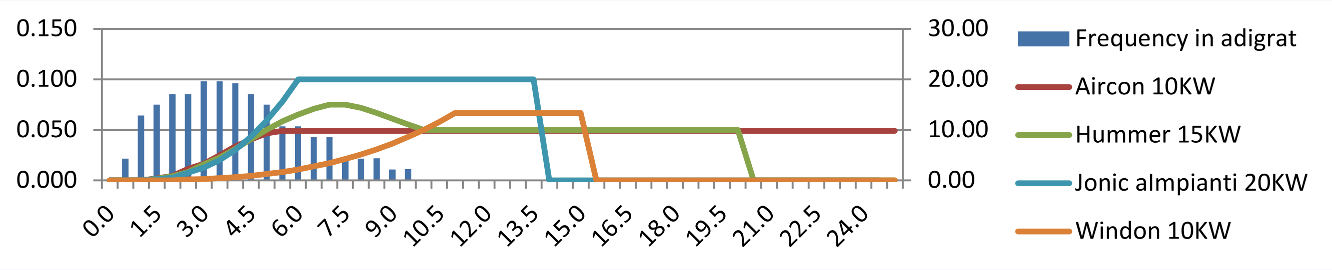

Figure 3: Wind speed distribution at 24m in Adigrat and Vs four potential power curves of wind turbines.

Wind turbines at 24 meter height in Adigrat						
S/No.	Turbine name	AEP (WH/m2)	Area(m2)	AEP(kWh/year)	Average annual energy consumption (kWh/year)	Percentage of saved energy (%)
1	Aircon 10KW	469292.31	38.49	18063.06	24000	75.26
2	Hummer 15KW	661807.77	39.59	26200.97	24000	109.17
3	JonicaImpianti 20KW	497249.96	50.27	24996.76	24000	104.15
4	Windon 10KW	241475.51	50.27	12138.97	24000	50.58

Table 6: Estimated annual energy production using power curve method

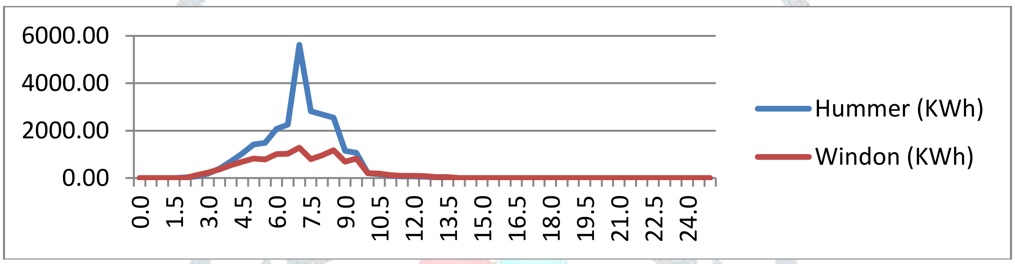

Figure 4: Comparison of AEP of Hummer and Windon turbines at their respective hub heights in Adigrat

The results from table 4 shows that turbine Hummer (15kW) gives the best AEP than the four comparative potential wind turbines listed. The electricity consumption at Adigrat which are selected condominium built sites are estimated to be 24000 KWh per year. Thus, the AEP from Hummer and JonicaImpianti turbine can displace above 100% of the current energy consumption of the whole building from the main grid. Therefore, Hummer15kW and JonicaImpianti 20KW can potentially reduce 100% of the electricity needed, as a result installation of the turbine can be considered as a potential renewable energy source for the condominium built.

Estimation of capacity factor

The capacity factor CF using Eq. 9 is calculated for one of the potential wind turbines called Hummer (15 kw) in Adigrat as an example as shown below and the rest CF values for the potential wind turbines are listed in table 4.12 using the same formula.

$$C_F = \frac{26200.97}{15\times 8760} = 0.20$$

Wind turbines at 24 meter height in Adigrat condominium built site			
S/No.	Turbine name	AEP(kWh/year)	CF Value
1	Aircon 10KW	18063.06	0.21
2	Hummer 15KW	26200.97	0.20
3	JonicaImpianti 20KW	24996.76	0.14
4	Windon 10KW	12138.97	0.14

Table7: Analysis of capacity factor for five potential wind turbines at 24m hub heights

From the results in table 7 Aircon wind turbine has the best capacity factor with 0.21% Adigrat compared to the other wind turbines. As author (Mathew, 2006) suggested that a reasonably efficient wind turbine at a potential site may range its capacity factor between 0.20 and 0.40, Hummer and Aircon wind turbines will work efficiently with this regime as its result lies in the intervals. Using annual energy production and capacity factor Hummer 15KW will be the best turbine in harnessing wind energy.

Power coefficient

This wind turbine has a reasonable efficiency (power coefficient) Cp value of 44% at its rated wind speed and it was calculated using Eq. 10. As theoretically 59.3% of the wind energy can be harnessed by wind turbines according to Betz limit but in practice a maximum of about 49% of the available wind energy is harnessed by the best modern wind turbines (Mathew, 2006; Wizelius, 2007). Thus, figure 5 is depicted below to show how much of the available energy in the wind could be harvested by the selected wind turbine Hummer as compared to the available wind energy and Betz theory.

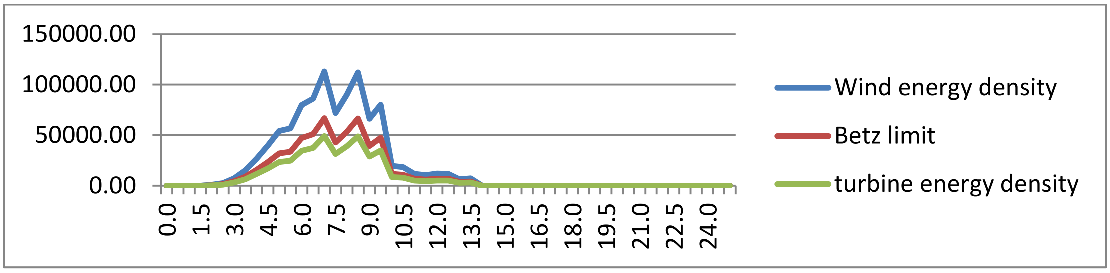

Figure 5: Energy density in Adigrat town

Economic analysis

Estimating the payback period will consider the investment cost (cost of turbine, cost of an inverter, installation), operation and maintenance cost, and annual energy production of the turbine and electricity tariff. The specification of turbines' shows that the installation cost of the selected 15kW wind turbine (Hummer 15kW) is 27600USD (690000birr). And , an average of 0.002USD (0.05birr) per kWh has been considered as the estimated operations and maintenance (O&M) cost of a small wind turbines that range between 0.001USD/KWh to 0.003 USD/KWh (IRENA, 2012). The current electricity tariff at Ethiopia is 0.08USD (2birr) per kWh and it is also used in this calculation.

Sensitivity analysis

The sensitivity analysis was conducted in order to further assess the turbine performance using the wind speed and tariff of electricity.

Wind speed variation

The sensitivity analysis on varied wind speeds was carried out to see the AEP generated from the chosen turbine at different wind speed conditions, which are between 3 and 7m/s, the results for this analysis are indicated in Figure 6.

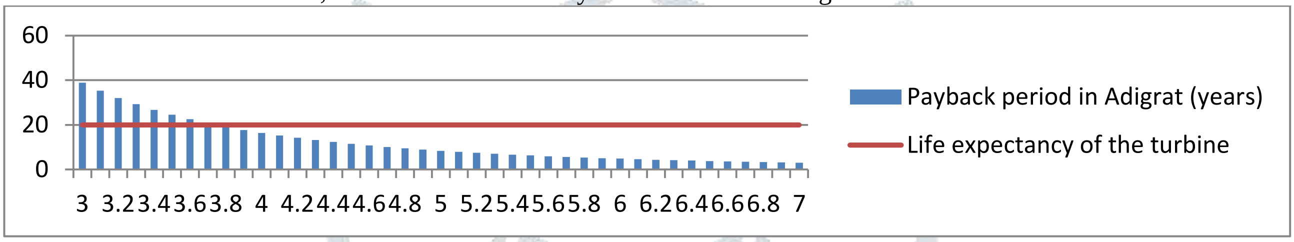

Figure 6: Payback period for Hummer turbine at various annual average wind speeds Adigrat

Tariff variation

In this research study, the sensitivity analysis was done using different electricity tariffs in order to see the influence of raised electricity price on the wind turbines economic performances. Therefore, to make the economic calculations average wind speed of the areas (4.26 m/s at hub height of 24 meters) together with ten different tariffs. The tariffs variation was done by starting with the current tariff 0.08USD/kWh (2birr), with this the other nine tariffs were predicted by considering an increment of 10% between each tariffs. The analysis results are illustrated in Figure 7 below.

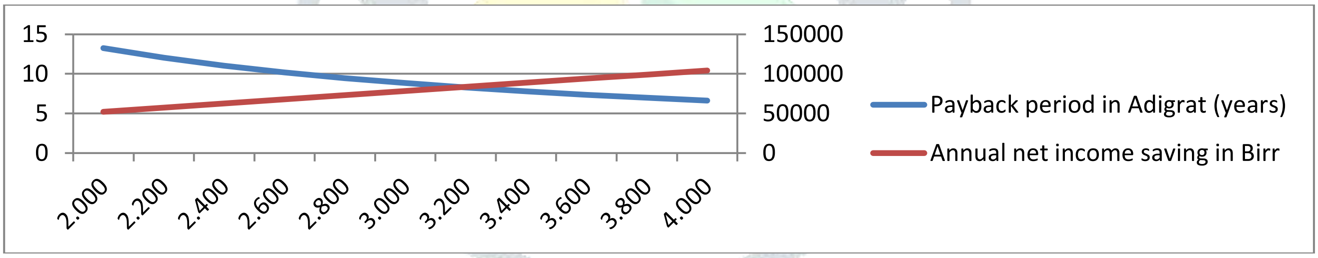

Figure 4.12: Tariff variation of electricity with Payback period and Total annual income saving in Adigrat

The results figure 4.12 shows that with an increase of the tariff for electricity, total annual income saving increases as well and Payback period also decrease. Hence, there will be a higher returns and lowers the payback period of the turbine installation.

Conclusion and recommendation

The results from this study has shown that the proposed tower mounted small scale standalone wind turbine installation at the condominium built is technically feasible and economically viable as a source of alternative renewable energy in order to produce clean energy and reduce electricity bills if the incentives given are in place.

Annual mean wind speed is estimated to be 4.26 m/s at 24 meters height. Hummer (15kW) was selected as the most appropriate small scale wind turbine to be installed. To this effect, the annual energy production of the turbine was calculated using the power curve method and it is found that above 100% of the annual electricity need of the selected condominium could be met using the selected turbine.. Likewise, the turbine has a better capacity factor of performances (CF) value of 0.20 which fits a reasonably efficient wind turbine at the potential site with CF value that ranges between 0.20 and 0.40. The turbine has also reasonable wind energy conversion efficiency (Cp) of 0.44 as compared to the maximum possible theoretical Betz limit of 0.593. The payback period of the turbine was found to be 13.23 years which is less than the turbine's working life of minimum of 20 years. Then again, as the payback period analysis is not certain, sensitivity analysis considering essential factors affecting the feasibility of the turbine installation was done to show the influence of speed variation and energy tariff on the payback period of the installation.

In addition the following recommendations are given:

[1] Increasing on-site energy efficiency should always be the first step.

[2] Owners of small wind turbines should create and participate in information platforms, where experiences on planning, technical and economic aspects can be exchanged with other owners and prospective investors. An association of small wind turbine owners would increase the pressure on central and local governments as well as policy makers.

[3] Turbine efficiencies and potential AEP should be additionally measured and stated for lower wind speeds. This needs to be conveyed in a way that laymen can understand the potential performance of a turbine on a site similar to theirs.

[4] State owned electricity retailers in particular have to show more commitment and offer better conditions for buy-back agreements (e.g. long-term contracts and higher buy-back rates).

[5] Creating incentives in forms of special loan schemes, subsidies, and guaranteed long-term buyback rates is required to take away the financial risks for potential investors. This should only apply for projects that are likely to be feasible. Therefore a nationwide database is necessary that lists in detail areas with good wind resources as well as other renewable energy resources such as solar or geothermal potentials.

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