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Assessment of Economic Viability of Wind Energy in Nepal: A Case Study of Ten Sites

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Abstract

This research assessed wind resource potential at ten sample sites using twelve months data measured in an hourly basis at site and analyzing recent global wind atlas dataset based on one kilometer resolution. Pertinent literatures on wind resources potential and its economic viability were reviewed with focus on the background, methodology and findings of those literatures. The wind speed data were received from different meteorological stations representing the sites under consideration. On the economic front, net present value cost and net cash flow were calculated by performing the life cycle cost analysis of each site considering 20 kW wind turbine. The average wind speed in sample sites ranges from 0.5m/s to 4m/s; the lowest wind speed recorded in Nepalgunj airport and the highest in Jumla airport. The result shows that Jumla airport has the highest wind resource potential followed by Patan Baitadi, Chainpur Bajhang, Thankot Kathmandu, Simikot airport and Biratnagar airport. The economic analysis resulted with negative net cash flow and net present value for all sites, therefore sensitivity analysis was conducted for four major parameters; investment costs, electricity production, subsidy- loan mix and tariff rate. Both net present value and net cash flow remained negative even after sensitivity analysis in five sites namely Kathmandu airport, Nepaljung airport, Pokhara airport, Simara airport and Simikot airport. Net cash flow changes to positive but net present value remains negative in Chainpur Bajhang, Biratnagar airport and Thankot Kathmandu after scenario analysis. Jumla airport and Patan Baitadi have positive result in both net present value and net cash flow after scenario analysis. Jumla airport has the highest wind resource potential and most economical in comparison to other nine sites, however none of the ten sample sites were found to be economically viable without considering more than three-forth subsidy support.

Keywords

Wind energy – Economic viability

1. Introduction

Renewable energy is the third largest contributor of the global electricity supply. Hydroelectricity shares 16.3% of world electricity supply and 75.1% of total renewable electricity [1]. Since 2008, wind power deployment has more than doubled and provided 2.5% of global electricity demand in 2012. Policy support has been instrumental in stimulating this tremendous growth. The IEA roadmap of wind technology targets 15% to 18% share of global electricity from wind power by 2050. In some countries, wind power provides 15% to 30% of total electricity. The technology has been improving rapidly and the costs of generation from land-based wind installations have continued to fall. Since 2000, the cumulative installed capacity of wind power has grown at an average rate of 24% per year [2].

Nepal has been facing chronic power shortages. Only 65% of the country's households have access to electricity, comprising 56% through national grid and 9% through off-grid solutions. More importantly, per capita electricity consumption is only 102 kilowatt hours (kWh) per year, one of the lowest in the world. Micro/mini hydro power and solar photovoltaic are popular renewable technologies and are disseminated through existing renewable energy subsidy policy in off-grid rural areas of Nepal. These two technologies have provided electrification service to about 12 percent households of rural Nepal.

Wind power development in Nepal dates back to 1970s with a pilot project in Agricultural farm of RampurVDC of Chitwan district and installation of wind turbine for pumping water in Ramechhap district. The first wind turbineof 20 kW capacity was installed in Kagbeni of Mustang District in 1989, however blade and tower of the wind generator were broken within a short period of installation and it is not in operation anymore. Wind turbines were installed in Chisapani of Shivapuri National Park and the Club Himalaya in Nagarkot, both of which are not functional anymore. In 2011, Alternative Energy Promotion Centre with the financial support from Asian Development Bank installed two 5 kW wind turbines in Dhaubadi village of Nawalparasi District with solar hybrid systems for rural electrification.

Wind energy is fast growing renewable energy technology and has become promising and most valuable choice among renewable energy sources. Hydro, solar and wind are commonly available energy sources in Nepal and the fossil fuel sources are yet to be explored.

Wind energy development is in early stage and detail resource assessment in the country is yet to be carried out; however, some projects are initiated but with limited wind data. Solar and Wind Resource Assessment was carried out especially focusing the buffered area which was relied on satellite data with low resolution of 5 km [3] [4]. Therefore this report might have limitation on availability of site specific wind speed data.

Neither detail resource assessment nor economic viability of wind energy has been done in Nepal. Nepal has contrasting terrain with high local relief in cross sectional distance of 200 km from north to south and the transportation accessibility is normally limited by the roughness of terrain. Like other infrastructure development program, the cost of energy projects also tends to increase with increasing difficulty of access.

The aim of this paper is to review the previous works carried out in wind resource assessment and its economic viability to build the knowledge on methodologies applied which can be useful for viability assessment of wind energy in Nepalese context. Further, comparative viability assessment of wind energy in three ecological regions of Nepal has been done.

This paper assessed wind resource of ten sample sites and also analyzed economic viability of the wind energy in those areas. These sample sites are meteorological stations established by department of hydrology and meteorology located in three ecological regions; 2 sites from mountain, 5 from hill and 3 districts from terai region. The paper intends to give an idea of wind energy viability in specific sites of the country which will be useful for policy makers for future energy planning and researcher to identify the gaps for further study in wind energy in Nepal. The hourly wind speed data for 12 months is taken, however data gap was observed for some hours at some sites.

This paper is structured in six sections. First section presents introduction of this study, second section is review of the literature, third section is about discussion of the methodology applied, forth section is about wind resource assessment, fifth section discusses economic analysis and finally last section concludes the research work.

2. Review

The SWERA report pointed out the need of further analysis and research for a complete assessment to identify micro-level potential of the wind resource in Nepal. The report also indicated that since there is no need of high wind speed for the small wind turbines, small system less than 400 watt could be installed to electrify the rural areas without long term data. This research has shown more than 300 w/m2wind power density in Mustang and Solukhumbu, between 200-250 w/m2in Humla and Sankhuwasawa, between 150-200 W/m2 in Myagdi and Manang, and between 100-150 w/m2in Bajhang, Darchula, Dolakha, Dolpa, Mugu, and Taplejung districts. Remaining districts have wind power density less than 100 w/m2 [3] [4].

Another study [5] conducted technical and financial analysis of wind energy resource of a 15 MW wind farm in Mustang for utility scale power generation. Hourly meteorological data recorded for the span of four years (2001-2005) at 10m and 20m height of Kagbeni and Thini areas were assessed. The study concluded the viability of utility scale electricity generation from wind resources at Mustang.

Wind is not stable source. It is affected by other meteorological factors and topography thereby rendering significant daily and seasonal variations. The instability of wind has a significant negative impact on the energy output of wind turbines, the utilization efficiency and the development costs of wind energy and other aspects [6]. Different approaches and methods have been developed for wind resource assessment, extrapolation of wind energy potential and the economic analysis of the wind energy. Accurate and reasonable descriptions of wind energy resources directly affect the selection of wind turbine, and estimation of generation capacity and economic benefits. Accurate wind energy resource assessment plays a vital role in wind farm planning by reducing investment risk and maximizing profit.

A comprehensive approach is developed to assess the theoretical wind energy potential, the fluctuations in wind speed, wind speed frequency distribution and wind power density, most probable wind speed and wind speed carrying the maximum energy at four sites of China. The research resulted that the Weibull distribution has the highest correlation coefficient (R2) and the lowest root mean square error (RMSE) i.e. the actual wind speed frequency follows Weibull distribution [6]. Method based on ensembles made of analogs between a short term observational record from the target site and a long term historical record from a nearby site is proposed which provides high quality long term wind resource estimation. This paper concluded that the wind speed time series reconstructed with the analog ensemble method to be of high quality, having consistently higher correlations and smaller biases, and this method is well suited to handle with complex terai [7]. Quantitative and objective wind energy index is designed to measure the potential of wind power production at a specific location that represents the actual wind energy production of a certain turbine type. It describes the wind energy index and necessary steps to obtain it. Meteorological reanalysis data are applied to obtain long-term low-scale wind speed data at specific turbine locations and the hub heights. This research established the relation between wind data and energy production via a five parameter logistic function using actual high-frequency energy production data [8].

An assessment is done about the requirement of a reliable estimate of the wind turbine production in order to know vertical profile of the wind speed. Owing to time variation of the vertical profile of wind speed, vertical extrapolation of wind power potential based on the measurements performed at only one height introduces an uncertainty in wind resource assessment using WAsP. The algorithm is tested by one year wind speed measurement data taken at three locations characterized by three different topographies of the terrain and different climatic conditions. The result showed that the mathematical model for vertical extrapolation gives good results for moderate and strong winds, and it results in insignificantly higher estimation error for weak and turbulent winds. The uncertainty of this wind speed estimation increases as the difference between the desired height and reference height increases [9].

The economics of wind energy is carried out by developing a probabilistic model to compute the long-term probability distribution of market clearing prices and wind farm revenues. This model specifically accounts for load uncertainty and the model uses one year. A year is divided into sixteen periods (4 seasons * 2 sets of hours * weekend or weekday) while analyzing the data. The validity of the model was verified through Monte Carlo simulation of the system that generates 1000 samples of the market price and the wind farm revenue. The validation result confirmed the superiority of the probabilistic model over a deterministic one. This model is useful in determining the economic effect of wind power as well as valuation of power purchase agreements in bilateral markets from a wind farm owner point of view [10].

The objective of a study conducted in two cities of the Iran to determine the wind energy potential was to improve understanding of the potential usage of wind energy. It employed Weibull probability distribution function using mean meteorological wind data measured at three hours intervals at a height of 10 m above ground level and gathered over a six year period. The hourly, diurnal, seasonal, monthly, and annual wind speed variations are analyzed and the economics of wind turbines is evaluated. The conclusion of the paper is that the monthly mean price of electricity generated from the 25 kW wind turbine for most of the months was less than or approximately equivalent to the existing tariff of renewable energy in Iran. The wind turbines selected for this study that operates at a 10 m height seems to be very cost effective for private investment [11]. Similarly, a research conducted to evaluate the wind energy characteristic and potential at Gharo Pakistan using five year data measured at 30 meter height gives an idea to the wind power project investor regarding the consistency of the wind resource. This research applied Weibull distribution and Rayleigh distribution functions to analyze wind variation and to determine technical potential of wind energy. The average wind speed for winter, spring, summer and autumn seasons are 3.61 m/s, 4.71 m/s, 7.63 m/s and 5.63 m/s respectively resulting in average annual wind speed to be greater than 5 m/s, and concluded site have good wind energy potential and thus suitable for development of wind power [12].

Around five years data was used to perform profitability analysis of wind energy production using economical and financial indexes. The computation was done by modeling wind speed process as an indexed semi-markov chain to predict and simulate the wind speed dynamics. This paper evaluated the utilization degree of wind turbine in conjunction with two financial indicators; semi-elasticity and relative convexity of the cash flow generated by the sale of electrical energy produced by a given wind turbine. The conclusion of the research is that the Indexed Semi-Markov Chain (ISMC) model is a more appropriate for wind speed analysis and application as the model reproduces almost exactly the same results obtained with real wind data [13].

Both technical and economic assessment of electricity generation was carried out using wind turbines at six sites of Algeria for the wind data recorded over 10 years. The study calculated the Weibull parameters and the power law coefficient at different heights by extrapolating the 10 m data. Present Value Cost (PVC) method was adopted in energy cost analysis. The result of the study proved the present value cost is more sensitive to investment costs, operation and maintenance costs, electricity production and turbine lifetime. The average cost per kWh ranges from USD 0.0342/kWh to USD 0.2105/kWh [14]. One year measured data of wind at three levels of height was used to evaluate the economic viability of wind energy in central region of Thailand. Field survey was conducted by observing wind speed at ground level and personal questioning to local people about wind potential round the year. Potential reductions of fossil fuel consumption and carbon dioxide emissions were examined for analyzing financial viability of wind energy. The annual mean wind speed was between 3 m/s and 5 m/s and it is recommended to combine wind energy with other renewable energy to maximize benefits in real situations of local wind conditions. This work made comparison of different cost and benefits of wind energy production and concluded that the annual energy production has the most impact on the uncertainty of the net present value, among other financial parameters. The paper recommended wind turbines with low cut in wind speed for weak and moderate wind resources [15].

Wind energy data measured once every six hours for the period of five years at a height of 10 m above the ground level was used to assess the wind power for five different locations in Jordan. The data of the wind speeds were fitted to the Weibull probability distribution describing frequency distribution for wind moving over Jordan. The maximum value of the wind speed is determined as 7.05 m/s in September and a minimum value of 1.15 m/s in November. The seasonal value of Weibull shape parameter is calculated to be between 1.65 and 2.78 while the scale parameter is between 1.1 and 9.49. The capacity factors of the three turbines in the selected sites ranged between 5.40% and 33.16% [16].

International Renewable Energy Agency (IRENA) and the Danish Technical University lunched Global Wind Atlas in October 2015 that provides wind resource data at one-kilometer resolution. In datasets that provide average wind speeds over large areas, the enhancement of wind speeds due to small scale features such as hills and ridges are not captured, making the resource appear weaker than it actually is. The Wind Atlas provides visual maps showing wind speeds at three different heights, and also provides tools to generate and export data and statistics such as wind rose diagram and wind speed distributions over a chosen area [17].

Conclusion of Review

Wind resources are measured at the specific sites at the height of 10 meter or above which can be extrapolated to vertical as well as horizontal areas. The wind turbines with low cut in wind speed is appropriate for weak and moderate wind resources. While extrapolating the wind data for higher heights, the uncertainty of the wind speed estimation increases with the increase in difference between desired height and reference height. Among the three distribution functions (Weibull distribution, Gamma distribution and Lognormal distribution), the Weibull distribution follows more accurate wind speed frequency.

The wind speed time series reconstructed with the analog ensemble method was found to be of high quality, having consistently high correlations and smaller biases; however this method requires both long term historical data and short term observational data.

Normally the hourly, diurnal, seasonal, monthly, and the annual wind speed variations are analyzed for wind resource assessment and the average wind speed of 5 m/s or more is consider as feasible for wind power generation. The instability of wind has a significant negative impact on the energy output of wind turbines, the utilization efficiency and the development costs of wind energy and other aspects.

The probabilistic models are useful for determining the economic effect of wind power and can also be used to effectively evaluate the long term economics of wind energy. The investment cost of small scale wind project is almost double of the utility scale wind power system. The turbine cost is the largest portion of the wind investment cost. The present value cost of wind energy is more sensitive to investment costs, operation and maintenance costs, electricity production and turbine lifetime. The annual energy production has the most impact on the uncertainty of the net present value, among other financial parameters.

3. Methodology

Research papers on wind resource assessment and economic analysis of wind energy were reviewed to get acquainted with the researches carried out in techno-economic assessment of wind energy. The review of research papers founded the basis for the adoption of the methodology for this research. Furthermore, guidelines and reports regarding the viability assessment of wind energy and current policies pertinent for the promotion of wind energy were also reviewed.

This research is based on both primary and secondary data. Secondary data are taken from Global Wind Energy Atlas published in October 2015 jointly by Danish Technical University and International Renewable Energy Association. This is satellite map and captured wind speed and direction in one kilometer resolution. Primary data are collected from ten meteorological stations of Department of Hydrological and Meteorology (DHM). These sites were selected based on the availability of recorded data for at least a year at the height of 10 m or above. The wind speed data measured at 10 m height in the interval of every one hour for the span of twelve months is used. The table 1 and the map below present the location of the sites.

These stations are located in the map of Nepal below with blue colored pins as a meteorological station.

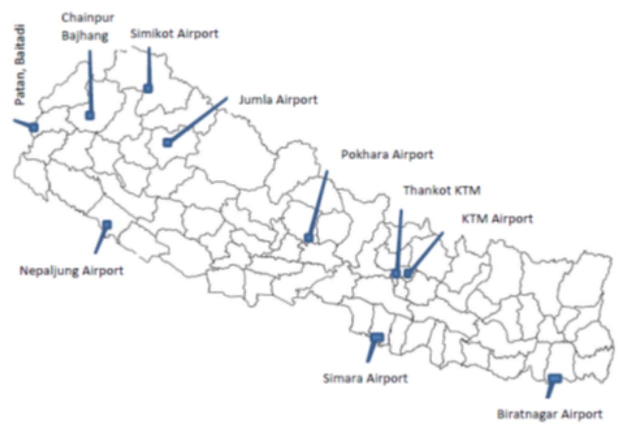

Figure 1: Station location

The power law method, most commonly used to adjust wind velocity at a reference level to another, is used to extrapolate wind speed data at hub height of 50 m from the ground level [14]. The following formula is used to extrapolate the wind speed:

$$V_i = V_m(Z/Z_m)^{\alpha}$$

Where V_M is the reference wind speed at 1 hr interval at the reference height of Z_M, Z is extrapolated height and Vi is the extrapolated wind speed and α is the power law coefficient. Value of α depends on the surface roughness coefficient and lies in the range 0.05-0.5 but in most cases it is assumed to be 0.143 [18]. Power law coefficient value of 0.143 is taken for this assessment for wind energy speed extrapolation.

For the purpose of financial assessment 20 kW capacity of wind system is considered for all sites with wind speed extrapolated for the height of 50 m. Capacity factors are calculated. Investment cost is calculated referring [17] and current wind installation cost of piloted wind projects in Nepal. Life cycle cost analysis of all sites is performed and the net present value cost and net cash

Table 1: Selected locations for the study

S.No	Meteoroligical Station	District	Longitude	Latitude	Elevation(m)	Data duration (1 year)
High Hill						
1	Simikot	Humla	81.82	29.97	2818	2011/12
2	Jumla Airport	Jumla	82.19	29.27	2375	2011/12
Hill						
3	Chainpur	Bajhang	81.20	29.55	1420	2013/14
4	Thankot	Kathmandu	85.20	27.70	1730	2012/13
5	Pokhara Airport	Kaski	83.98	28 .20	827	2014/15
6	Kathmandu Airport	Kathmandu	85.37	27.70	1337	2014/15
7	Patan west	Baitadi	80.32	29.28	1266	2013/14
Terai						
8	Biratnagar airport	Morang	87.27	26.78	72	2014/15
9	Nepalgunj airport	Banke	81.67	28.10	165	2014/15
10	Simara Airport	Bara	84.98	27.17	130	2013/14

Table 2: Assumptions for financial assessment and scenario analysis

Parameters	Assumptions
Interest rate(%)	10%
Discount rate(%)	10%
Inflation rate(%)	7%
Subsidy-credit mix(%)	70/20
Tariff rate	200NPR/kwh
1 ton Co2 eq	500 NPR
Scenario Analysis	
Decrese in investment cost(%)	15%
Increase in Annual energy production	10%
Change in subsidy-credit mix	Subsidy increase by 15%
Tariffrate	Increase by 15%

flow are calculated. The total investment cost is double of utility scale wind project. Battery replacement cost is planned for every 5 years and the transportation cost of mountain region is double of hill and the same cost for hill is double than that of considered for terai region. Sensitivity analysis is done for investment costs, annual electricity production, subsidy-loan mix and tariff rate. The assumptions considered in financial assessment including scenario analysis are given in the Table 2.

4. Wind Resource Analysis

Wind Atlas Data Analysis

Global Wind Atlas, October 2015 is used to analyze wind speed and wind rose in overall Nepal as well as separately in three ecological regions. Further wind speed of ten sample clusters is assessed and this data is compared with the site specific measured data. The figures below 2.1-2.6 give the wind speed and wind rose of Nepal.

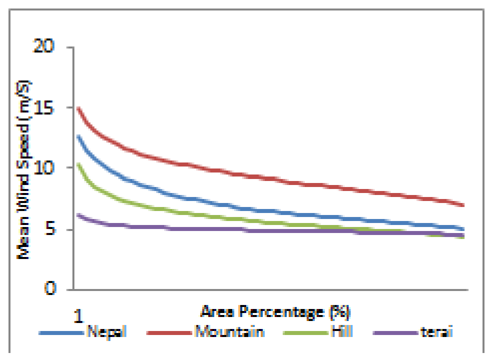

Figure 2: Average wind speed in Nepal and three Ecological regions

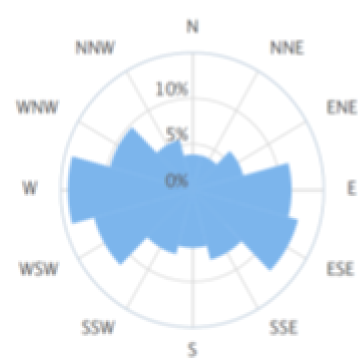

Figure 3: Wind rose frequency in Nepal

The data from global wind atlas shows that wind speed is highest in mountain region and the wind rose is concentrated between south-west to north-west whereas the wind speed in Terai is lowest and the wind rose is dispersed in both west and east. Among the ten sample clusters, Jumla has the highest wind speed followed by Humla.

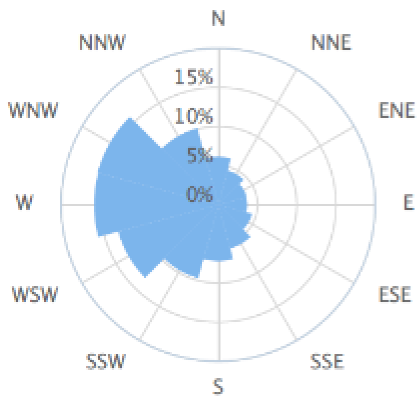

Figure 4: Wind rose frequency in mountain

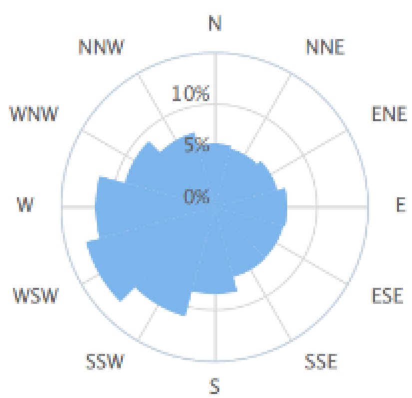

Figure 5: Wind rose frequency in hill

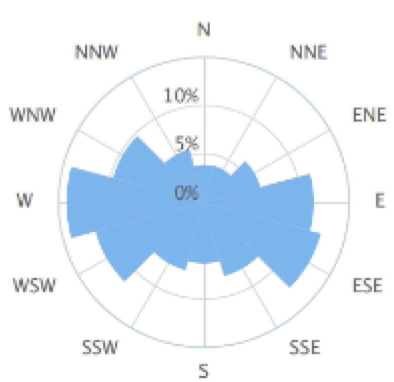

Figure 6: Wind rose frequency in terai

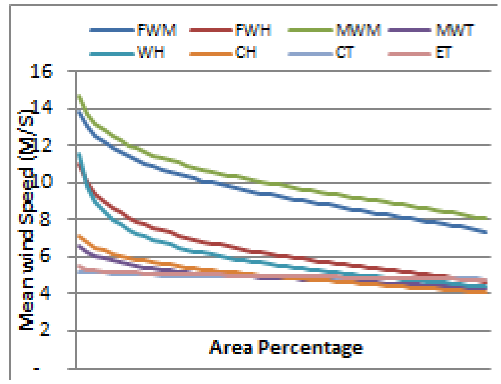

Figure 7: Average wind speed in 10 sample clusters

On lower side Nepalgunj is followed by Simara and Biratnagar. Similarly, Baitadi, Bhajang and Kaski are in medium level wind speed clusters.

Wind resource assessment of ten sample stations

As the wind speed is different in mountain, hill and terai regions, total samples are categorized into three groups based on its location. Three stations located in high hill region were Jumla airport and Simikot airport, elevation ranging from 2375 meter to 2975 meter. As shown in figure 7-10 average wind speed based on daily record is 4m/s, and 2.5m/s in Jumla and Humla respectively. Frequency of wind speed above 3 m/s is 30.2% and 15.1% in Jumla and Humla respectively. Considering the minimum 3 m/s cut in wind speed, Jumla has higher availability to convert wind resources into energy compared to Humla region which is consistent with global wind atlas data.

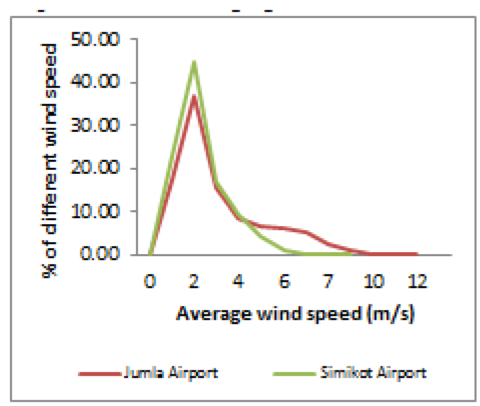

Figure 8: Average wind speed(m/s) distribution in Mountain

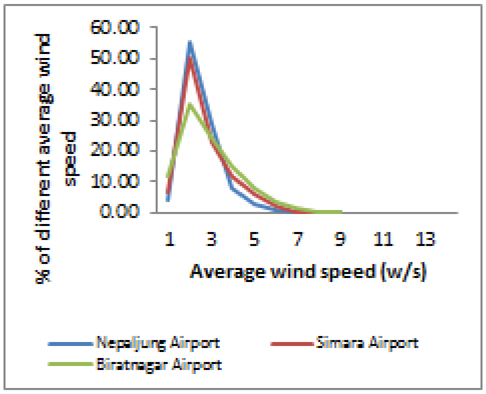

Figure 9: Average wind speed(m/s) distribution in terai

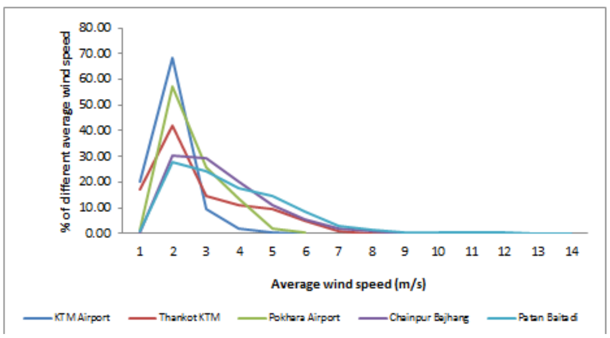

Figure 10: Average wind speed(m/s) distribution in hill

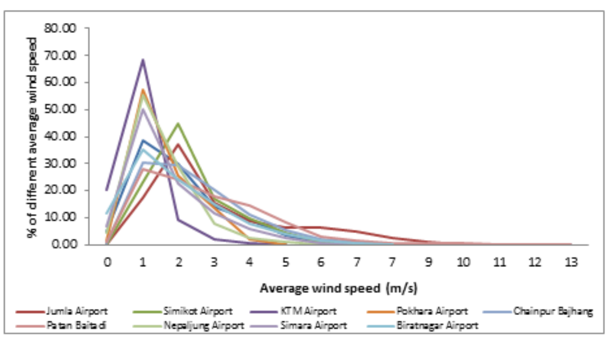

Figure 11: Average wind speed in ten stations

The average wind speed in hilly region of Kathmandu airport, Thankot Kathmandu, Chainpur Bajhang, Patan Baitadi and Pokhara airport is 1.18m/s, 2.19 m/s 3.3m/s, 3.5/m/s and 1.96m/s respectively. Similarly, availability of wind speed above 3m/s in Kathmandu airport is 0.4% whereas it is 15.8% in Thankot, 1.9% in Pokhara, 19.6% in Bajhang and 29% in Baitadi clearly showing more wind resource potential in Baitadi, Bajhang and Thankot, Kathmandu.

Table 3: Frequency of three category of average wind speed in ten locations

Location	Wind Speed		
	Up to 3	3 to 5	5 to 13
Jumla airport	69.8	15	15.1
Simikot airport	84.7	13.8	1.4
KTM airport	99.6	0.4	-
Thankot KTM	84.2	14.6	1.2
Pokhara airport	98.1	1.9	-
Chainpur Bajhang	80.5	16.3	3.3
Patan Baitadi	71.0	22.8	6.2
Nepaljung Airport	96.2	3.4	0.4
Simara airport	91.3	8.3	0.4
Biratnagar airport	86.3	11.7	2

Out of three locations of Terai region, Nepalgunj has lowest average speed of 0.5m/s followed by 2.4m/s in Simara and 2.8 m/s in Biratnagar. Only 3.8% of hours in Nepalgunj experiences wind speed of more than 3/s in a year whereas Simara has 8.7% and Biratnagar has 13.7% of time having productive wind speed above cut in speed. The result shows high wind speed in eastern part than in western part of the Terai leading to more technically feasible wind energy resources in eastern terai.

As shown in Table 3, the maximum hours of all sites lies at the wind speed ranges upto 3m/s. For most of the hours, 99.69% of Kathmandu airport lies below 3m/s wind speed whereas Jumla airport has lowest occurrence period below 3m/s wind speed.

Average wind speed of all ten stations categorized into three wind speed groups of upto3m/s, 3-5m/s and above 5m/s is presented in table 4. Jumla Airport has the highest availability of wind speed above 5m/s followed by Patan Baitadi, Chainpur Bajhang, Biratnagar airport, Simikot airport and Thankot Kathmandu. Patan Baitadi has highest hours of wind speed of 3-5m/s, followed by Chainpur Bajhang, Jumla airport, Thankot Kathmandu, Simikot airport, and Biratnagar airport. The result shows that Jumla airport is the highest wind resource potential site followed by Patan Baitadi, Chainpur Bajhang, Thankot Kathmandu, Simikot airport and Biratnagar airport. Both measured data and extrapolated data have similar result showing the lowest potential in Kathmandu airport and highest potential in Jumla Airport.

Wind speed data extracted from the Global Wind Atlas shows higher wind speed, in general, than the site specific data collected in all clusters. However the ranking of wind speed is similar in both data sources. Jumla has the highest wind potential and Nepalgunj and Simara have the lowest wind speed in both data sources. Medium level speed sites are not in exactly same order but the range of wind speed remains more or less same. However, wind resource potential assessment finding of this research has reverse result with [3] [4] , especially in case of Jumla and Humla. These differences in finding may be due to two reasons. Firstly this research is based on measured data whereas the earlier research was based on satellite data of 5 km resolution. Secondly, earlier research has average wind speed value for whole district but this research collected site specific data.

5. Economic Analysis

Net present value and net cash flow of all sample sites have been calculated. Though the different economic parameters such as internal rate of return, net present value, benefit cost ratio, return on investment, payback period and energy generated cost are supposed to be calculated to assess the viability of the wind energy projects in the studied sites, calculation of all indicators were not possible as the net present value is negative for all sites and annual cash flow is always negative for seven sites. The annual cash flow is positive after 7th year for Jumla airport, after 12th year in case of Patan Baitadi and after 17th year in Chainpur Bajhang. The summary of the result of the economic analysis is presented in the table 2.

Table 4: Finding of economic analysis

Sample sites	NPV(in NPR)	Net cash flow
Chainpur Bajhang	7247634	+17th yearonwards
Biratnagar airport	7623474	(-)
Jumla airport	5242235	+7th yearonwards
Kathmandu airport	8559803	(-)
Nepalgunj airport	8257259	(-)
Patan Baitadi	6135259	+12th years onwards
Pokhara Airport	8371941	(-)
Simara airport	8022408	(-)
Simikot Humla	8241773	(-)
Thankot Kathmandu	7667846	(-)

Scenario Analysis

Sensitivity analysis is conducted in different scenarios of major parameters; investment costs, electricity production, subsidy- loan mix and tariff rate. Considering unattractive results from economic assessment, scenario analysis of the key parameters is performed for potential positive changes in net present value and net cash flow. The result of scenario analysis is depicted in the table 5.

Both net present value and net cash flow remains negative even after reducing investment cost by 15%, increasing subsidy (decrease loan share) by 15%, increase in tariff by 15% and increase in annual energy output (increase rotor diameter by 10%) in five sites namely Kathmandu airport, Nepaljung airport, Pokhara airport, Simara airport and Simikot airport. Net cash flow changes to positive but net present value remains negative in three sites namely Chainpur Bajhang, Biratnagar airport and Thankot Kathmandu after scenario analysis. Jumla airport and Patan Baitadi have positive result in both net present value and net cash flow after changes in four parameters. Jumla airport has the highest net present value.

6. Conclusion

Ten sample sites located in the altitude ranging from 72 m to 2800 m are selected from 9 districts representing all ecological regions. Hourly wind speed data recorded in the site for the period of 12 months are analyzed to assess the wind resource potential in those sites. Jumla airport stands in highest wind resource site followed by Patan Baitadi and Chainpur Bajhang. The wind turbines with low cut in wind speed is appropriate for these sites as the wind resource is weak or moderate. Investment cost is most sensitive to present value cost followed by subsidy-loan mix, annual energy cost and the tariff rate. Analysis of net present value and the net cash flow result has also ranks these sites in same order. Sensitivity analysis for the four major parameters has resulted Jumla airport in relatively highest viable site, Patan Baitadi is in second rank and Chainpur Bajhang in the third rank in terms of economic viability as well. Both primary and secondary data supported that the Jumla airport has the highest wind resource potential and most economical in comparison to other nine sites. However none of the ten sample sites seems economically viable without consid-

Table 5: Finding of scenario analysis

Name of Sites	Investment cost (-15%)		AEP (+10% rotor diameter)		Subsidy-loan mix (+15% subsidy)		Tariff rate (+15%)		Mix of all	
	NPV	Cash flow	NPV	Cash flow	NPV	Cash flow	NPV	Cash flow	NPV	Cash flow
ChainpurBajhang	-3969556	+17th Y onward	-6944950	+17th Y onward	-4853185	+17th Y onward	-7061176	+17th Y onward	-1046810	+2nd Y onward
Biratnagar airport	-4394691	(-)	-7418332	(-)	-5265032	(-)	-7407096	(-)	-1678177	+2nd Y onward
Jumla Airport	-1780130	+2nd Y onward	-4408954	+2nd Y onward	-2742812	+2nd Y onward	-4742104	+4th Y onward	+2157734	+2nd Y onward
Kathmandu airport	-5331020	(-)	-8551666	(-)	-6201361	(-)	-8554790	(-)	-2958375	(-)
Nepalgunj Airport	-5053123	(-)	-8194889	(-)	-5916620	(-)	-8218838	(-)	-2603825	(-)
PatanBaitadi	-2857181	+2nd Y onward	-5599365	+8th Y onward	-3740810	4th Y onward	-5805141	+9th Y onward	+72603	+2nd Y onward
Pokhara Airport	-5143158	(-)	-8324353	(-)	-6013499	(-)	-8342626	(-)	-2784716	(-)
Simara Airport	-4818272	(-)	-7910709	(-)	-5681969	(-)	-7953606	(-)	-2282895	(-)
SimikotHumla	-4865307		-8110653	(-)	-5775311		-8161002	(-)	-2168791	(-)
Thankot Kathmandu	(4439063)	(-)	(7472398)	(-)	(5309403)	(-)	(7547447)	(-)	-1739490	+3rd Y onward

ering more than third-forth subsidy support. These ten sample sites are selected among meteorological stations which were established not for wind resource measurement purpose. So stations with specific objective for wind energy have to be established in different locations of Nepal for more realistic wind resource mapping.

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