Economic Viability Analysis of Wind Energy in Nepal

Laudari R.*, [1], Banskota K.[+] and Sapkota B.*

www.rericjournal.ait.ac.th

Abstract – *Shifting the energy mix of Nepal from the domination of traditional biomass followed by imported fossil fuel is a matter of urgency to drive the nation towards a low carbon and self-energy reliance economy. The full deployment of economically viable wind energy can be instrumental in increasing the share of renewable energy. The objective of this paper is to analyze economic viability of wind energy in different parts of Nepal based on the data from twelve research sites, four case study sites and the Global Wind Atlas dataset. The research found that viability of wind energy is high in high mountains, mid hill river corridors/valleys. Full capitalization of wind energy reduces the use of 0.31million kl fossil fuel annually, substitutes about 6.8% of annual import of petroleum fuel, avoids 4.5 million tons of* CO_2 *emission annually and increases independency in energy supply in the country. The financial surplus generated due to petroleum fuel import substitution and investment grant reduction will be sufficient in producing 1082MW wind energy. Based on a cost benefit analysis, the implementation of a suitable feed-in-tariff policy coupled with the scaled-up plan of wind energy is an appropriate policy for enhancing the viability of wind power generation in Nepal.*

Keywords –*cost benefit analysis,* CO_2 *avoidance, ecological region, economic viability, wind energy.*

1. INTRODUCTION

1.1 Introduction

The share of renewable energy in the total national energy supply in Nepal is only five percent [1]. Despite having good potential of renewable energy resources, including wind energy, Nepal has been importing huge amounts of fossil fuel for energy generation, fueling transportation, running industries, cooking and other uses. In Nepal, 563 kW power has been produced from wind solar hybrid project, and 32 MW from mini/micro hydro and 0.93 million households are electrified from the solar system whereas there is not a single wind power project in Nepal [2]. Wind energy represents a mainstream energy source of new power generation and an important player in the world's energy market [3]. Despite this, wind is still an unharnessed energy resource in Nepal.

An accurate mapping of wind resource is the first requirement to assess the potential of wind energy. The economic loss or gain from wind power investments depends on how well the energy production is estimated before its installation [4]. Wind speed, wind power density, capacity factor and total energy production are fundamental aspects for assessing the wind energy potential in any location [5].

Wind energy and solar energy are intermittent sources of electricity generation and complement each other in terms of time and region and both can enhance the reliability of electricity supply [3]. And where available, wind energy can be harnessed during both in daytime and nighttime. Hybridization of wind energy with another energy sources, such as hydro-power or solar PV remains an unexplored alternative in the renewable energy sector [6]. Small-scale wind systems are emerging as an alternative component of renewable electrification schemes for rural communities in hybrid off-grid and mini-grid systems [7].

Recognizing the importance of generating power from wind, the Government of Nepal emphasized the need to map wind power potential in Nepal [8]. Measuring wind data requires establishing purposeful met masts all over the country which is both very costly and time consuming, while wind farm sitting cannot be planned without having reliable data [9]. In Nepal, the wind energy potential was assessed focusing on the buffered area within the grid connection [10]. The SWERA study concluded that 3000 megawatt of energy can be generated from wind with consideration of 10% of area within the boundary of 10 km from the national grid.

The Government of Nepal has a policy to promote wind or wind-solar hybrid system in off-grid locations by providing a capital investment grant ranging from $3,940 to $4,545 for 5 kW up to 100 kW [11]. Despite such a policy, only 11 wind solar hybrid projects (12 to 80 kW) have so far been installed in the country for off-grid electrification ranging the capacity from. These projects are scattered in 10 districts and in all three ecological regions of Nepal.

This study aimed to analyze the economic viability of wind energy in Nepal. Economic analysis of research sites, case study projects and cost of deploying full potential of wind energy were conducted to assess the viability. Cost benefit analysis (CBA) was used to assess the economic viability of wind energy.

*Department of Applied Sciences and Chemical Engineering, Institute of Engineering, Tribhuvan University, Nepal.

[+]Kathmandu University, Nepal.

[1]Corresponding author;
Tel: +977-9851125430.
Email: raju.laudari@gmail.com

Despite the growing importance of wind recognition as an importance of energy, there is no substantial research on the economics of wind energy in Nepal. The data required to carry out the viability of wind research in Nepal is not available through one source and has been gathered from various domestic and international sources and is explained later below.

This paper is divided into five sections. Following the introduction, the second section briefly discusses the economics of wind energy. The third section presents the methodology of the study and the data required for assessing the economic viability. The different data sources utilized to carry out the CBA are also explained in this section. The fourth section presents the study findings and the last section concludes the study.

1.2 Cost of Wind Energy

The levelized cost of energy (LCoE), lifetime cost divided by energy production, can be used to analyze wind projects [12]. LCoE provides an accurate representation of the cost required to install and operate the wind turbine [13]. It determines how much money must be earned per unit of electricity to recover the lifetime costs of the energy system. The principal components of the LCoE of a power project include capital costs, operation and maintenance costs, the expected annual energy production and the discount rate. The range of LCoE for land-based wind is \$58–\$108/MWh [12] and for small wind it is in the range of \$ 0.15 to \$ 0.35/kWh [14].

1.3 Benefits of Wind Energy

Profitability of wind power plant varies greatly according to the wind resource, wind turbine, capital and operating expenditure, system marginal price, and renewable energy certificate price[2] [15]. An important economic benefit of wind power is that it reduces the exposure of the economy to fuel price volatility. Wind energy also reduces the imports of fossil fuel, and helps improve the country's trade balance, contributes to the reduction of traditional energy sources such as biomass and greenhouse gases. In addition, wind energy has lower water-consumption footprints than fossil fuel and wind tower infrastructure is less demanding in land compared to solar or hydro power infrastructures. The various benefits from wind energy such as energy used for lighting and other end uses, replacement of diesel, kerosene and dry-cell battery use, reduction on the import of diesel and kerosene, CO_2 avoidance, and employment generation benefits are the major benefits generated by wind energy whose economic values have been calculated in this study.

1.4 Externalities

An externality occurs when a project or an activity has an impact on someone who is not part of the decision-making process. Externalities can be both positive and negative although it is generally thought to be negative [16]. An externality exists if two conditions are met. First, some negative (or positive) impact is generated by an economic activity and imposed on third parties. Second, the impact must not be priced in the market place [17]. Wind energy has both positive and negative externalities in which negative externalities are cost whereas positive externalities are benefits. Externality costs are related to noise pollution, adverse health effects, loss of visual amenities, impacts on wildlife, and so on [18].

1.5 Policy Incentives

Since wind power is more capital intensive than conventional fossil-fuel fired generating technologies, the relatively high capital cost continues to be an obstacle to the adoption of wind power at the scale supported by its potential [19]. Feed-in-Tariff (FIT) is one policy mechanism that is designed to accelerate investment in renewable technologies, including wind energy [20]. This study compares benefits and costs of the capital investment grant and FIT policy in expediting wind energy development in Nepal. Current rates of FIT have ranged between 0.134 and 0.201 Euro/kWh in China and between 0.136 and 0.208 Euro/kWh in India in 2020[3]. Similarly, this rate was 0.25 Euro/kWh in Israel, and ranged between 0.167 and 418 Euro/kWh in Japan; 0.262 and 0.285 Euro per kWh in Italy and 0.247 Euro/kWh in Switzerland [21].

1.6 Discounting

Lifetime cost and benefits incurred by a project have to be discounted using an appropriate discount rate to reflect the present value. The discount rate reflects the opportunity cost of capital [22]. The Asian Development Bank (ADB) defines Economic Internal Rate of Return (EIRR) as discount rate [23], whereas the World Bank treats the discount rate as the cost of capital for calculating the net present value of the stream [24]. Multilateral Development Banks (MDBs) including ADB evaluate benefits and costs of development projects using a uniform cut-off discount rate of 10–12% [25]. ADB recommended a discount rate of 10 to 12% for the project appraisals in its member states including Nepal [26].

1.7 CBA Decision Making Criteria

Cost-benefit analysis is a widely used economic tool for the selection of projects and policies that are of interest to the society [27]. The basic rationale of CBA lies in the idea that things are worth doing if the benefits resulting from doing them outweigh their costs [28]. In the context of project evaluation, a cost-benefit test is a simple decision rule which consists of accepting only those projects which make a positive profit at shadow prices [29]. It is a public policy decision tool which facilitates the allocation of resources to their most valuable uses. If the sum of net present value of benefits

---

[2] A REC is a market-based instrument that represents the property rights to the environmental, social and other non-power attributes of renewable electricity generation. RECs are issued when one MWh of electricity is produced and supplied to the electricity grid from a renewable energy resource (https://www.epa.gov/greenpower/renewable-energy-certificates-recs).

[3] http://smallwind.wwindea.org/policies/

outweighs the net present costs, the action is undertaken and vice versa [30].

The main performance indicators of CBA are net present value (NPV), internal rate of return (IRR), benefit cost ratio (B/C), LCoE and payback period. Although there is no agreement in the literature as to which is the best indicator to decide, it was found that 52.50% authors preferred NPV to IRR, while only 10% viewed that IRR is better than NPV, and remaining 37.50% opined that the appropriateness of IRR or NPV depends on the nature of the cases [31], [32]. LCoE is frequently used to assess the techno-economic performance of energy production technologies and the cost of electricity at the point of connection to a load [33]. CBA decision criteria are estimated to examine the economics of wind energy and feasibility of the project [34].

2. METHODOLOGY

The methodology of the research consists of description of research sites, methods of data collection, and tools and techniques of data analysis.

2.1 Research Sites

CBA was conducted in 12 research projects and four case study projects; the details of the location of research sites are given in Table 1 and explained below. These sites are scattered across all the three ecological regions and located in ten districts of Nepal that have varied altitudes. Four sites are located in the mountain region, five sites in the mid-hills and the remaining two sites are in the flat Terai region as shown in Table 1. Vorleni, Jumla, Patanwest, Kagbeni and Thini are located in the river corridor; Thalaha is in flat low elevation or Terai; Ramechhap, Nagarkot, Tansen, Badanda and Hansapur are at the top of the hill; and Fakhel is located in other category of topography (Table 1).

2.2 Data Needs and Sources

Data were collected from both primary and secondary sources. The data collected from research sites and case study sites are the primary sources, and the Global Wind Atlas (GWA) data is the secondary source. The wind resources mapping carried out by SWERA is utilized to draw the full potential of wind energy in Nepal and the Global Wind Atlas (GWA) data is used for assessing technical potential in various 15 clusters of three ecological regions. GWA data are also used to compare ecology-wise wind energy potential, including triangulation with measured wind speed and wind power density. This research assesses the economics of wind power generation in Nepal based on regularly measured wind climate data from 12 sites. Additional data was also obtained from wind solar hybrid power projects operated in off-grid parts of Nepal and is referred to as case study sites. The DHM and AEPC data provide location specific wind data for 12 sites, and actual cost and benefit data are obtained from the case study sites. Data collected from research sites (Table 1) are used to analyze decision criteria of CBA at both project level and national level. Case study data are triangulated with the result of research projects.

2.2.1 Research sites data

Site specific technical wind data like wind speed, wind power density, wind rose and wind turbulence were collected from the sites met masts installed by Alternative Energy Promotion Centre (nine sites) and the meteorological stations of Department of Hydrology and Meteorology (three sites) as shown in Table 1.

Table 1. Research sites.

Location	Longitude	Latitude	Elevation (m)	Ecological region	Topography
Simikot	81.49.11	29.58.14	2,969	Mountain	Top of hill
Jumla	82.11.35	29.16.28	2,376	Mountain	River corridor
Patan west	80.32.57	29.27.45	1,271	Mid-hill	River corridor
Simara	84.59.25	27.09.43	135	Terai	Flat
Vorleni	85. 24.49	27.19.08	240	Terai	River corridor
Thalaha	87.22.47	26.30.09	79	Terai	Flat
Fakhel	85.13.01	27.35.57	1,829	Mid-hill	Mid of hill
Nagarkot	85.31.16	27.42.52	1,907	Mid-hill	Top of hill
Tansen	83.33.01	27.52.05	1,305	Mid-hill	Top of hill
Thini	83.43.34	28.46.08	2,865	Mid-hill	River corridor
Kagbeni	83.46.55	28.50.11	2,835	Mountain	River corridor
Okhaldhunga	86.30.12	27.18.53	1,803	Mountain	Top of e hill
Ramechhap	86.04.55	27.19.28	1,402	Mid-hill	Top of hill
Hansapur	82.54.17	27.56.01	853	Mid-hill	Mid of hill
Nepalgunj	81.40.07	28.06.04	157	Terai	Flat
Baddanda	82.49.22	27.57.27	895	Mid-hill	Top of hill

2.2.2 Project level data from four wind-solar projects (case study)

In order to triangulate the findings from the research sites, case studies were conducted to collect the additional data related to investment cost and energy revenue. Case studies were carried out in four wind solar hybrid projects installed in Dhaubadi (Nawalparasi district), Danbibada (Jumla district), Vorleni (Makawanpur district) and Chisapani (Sindhuli district). These projects were installed between 2011 and 2017 with capacity ranging from 12 kW to 35 kW. Data on investment cost, operation and maintenance cost, energy revenue, fuel replacement, lighting and productive use of energy, operation hours and local employment generation were collected. Face-to-face semi-structured interviews were conducted with power plant management committees, beneficiary households and enterprise owners.

2.2.3 Global Wind Atlas (GWA) data

Ecology-wise wind speed and wind power density data were obtained from Global Wind Atlas (GWA) to compare the technical potential of wind energy with and within ecological regions. The GWA modeling process is made up of a calculation of local wind climates for every 1000 m at three heights: 50m; 100 m and; 200 m.

2.2.4 Other secondary sources data

Potential energy production from the studied projects was calculated from the specification of 100 kW wind turbine for class III wind, NPS-100C-24 turbine [4]. Transportation cost was taken from the rates published by the concerned local authority (District Coordination Committee). Due to the lack of experience of wind projects in Nepal, secondary data like lifetime of the wind plant, discount rate, CO_2 emission and avoidance, fossil fuel for power generation, and land requirement were taken from various sources by reviewing the relevant reports, journal papers, books and websites as presented in Table 2 to supplement the primary data that required for cost benefit analysis.

2.3 Data Analysis

2.3.1 Technical potential analysis

The Wind Atlas Analysis and Application Program (WaSP) model has been applied for the technical analysis of the wind data.Vertical extrapolation of wind to 50 meter height, wind power density, capacity factor, full load hours and annual energy production (AEP) potential were calculated for the purpose of analyzing technical potential of wind by using the following formula:

$$\text{Vertical extrapolation to 50 m } (V_2) = V_1\left[\frac{Z_2}{Z_1}\right]^{a} \quad (1)$$

Where, V_2 is wind speed at the required height Z_2; V_1 is wind speed at the reference height Z_1; and α is wind shear/power law exponent.

[4] http://www.northernpower.com/wp-content/uploads/2014/09/20150212-brochure-NPS-100C-24-UK.pdf

$$\text{Wind power density} = \frac{1}{2n}\sum_{i=1}^{n}(\mathrm{p})Vi^{k3}\mathrm{w}/m^2 \quad (2)$$

Where 'n' is 8760 (hours in a year); 'p' is the air density (kg/m³); 'V_i^3'is the cube of the i^{th} wind speed value; 'i' is the measured hourly wind speed; 'm/w^2' is watt per square meter and 'k' is shape parameter.

$$\text{Capacity factor} = \frac{\text{Annual energy production in kWh}}{\text{Nominal power in kW} * 8760} \quad (3)$$

$$\text{Full load hours} = \frac{\text{Annual energy production in kWh}}{\text{Nominal power in kW}} \quad (4)$$

$$\text{AEP} = \frac{\text{CF} * \text{Area of the wind turbine rotor in m}^2 * \text{WPD in W/m}^2}{\text{Nominal power in kW}} \quad (5)$$

Where CF is capacity factor.

2.3.2 Cost benefit analysis

CBA criteria such as NPV, IRR, BC ratio, LCoE and the payback period were estimated and analysed (in excel) to assess the economic viability of generating wind energy. The various parameters calculated for the analysis used the following formulas:

$$NPV = \sum_{t=0}^{n}\frac{Rt}{(1+i)t} \quad (6)$$

$$IRR\ is\ 0 = NPV = \sum_{t=1}^{T}\frac{Ct}{(1+IRR)t} - Co \quad (7)$$

$$BC\ ratio = \frac{Present\ value\ of\ benefit}{Present\ value\ of\ cost} \quad (8)$$

$$Pay\ back\ period = \frac{Initial\ investment\ cost}{Net\ cas⍰\ flod\ per\ period} \quad (9)$$

$$LCoE = \frac{Capitaninvestment + \sum_{t=1}^{T}\frac{O\&Mcost}{(1+Dr)n}}{\sum_{n=1}^{N}\frac{Netannualenergygenerated(1-Df)n}{(1+Dr)n}} \quad (10)$$

The additional energy generated by utilization of wind power adds multiple benefits to the country as pointed out above. The positive externality that accrues are additional values to the stream of the benefits generated by wind power. Moreover, the impact of the power plant on the beneficiary communities was estimated based on case study. CB was analyzed with regard to the following three cases:

1. Establishment and operation of wind power plant without any incentives *i.e.* no intervention by the government
2. Providing the capital investment grant based on the provision of existing Renewable Energy Policy 2073
3. Introduction of the feed-in tariff policy mechanism (at the rate of 0.3 $/kWh) and cost reduction with the increase in the economy of scale

Investment cost reduction potential in wind energy deployment in Nepal is projected based on the experience of a few wind-solar projects implemented in Nepal and the global wind energy investment learning curve.

Sensitivity analysis was conducted in light of the 20% variation towards the worse condition than the expected situation in second and third cases.

Table 2. Other secondary data for economic analysis.

Description	Values	Unit	Sources of data
Discount Rate	10-15	%	[26]
Life of wind power project	20	Years	[35]
Project cost of small-scale wind project	3100 to 4400	USD/KW	[36]
Turbine cost	65-85	% of total project cost	[37], [38]
Operation cost	14	USD/kW/y	[38]
Repair and maintenance cost	28	USD/kW/yr	[38]
Power loss (in energy estimation)	25	% of theoretical power curve	[38]
Scrap value	10	% of turbine price	[39]
Co_2 avoidance	690	gCo2e/kWh	[40]
Life cycle GHG emission	10-20	gCO2e/kWh	[41]
PPA rate of NEA (raised by 3% annually)	0.097	USD	https://www.nea.org.np/admin/assets/uploads/PPA_Rates.pdfU
Price of a CO_2 allowance	5	USD	Average CER selling rate in Nepal
Land lease rent	157.23	USD per hectare/y	[38]
Land requirement	55	Hectare/MW	[38]
Feed in tariff rate for wind	0.08-1.14	USD/kWh	https://www.winston.com/images/content/9/1/v2/91697/Feed-In-Tariff-Handbook-for-Asian-Renewable-Energy-Systems.pdfU
Wind energy potential	3000	MW	[10]

3. RESULTS AND DISCUSSION

3.1 Wind Energy Potential in Research Sites

Wind speed, capacity factor, wind power density and full load hours are analyzed to assess energy potential assuming 100 kW wind energy projects in all the twelve sites. All the twelve research sites (Table 1) were found technically feasible for either commercial-scale wind energy production or small-scale wind project or seasonal production of wind energy considering the average wind speed and the WPD of the sites [9]. The wind speed of all research sites is within the range of cut-in-speed and cut-off-speed[5]lying between 3.3 m/s to 8.1 m/s. Wind speed varies in both time and space, determined by such factors as geographic and weather conditions. The highest wind speed was observed in Kagbeni and the lowest in Nagarkot (Table 3).

The capacity factor of a wind power project is the ratio of average generated power and the rated peak power. Due to the intermittent nature of wind, wind turbines do not generate the equal amount of power all the time. In fact, the capacity factor of a wind turbine is very sensitive to the average wind speed. Of the total twelve research sites, the capacity factor of five projects, namely Patanwest, Simikot, Tansen, Nagarkot and Thalaha was too low (11.3,7.2, 10.1, 10.1 and 7.8% , respectively) to produce energy. However, the capacity factor in the other seven sites *i.e.* Thini, Kagbeni, Vorleni and Badanda were above the minimum level (20%)[6] ranging between 21.1 to 34.4% and the capacity

[5]The typical cut-in speed is 3.5 m/s and the cut-out-speed is 25 m/s. http://www.level.org.nz/energy/renewable-electricity-generation/wind-turbine-systems

[6] file:///C:/Users/rlaudari/Downloads/RERL_Fact_Sheet_2a_Capacity_Factor.pdf

factor in Jumla, Ramechhap and Hansapur was close to the minimum range (15.6 to 17.2%).

In principle, wind power density indicates the amount of energy available at a particular site for conversion by a wind turbine. The analysis shows that two project sites *i.e.* Thini and Kagbeni have very good densities and five sites, namely Jumla, Mansapur, Badanda, Vorleni and Ramechhap have fairly good densities (Table 3).The other remaining five sites *i.e.* Patanwest, Simikot, Tansen, Nagarkot and Thalaha have a fair level of density that is lower than 100W/m^2 [3] and thus does not support energy generation.

Full load hours are the number of hours in a year during which the turbine runs at full power in order to produce the energy delivered throughout the year. Seven project sites (*i.e.* Jumla, Hansapur, Badanda, Kagbeni, Thini, Vorleni and Ramechhap) have full load hours ranging from the level of low wind area to the level of coastal areas. The remaining five sites have full load hours far below the reference level of 1500 hours [41] at the low wind area (Table 3).

Table 3. Wind speed, capacity factor, wind power density and full load hours of research sites.

Research sites	Wind speed (m/s)	Wind power density (W/m^2)	AEP (kWh)	Capacity factor (%)	Full load hours
Patanwest	4.0	103.1	99,413	11.3	994
Simikot	3.6	54.7	63,504	7.2	635
Jumla	4.8	187.5	150,283	17.2	1,503
Hansapur	4.4	134.1	136,952	15.6	1,370
Badanda	5.4	213.8	190,650	21.8	1,907
Kagbeni	8.1	1,091.0	277,486	31.7	2,775
Thini	7.5	808.4	301,204	34.4	3,012
Tansen	3.7	81.6	88,478	10.1	885
Nagarkot	3.3	93.5	88,502	10.1	885
Vorleni	5.2	174.3	184,523	21.1	1,845
Ramechhap	4.6	137.3	147,578	16.8	1,476
Thalaha	3.5	62.5	68,381	7.8	684

The annual energy production (AEP) of a wind turbine is the total amount of electrical energy it produces over a year. Wind speed and wind power density are the major determinants of AEP. Among the research sites, Thini has the highest (301,204 kWh) energy production potential followed by Kagbeni, Badanda, and Vorleni, whereas Simikot has the lowest (63,504 kWh).

Among the research sites, five sites *i.e.* Patanwest, Simikot, Tansen, Nagarkot and Thalaha have lower full load hour, capacity factor and wind power density than the minium required to become viable for wind energy generation, resulting in low annual energy production. Therefore, these five sites are not considered for the cost benefit analysis.

3.2 *Ecology Wise Wind Potential (Global Wind Atlas Data)*

Average wind speed and wind power density data were borrowed from the Global Wind Atlas. The whole country is grouped into 15 clusters to get the wind climate data. Table 4 shows the wind speed and wind power density of the three ecological regions of Nepal, grouping them into five clusters from west to east. This data were accessed from the website of the Global Wind Atlas [7] which shows the data for 10% of the windiest areas of a particular cluster at 50 meter hub height of each part.

Wind speed in the mountain, mid-hill and Terai ranges from 7.7 to 11.3 m/s, 4.26 to5.41 m/s, and 3.74 to 4.48 m/s respectively, whereas power density in these regions lies between 519 and 1880 w/m^2, 111 and 239 w/m^2, and 66 and 133 w/m^2, respectively (Table 4). Wind potential is higher in the eastern mountain, and western hill and the terai followed by the western mountain, and the mid-western hill and the terai. Both average wind speed and wind power density are appropriate for commercial wind farming in the mountain region, while the small wind turbine can be viable in the mid hill. Wind speed and wind power density are further lower in the Terai and thus not feasible even for the small turbine, especially in the central and eastern parts of the Terai. The result shows the viability of wind energy in the mountain region and the lowest technical potential of wind energy in the Terai, which is consistent with the research site specific data.

[7]https://globalwindatlas.info/en/area/Nepal?print=true,

Table 4. Wind speed and wind power density in three ecological regions.

Ecological region	Wind speed (m/s)					Wind power density(w/m^2)				
	WF	MW	W	C	E	E	MW	W	C	E
M	9.5	8.6	11	7.7	11.3	756	578	1075	519	1880
MH	5.4	5.3	4.9	4.3	4.7	213	191	239	112	155
Terai	4.0	4.3	4.5	3.7	3.9	100	102	133	66	88

FW=Far-western, MW=Mid-western, W=Western, C=Central and E=Eastern, M=mountain, MH=mid hill
Sources: Global Wind Atlas

Table 5. Fossil fuel replacement, import substitution and GHG avoidance.

Research sites	Replacement of fossil fuel (Lire/Year)	Import substitution (USD/Year)	PV of GHG avoidance (USD)
Jumla	14,427	10,598	4,065
Hansapur	13,147	9,658	3,704
Badanda	18,302	13,445	5,157
Kagbeni	26,639	19,569	7,506
Thini	28,916	21,242	8,147
Vorleni	17,714	13,013	4,991
Ramechhap	14,167	10,408	3,992
Total	133,312	97,934	37,562

Sources: Authors' calculation from the research sites data

3.3 Cost Benefit Analysis of Research Projects

3.3.1 Scenarios and CBA decision criteria

Benefit cost is anlysed under three differnet scenarios namley fossil fuel replacement, import substitution and GHG avoidance. Fossil fuel replacement is estimated by multiplying total energy production potential from a wind power plant and diesel requirement to produce one kWh energy. The possible import substitution from a research projectis estimated in the monitory value[8] by multiplying the quantity of diesel required to produce the equivalent amount of energy from the project by the import price of diesel. Similarly, GHG avoidence is the product of potential lifetime energy production from the project and the amount of CO_2 avoided from one kWh wind energy [41].

Overall, the seven projects each assuming 100 kW wind turbine are found to replace 133,313 litre diesel, substitute $97,934 import of fossil fuel and avoid 37,562 ton CO_2 equivalent annually (Table 5). The Thini project has the highest contribution followed by Kagbeni, Badanda and Vorleni and so on.

The research adopted five decision parameters, namely NPV, IRR, B/C ratio, payback period and LCoE for cost benefit analysis of wind engergy. All study projects in the first case without incentives have negative net present values that lie between -$420,980 and -$207,698 whereas these values become positive for all projects in both second case (capital investment grant) and third cases (introduction of FIT policy and decreased investment cost) and the NPV ranges from $5,643 to $477,562 (Table 6).

An IRR higher than the discount rate of a project is economically acceptable, and thus, suitable for investment as NPV becomes positive in such a situation. In the first case scenario, IRR was below the discount rate (11%) in all seven projects (-3% to 5%), while this value was above the discount rate for all projects in both second and third case (11.6% to 32.3%) with the highest value for Thini and the lowest for Hansapur (Table 6).

The B/C ratio greater than one is acceptable for the investment project. This ratio can complement the NPV in ranking projects wherever budget constraints apply. The B/C ratio remained between 0.3 and 0.7 in all research projects in the first case scenario, while the values became greater and were between 1.03 and 2.32 in all projects in the second and third scenarios. The B/C ratio of the Thini project was the highest followed by Kagbeni, Badanda and Vorleni projects, whereas Hansapur had the lowest as shown in Table 6.

The projects having larger cash inflows in the initial years are generally ranked better while assessing the payback period compared to the similar projects having larger cash inflows in the later years. There is no rule of thumb about the payback period of the investment project. However, the payback period is not acceptable for investment when it is more than the project lifetime from financial point of view. The payback period was found greater than the lifetime of the project ranging from 21 to 46 years in the first scenario. This period lies between 3.88 and 10.81 years in the second and third scenarios. Therefore, investment in small wind turbine would be worthwhile

[8] 108.9 Nepalese rupees = 1 US dollar (constant price 2017). (https://www.nrb.org.np/fxmexchangerate.php?YY=2017&MM=01&DD=01&B1=Go)

if the incentives were available as per these scenarios (Table 6).

The LCoE allows for the direct comparison of the costs of electricity generation projects with the unequal economic life of the project, project costs, capacity factor, efficiency, and risks and returns. The LCoE of research projects after providing the incentive in the second scenario lies between 0.07 and 0.16 $/kWh, while in the third scenario the lowest LCoE was 0.15 $/kWh and the highest was 0.33 $/kWh. The LCoE of small wind projects in the incentives assumed in the third scenario ranged between 0.07 and 0.33 $/kWh, which is the allowable level from the viability perspective and is in line with the international experience [14] as presented in Table 6.

Table 6. NPV, IRR, B/C ratio, payback period and LCoF in three cases.

Cases	CBA performance indicators	Research projects						
		Jumla	Hansapur	Badanda	Kagbeni	Thini	Vorleni	Ramechhap
1. Without additional support (no incentives)	NPV	(384,748)	(420,890)	(354,093)	(240,755)	(207,698)	(359,146)	(407,099)
	IRR	-1%	-3%	0%	2%	5%	0%	-3%
	B/C ratio	0.4	0.3	0.4	0.6	0.7	0.4	0.3
	Payback period	42	46	33	23	21	34	43
	LCoE	0.49	0.55	0.40	0.27	0.25	0.41	0.51
2. Investment grant at current policy rate	NPV	41,708	5,643	72,441	185,778	215,935	67,387	19,435
	IRR	15.4%	11.6%	18.6%	29.4%	32.3%	18.2%	13.2%
	B/C ratio	1.48	1.03	1.41	2.07	2.23	1.39	1.11
	Payback period	9.85	10.81	7.94	5.49	5.02	8.08	10.03
	LCoE	0.13	0.16	0.12	0.08	0.07	0.12	0.15
3. Introductio n of FIT with cost reduction	NPV	79,379	23,448	169,957	412,198	477,562	155,808	53,013
	IRR	14.6%	12.1%	18.5%	28.3%	30.9%	17.9%	13.4%
	B/C ratio	1.32	1.07	1.47	2.14	2.32	1.43	1.15
	Payback period	7.70	8.45	6.13	4.22	3.88	6.29	7.84
	LCoE	0.29	0.33	0.24	0.16	0.15	0.25	0.31

Table 7. Ecology wise distribution of viable research sites.

Ecological region	Research sites			Wind speed and WPD of viable sites	
	No. of research sites	No. of technically feasible sites	No. of economically viable sites	Wind speed (m/s)	WPD (W/m^2)
Mountain	4	4	3	4.8 to 8.1	187.5 to 1091
Mid hill	9	7	4	4.4 to 5.2	134 213.8
Terai	3	1	-	-	-

Sources: Authors' calculation from the research sites data

The value of all the indicators of two mountain region projects (*i.e.* Kagbeni and Thini) is higher than that of the research sites of the mid hill and Terai. However, the value of two projects of the mid hill (Badanda and Vorleni) is higher than that of the Jumla project of the mountain region.

The finding shows that the wind energy generation in Nepal without incentives is not viable. This result is consistent with the global experience that investing in wind power is 34% more expensive than investing in the conventional power plant [41]. However, the 23% LCOE learning rate for onshore wind for the period of 2010 to 2019 shows that wind energy cost has been decreasing annually [50].

3.3.2 Ecology wise distribution of viable research sites

Table 7 presents the ecology-wise distribution of all the twelve research sites, and the technically feasible and economically viable projects. The research shows that measured wind speed and wind power density are higher in the research sites of the mountain than those of mid-hill and Terai.

3.4 Economic Analysis of Case Study Projects

3.4.1 Costs and benefits analysis

In order to triangulate the findings from the research projects, case studies were conducted to collect the additional data related to investment cost and energy revenue. Among the research sites, the wind power plant has been installed only in Vorleni and Jumla; therefore other two case study projects (Dhaubadi and Chisapani) were taken from the nearest possible locations of the research project sites. The case study assesses costs and benefits of the projects for the beneficiaries, analyzes the trend of investment cost and assesses self-sustainability of the projects. Energy production potential and transportation cost are site specific data in case of research projects, and the other data are drawn from the secondary sources for the cost benefit analysis. Case study data are additional to the result of the CBA of the research sites, which complement the above result discussed in sub-section 3.2.1.1 and 3.2.1.2.

Table 8 shows that investment cost on wind energy is declining over time. The most recent Chispani project (2017) investment cost per ($) per kW was only about 55% of the investment cost borne by Dhaubadi project installed in 2011.

All the case study projects have provided lighting services, on an average, for four to six households per kW. The projects also supplied electricity for street lighting and electrifying other public buildings like police offices, schools, and community buildings. The Dhaubadi and Vorleni projects supply power only 2 and 4-5 hours respectively, whereas the remaining two projects *i.e.* Chisapani and Dangibada provide energy almost twenty-four-seven. A few different micro-enterprises also use the electricity to run their enterprises.

Each project has created at least one job. Dhaubadi and Vorleni projects have replaced one set of dry cell battery and 2.5 to 3 litres of kerosene used for lightning per household per monthly. Likewise, the solar home system used for lighting in Dangibada and Chisapani sites was replaced by the project-generated energy. The operation cost of each of the sites was found to be only 51% to 80% of its income.

3.4.2 CBA criteria analysis of case study projects

So far as Jumla and Vorleni projects are concerned, research project study data were compared with case study data with reference to cost benefit analysis criteria *i.e.* NPV, IRR, B/C ratio, LCoE and payback period as presented in Table 9. This analysis is conducted in the current investment grant policy incentive scenario.

As Table 9 reveals, NPV, payback period, LCoE, IRR and B/C ratio of the Jumla project were $1,045 and $2,825, 12.7 year and 9.7 years, 0.16$/kWh and 0.22$/kWh, 11.3% and 13.6%, and 1.02 and 1.04 respectively. In each comparison the former refer to the research project and the latter to the case study scenario. Similarly, NPV, payback period, LCoE, IRR, B/C ratio and yearly net real rate of return of Vorleni project were $7,187 and ($4,169), 10.4 year and 16.4 year, 0.14$/kWh and 0.11$/kWh, 13.5% and 9.6%, and 1.14 and 0.93 respectively. In each comparison the former refers to the research project and the latter to the case study scenario. The value of NPV, payback period, LCoE, IRR and B/C ratio are lower in research project than the case study scenario for Jumla project whereas the value of all CBA decision criteria are lower in case study project than in the research project scenario for the Vorleni project. The productive use of energy in Jumla project is much higher than the Vorleni project. Similarly, the number of household connections per kilowatt in Vorleni is lower than in the Jumla project. The case study result shows that the optimum utilization of energy for productive and other uses increases the income stream of the project and thus enhances economic viability.

Table 8. Case study sites.

Case study sites	Year established	Installed capacity kw	Initial investment costs $ /kW
Dhaubadi	2011	12	9,104
Dangibada	2016	26	5,693
Vorleni	2013	25	5086
Chisapani	2017	35	5,077

Sources: www.aepc.gov.np

Table 9. Comparative result of research projects and case study analysis.

CBA Investment decision criteria	Result of Jumla project		Result of Vorleni project	
	Research Project	Case study	Research Project	Case study
NPV ($)	1,045	2,825	7,187	(4,169)
Payback period (Y)	12.7	9.7	10.4	16.4
LCoE ($/kWh)	0.16	0.22	0.14	0.11
IRR (%)	11.3%	13.6%	13.5%	9.6%
B/C ratio	1.02	1.04	1.14	0.93

Sources: Authors' calculation from the research sites data

3.5 National Level Economic Analysis of Wind Energy

3.5.1 CBA decision criteria

The wind energy production potential in Nepal is 3,000 megawatts [10]. Due to low energy production potential in five projects among technically feasible 12 research sites, we proportionally reduced the 3000 MW to 1750 MW for the purpose of national level benefit cost analysis of wind energy. Taking into account of wind power density and wind speed in different sites, Nepal falls into the zone having low to medium full load hours of wind. Due to difficult topography and higher wind potential in the northern part of the country, the transportation of large sized wind turbines is difficult. Therefore, only small and medium sized wind turbines are assumed to be feasible for Nepal. Wind energy potential is computed based on wind climate data in the research site (Vorleni), in which wind power density is around 300 W/m^2. It is assumed that small wind power plants are bundled in local mini-grids, and the power is supplied directly from mini-grids to the end-users or connected into the larger grid system. Costs and benefits of wind energy production are calculated, comparing them with diesel requirement to generate the same quantity of energy from the wind power plant. NPV, IRR, B/C ratio, LCoE, payback period, value of CO_2 avoidance and value of potential fuel replacement are computed for the analysis of costs and benefits at the national level (Table 10).

As presented in the Table 10, there is no incentive in the first case and hence no distortion is expected in the market. In this case, NPV is negative; BC ratio is only 0.54, payback period is 28 years; IRR is 3.1% and LCoE 0.34. In the second case with investment grant, NPV increases to $2.86 billion, the B/C ratio becomes 2.57, the payback period decreases to 3.9 years; IRR increases to 41% and LCoE decreases to $0.07/kWh. The third case with the feed-in-tariff, is more pragmatic and sustainable in which the government sets the goal of exploiting the total potential of wind energy within a certain period of time. To this end, the feed-in-tariff policy mechanism is introduced by developing the necessary infrastructure. Based on this assumption, NPV becomes positive and reaches $2.73 billion; IRR rises to 18%; B/C ratio reaches 1.43; LCoE drops to 0.24, the payback period decreases to 6.3 years and the present value of annual energy revenue increases to $353 million. Similarly, the present value of annual potential CO_2 avoidance in all cases remains $4,334,740. Energy production potential and the avoidance of CO_2 are two major variables that determine benefits of deploying full potential of wind energy in Nepal. Energy production from one kilowatt wind project in China is 2276 kWh in a year and the possible CO_2 avoidance from one megawatt wind energy is 3075 CO_2 equivalent [43] Similarly, energy production from one kilowatt wind project in India is 1806 kWh in a year and the potential CO_2 avoidance from one megawatt wind energy is 1954 CO_2 equivalent [44] On the other hand, energy production from one kilowatt wind project in Nepal is estimated 1843 kWh in a year and the possible CO_2 avoidance from one megawatt wind energy is 1272 CO_2 equivalent. Values of both variables are lower in our calculation than the project in China, thus estimated values of these variables are more conservative in our calculation than the wind project in China.

The first case is not a viable option, as all the performance indicators are not within the acceptable range, whereas the analysis of the second and third options shows that all indicators are positive and thus are within the acceptable level. In the first case scenario, neither the communities nor the private investors can be motivated to invest in wind power.

3.5.2 Other benefits of full deployment of wind energy in Nepal

Currently some wind solar hybrid systems are installed for the off-grid electrification solution in rural Nepal in which per kilowatt cost lies between $5,077 to $9,104. Similarly, the current capital investment grant for wind power production is $3950/ kW as provisioned in Renewable Energy Subsidy Policy 2073.

The finding indicates that about 6.91 billion US dollar capital investment grant is essential to install 1750 MW wind power plants in Nepal, if capital cost remains constant [45] and investment grant [11] is continued. When the investment cost decreased with the optimum generation of wind energy, additional capital investment grant would not be required. It is rather beneficial to introduce the feed-in-tariff policy mechanism. With the implementation of the feed-in-tariff policy at the rate of $0.28/kWh, the financial burden on the nation will be reduced to 5.27 billion US dollar if the amount difference between proposed FIT rate and current power purchase agreement rate is subsided. Therefore, the nation will have financial surplus of $1.44 billion and the potential substitution of fossil fuel is $1.81 billion after installation of 1750 MW wind energy by switching from capital investment grant to feed-in-tariff policy mechanism. In this context, the total amount of financial surplus and import substitution ($3.25 billion) will be sufficient to generate 1082 megawatt electricity from the renewable energy sources. Table 10 shows the benefits of full exploitation of wind energy potential in Nepal. According to World Integrated Trade Solution (WITS), the value of total annual import in Nepal is $10.04 billion and the value of petroleum oil and gas import is 1.33 billion $ (10%) in 2017[9]. Installation of 1750 MW small wind turbines can substitute 0.09 billion US dollar import annually for the twenty years' period, which is 0.09% of the total annual import and 6.81% of annual petroleum oil and gas import in Nepal (Table 11). In the context of current dependency on imported fossil fuels for energy generation, running vehicles and other purposes have negatively impacted the national economy, including the trade balance. In this regard, deployment of potential wind energy appears beneficial for the nation.

[9] https://wits.worldbank.org/CountryProfile/en/Country/NPL/Year/LTST/Summary , 2 August 2019)

Table 10. National level economic analysis result.

CBA investment decision criteria and cost and benefit items	Without incentives (4400USD/kW)	Capital investment grant (3950USD/kW)	FIT policy and investment cost reduction
NPV ($) in million	(3,988.2)	2,866	2,730
B/C ratio	0.54	2.57	1.43
IRR (%)	3.1	41.0	18.0
Payback period (Y)	28.0	3.9	6.3
LCoE (kWh)	0.34	0.07	0.24
PV of energy revenue (USD/Y)	139,347,631	139,347,631	353,820,211
Fossil fuel replacement (Litre/y)	309,667,680	309,667,680	309,667,680
PV of replaced fossil fuel (USD/Y)	90,577,974	90,577,974	90,577,974
PV of CO_2 avoidance (USD/Y)	4,334,740	4,334,740	4,334,740

Table 11. Benefits of full exploitation of wind energy potential.

Description	Rate ($/kW)	Installation capacity/ power output	Total required amount ($)
Investment grant based on existing policy	3,950	1,750 MW	6.91
Investment grant after cost reduction	0	1,750 MW	-
Present value of petroleum fuel substitution ($/lifetime)	0.8	-	1.81
Present value of budget required for FIT ($/lifetime) implementation	0.203	3,225,705 MWh	5.27
Required government investment due to switching from investment grant to FIT policy		-	1.44
Additional RE generation potential from surplus and import substitution (kW)	3000	1082 MW	3.25

Sources: Authors' calculation and [10].

3.5.2 Other benefits of full deployment of wind energy in Nepal

Currently some wind solar hybrid systems are installed for the off-grid electrification solution in rural Nepal in which per kilowatt cost lies between $5,077 to $9,104. Similarly, the current capital investment grant for wind power production is $3950/ kW as provisioned in Renewable Energy Subsidy Policy 2073.

The finding indicates that about 6.91 billion US dollar capital investment grant is essential to install 1750 MW wind power plants in Nepal, if capital cost remains constant [45] and investment grant [11] is continued. When the investment cost decreased with the optimum generation of wind energy, additional capital investment grant would not be required. It is rather beneficial to introduce the feed-in-tariff policy mechanism. With the implementation of the feed-in-tariff policy at the rate of $0.28/kWh, the financial burden on the nation will be reduced to 5.27 billion US dollar if the amount difference between proposed FIT rate and current power purchase agreement rate is subsided. Therefore, the nation will have financial surplus of $1.44 billion and the potential substitution of fossil fuel is $1.81 billion after installation of 1750 MW wind energy by switching from capital investment grant to feed-in-tariff policy mechanism. In this context, the total amount of financial surplus and import substitution ($3.25 billion) will be sufficient to generate 1082 megawatt electricity from the renewable energy sources. Table 10 shows the benefits of full exploitation of wind energy potential in Nepal. According to World Integrated Trade Solution (WITS), the value of total annual import in Nepal is $10.04 billion and the value of petroleum oil and gas import is 1.33 billion $ (10%) in 2017[10]. Installation of 1750 MW small wind turbines can substitute 0.09 billion US dollar import annually for the twenty years' period, which is 0.09% of the total annual import and 6.81% of annual petroleum oil and gas import in Nepal (Table 11). In the context of current dependency on imported fossil fuels for energy generation, running vehicles and other purposes have negatively impacted the national economy, including the trade balance. In this regard, deployment of potential wind energy appears beneficial for the nation.

3.6 Sensitivity Analysis

The sensitivity of energy yielding from the wind power plant varies with the variation in wind speed. The sensitivity is greater in low wind speed sites than in high wind speed sites. In a low wind speed site, one percent

[10] https://wits.worldbank.org/CountryProfile/en/Country/NPL/Year/LTST/Summary , 2 August 2019)

change in wind speed might result in a two percent change in energy, whereas in a high wind speed location the value is only 1.5 percent[11]. The present value cost of wind energy is sensitive to energy production, investment costs, discount rate, operation and maintenance costs and turbine lifetime [46].

Potential energy production, investment cost, scale and type of incentives, investment grant and discount rate primarily determine the economic viability of wind energy. The case without an incentive was excluded in sensitivity analysis because none of the research projects are viable in this situation as discussed in section 3.2.1. Confined to the second and third scenarios, sensitivity was analyzed taking into account of the 20% variation in the determinants of technical potential and economic viability assessment. The second case entails continuing the existing investment grant, while the third case comprises introduction of FIT policy with the assumption of capital cost reduction. The outcomes of sensitivity analysis are presented in Tables 12 and 13.

Sensitivity analysis is conducted in five scenarios *i.e.* reduction in energy production, increase in discount rate, increase in investment cost, reduction in feed-in-tariff rate and reduction in investment grant which apply to both the cases. Table 11 illustrates the result of the sensitivity analysis of the second case.

Kagbeni and Thini projects continued to be viable even in all five scenarios, while Hansapur turned uneconomical in the situation of decreased energy production, increase in investment cost and decline in investment grant. Jumla and Ramechhap sites were not viable in case of increase in investment cost and decrease in investment grant. Similarly, Badanda and Vorlrni sites were found unviable only in the case of increase in investment cost in the existing incentives situation. Table 13 shows the result of the sensitivity analysis of the third case.

Five projects, viz Kagbeni, Thini, Vorleni, Badanda and Jumla continued to be viable in all five scenarios, whereas only Hansapur and Ramechhap projects became economically unviable only in the case of reduction in energy production. However, Ramechhap and Hansapur projects remained viable up to 19% and 14%, respectively so far as reduction in annual energy production is concerned (Table 13).

Thini and Kagbeni projects can be retained economically doable in all situations of sensitivity analysis. Five sites except Hansapur and Ramechhap remain viable in all scenarios of the third case. Badanda and Vorleni are second in rank, Jumla and Ramechhap are in the third position and Hansapur is the weakest project in terms of viability based on the result of cost benefit assessment as well as analysis of its sensitivity.

As given Table 12 and Table 13, energy production is the most sensitive variable followed by the discount rate based on all cases and scenarios. Capital investment cost is the most sensitive variable followed by investment grant, potential energy production and discount rate in the incentive mechanism of continuation of investment grant. On the other hand, potential energy production, discount rate, feed-in-tariff and investment cost are the sensitive variables (in descending order) in the incentive mechanism of FIT with the assumption of investment cost reduction.

The result clearly shows that wind speed, the most important parameter that determines magnitude of potential energy generation, has a decisive role in making the wind power plant viable. Furthermore, all the economically viable sites after providing incentives are potential for wind farming in all the scenarios.

4. DISCUSSION

Since wind power is relatively more capital intensive than conventional fossil-fuel fired generating technologies, the high capital costs continue to be an obstacle to the adoption of wind power [19]. Hence, special purchasing price for renewable energy is commonly set by governments to foster the development and investment in generating renewable energy. Such a policy affects the actual lifecycle costs of the wind energy system and reduces the payback period [47]. The Feed-in-Tariff policy can accelerate investment in renewable technologies, including wind energy [20]. This policy has been responsible for 45% of the global wind turbine deployment [48]. Under this policy scheme, providers of energy from renewable sources receive a price for what they produce based on the generation costs. This purchase guarantee is offered generally on a long-term basis, ranging from 15 to 20 years. A well-designed FIT policy can be cost-effective as well as cost-efficient, and it is recognized as one of the most effective policies to stimulate investments in renewable energies [49]. FIT payments can be based on the levelized cost of service plus a specified return or the value of generation to the utility and/or society [42].

However 3.5m/s wind speed is cut-in speed of the modern wind turbine, leading to a conclusion that for any wind energy generation project to be technically feasible and economically viable in Nepal requires more than 4m/s (4.4m/s) wind speed and higher than 134w/m², *i.e.* fairly good category (100w/m²≤P/A<300w/m²) wind power density.

The research showed that only 58.33% of technically feasible sites are economically viable. Similarly, the result demonstrates that technical potential of wind energy is higher in the mountains and river corridors than in flat topography such as in Terai. Four of the 12 research sites located in river corridors and three sites situated in the mountains were found technically potential and economically viable for wind energy generation with certain incentives such as the capital investment grant and enforcement of the feed-in-tariff policy mechanism.

[11]accessed from: https://www.wind-energy-the-facts.org/the-importance-of-the-wind-resource.html on 21 August 2019

Table 12. Result of sensitivity analysis (continue investment grant).

Scenarios	Parameters	Research projects						
		Jumla	Hansapur	Badanda	Kagbeni	Thini	Vorleni	Ramechhap
20% reduction in energy production	NPV	16,368	-17,516	40,201	138,854	165,001	36,184	5,522
	Payback	11.31	12.41	9.11	6.3	5.77	9.27	11.52
	LCoE	0.16	0.2	0.14	0.1	0.09	0.15	0.18
	IRR	13%	9%	15%	25	27.54%	14.97%	10%
	B/C	1.29	0.9	1.23	1.8	1.94	1.21	0.97
20% increases in discount rate	NPV	34.877	1,204	64.35	171,580	200,328	59,714	14,273
	Payback	9.05	9.93	7.29	5.04	4.61	7.42	9.21
	IRR	0.14	0.18	0.13	0.09	0.08	0.13	0.16
	LCoE	0.17	13%	21%	32.4	35.54%	20.33%	15%
	B/C	1.4	1.01	1.38	2.01	2.17	1.36	1.09
20% increase in investment cost	NPV	-48,940	-86,591	-13,719	109,441	142,281	-19,465	-71,597
	Payback	16.5	18.1	13.16	9.07	8.33	8.68	16.8
	LCoE	0.22	0.16	0.19	0.13	0.12	0.13	0.24
	IRR	8.00%	5%	10%	17.37%	19.23	17.07%	6%
	B/C	0.89	0.69	0.95	1.39	1.5	1.34	0.75
20% reduction in feed-in-tariff rate	NPV	58.784	21,134	94,005	217.165	250,005	88,259	36,127
	Payback	9.05	9.93	7.29	5.04	4.61	7.42	9.21
	LCoE	0.13	0.16	0.12	0.08	0.07	0.12	0.15
	IRR	17%	13%	21%	32.40%	35.5	20.33%	15%
	B/C	1.6	1.12	1.53	2.25	2.42	1.51	1.21
20% reduction in investment grant	NPV	-26,523	-64,173	8,699	131.858	164,698	2,952	-49,179
	Payback	14.95	16.4	11.94	8.24	7.56	12.22	15.22
	LCoE	0.2	0.24	0.17	0.12	0.11	0.18	0.22
	IRR	0.09	6%	12%	19.35	21.37	11.2	7%
	B/C	0.98	0.75	1.03	1.51	1.63	1.01	0.81

Source: Authors' calculation from the research sites data.

Table 13. Result of sensitivity analysis (FIT and decreased investment cost).

Scenarios	Parameters	Research projects						
		Jumla	Hansapur	Badanda	Kagbeni	Thini	Vorleni	Ramechhap
20% reduction in energy production	NPV ($)	25,227	(25,895)	101,265	312,220	369,039	89,325	(159.3)
	Payback (y)	8.84	9.7	7.03	4.84	4.45	7.22	9
	LCoE ($/kWh)	0.36	0.41	0.30	0.18	0.19	0.31	0.38
	IRR (%)	12%	10%	16%	20%	26.6%	15%	10.99%
	B/C	1.29	1.04	1.44	2.1	2.27	1.4	1.12
20% increases in discount rate	NPV ($)	76,996	22,524	167,462	407,014	471,833	153,492	51,777
	Payback (y)	7.07	7.76	5.63	3.88	3.56	5.78	7.2
	LcoE ($/kWh)	0.31	0.36	0.26	0.18	0.16	0.27	0.33
	IRR (%)	16%	14%	20%	31%	34%	20%	15%
	B/C	1.3	1.06	1.47	2.14	2.31	1.43	1.15
20% increase in investment cost	NPV ($)	86,474	27,275	186,952	450,487	521,668	171,300	59,445
	Payback (y)	7.74	8.49	6.15	4.24	3.89	6.32	7.88
	LcoE ($/kWh)	0.31	0.36	0.26	0.18	0.16	0.27	0.33
	IRR (%)	15%	12%	19%	28%	31%	18%	14%
	B/C	1.31	1.07	1.48	2.15	2.33	1.44	1.15
20% decrease in feed-in-tariff rate	NPV ($)	80,329	24,315	171,163	413,953	479,468	156,976	53,947
	Payback (y)	7.86	8.62	6.25	4.31	3.96	6.42	8
	LcoE ($/kWh)	0.29	0.33	0.24	0.16	0.15	0.25	0.31
	IRR (%)	15%	12%	19%	28%	31%	18%	13%
	B/C	1.32	1.07	1.47	2.15	2.32	1.44	1.15
20% reduction in investment grant	NPV ($)	116,232	57,033	216,710	480,245	551,426	201,058	89,203
	Payback (y)	7.07	7.76	5.63	3.88	3.56	5.78	7.2
	LcoE ($/kWh)	0.29	0.33	0.24	0.16	0.15	0.25	0.31
	IRR (%)	16%	14%	20%	31%	34%	20%	15%
	B/C	1.43	1.16	1.6	2.33	2.52	1.56	1.25

Source: Authors' calculation from the research sites data.

The goal of full utilization of potential energy from wind power would play a catalytic role in the reduction of capital investment cost in Nepal. The implementation of suitable feed-in-tariff policy mechanism coupled with scaled up plan of wind energy can ensure increment in the viability of wind power generation, especially in mountains and mid-hill regions.

Energy production potential in a particular location is the most sensitive factor in making the wind power plant economically viable in Nepal. Discount rate, feed-in-tariff, investment cost and investment grant are other such factors after the average annual energy production.

Up to 14% variation in CBA decision criteria in all scenarios of sensitivity analysis does not bring any significant change in the viability of the research projects. Twenty percent reduction in energy production rendered only two projects, namely Hansapur and Ramechhap uneconomical in the case of introducing FIT policy and reduced capital cost.

Like in other parts of the world, none of the research projects were found economically attractive to invest unless certain incentives are provided for power generation. As wind energy is emerging as a mainstream source of energy in the world, and with the additional research effort and development together with policy incentives over the next decade, the wind power generation cost is likely to be much lower than what it is currently.

Connection of produced wind energy in local or national grids would significantly contribute to capacity factors of energy power plants which, in turn will enhance economic viability of the plants. This ultimately promotes energy mix and ensures sustainable energy supply as well as energy security of the nation.

5. CONCLUSION

The measured wind data in the research sites and the modelled data produced by the Global Wind Atlas regarding technical potential of wind energy in three ecological regions have a similar finding which shows that the highest technically potential wind energy in mountains followed by mid-hill and the Terai. In the present study none of the research projects were found economically attractive to invest unless certain incentives are provided for power generation.

By assessing and analyzing seven viable research projects and four case study projects, this research resulted in net benefits by switching to the feed-in tariff policy from the capital investment grant. Similarly, a significant surplus can be achieved by the government with the import substitution of petroleum fuels; revenue can be generated from the avoidance of GHG emission, contribution to mitigating global climate change, creating employment opportunities, and operating cost benefits to the beneficiaries especially in remote mountain areas. The surplus to the nation can be available to generate additional clean energy. Furthermore, as wind energy is viable in remote areas, financial benefits arise from import substitution and GHG mitigation. Moreover, saving from policy switching could be directly used for the overall development of these areas. This result should motivate policy makers to reform energy policy towards increasing self-reliance on sustainable energy solution and researchers to intensify the researches in supporting the results of this research. In addition, wind energy can be a source of sustainable energy in remote mountain areas which may not be covered by the national grid for years to come and where water availability for micro hydro is low for electricity generation.

ACKNOWLEDGEMENT

Authors are thankful to Alternative Energy Promotion Centre and Department of Hydrology and Meteorology for allowing us to access the primary data of wind climate measured by installing dedicated met masts or in the meteorological stations required for the principal author's research work. The authors are grateful to the Management Committee members and the productive end-users of the case study sites for their support in the collection of project's cost benefit data. The principal author's PhD research would not have been possible without these data.

REFERENCES

[1] NPC. 2020. *Fifteenth Plan of Nepal*. National Planning Commission, Government of Nepal, 566 p.

[2] AEPC. 2019. *Progress at a Glance: A Year in Review 2018/19*. Alternative Energy Promotion Centre, 179 p.

[3] Tong W., 2010. *Fundamentals of Wind Energy: Wind Power Generation and Wind Turbine Design*. WIT Press, 46.

[4] Acker T. and A. Chime, 2011. *Wind Modeling using WindPro and WAsP Software.* Sustainable Energy Solution lab, Mechanical Engineering Department, Northern Arizona University, 11.

[5] Gul M., Tai N., Huang W., Nadeem M.H., and Yu, M., 2019. Assessment of wind power potential and economic analysis at Hyderabad in Pakistan: Powering to local communities using wind power. *Sustainability* 11(5): 1-23.

[6] Lee J. and F. Zhao, 2020. Global Wind Report. Global Wind Energy Council, 78.

[7] IRENA, 2015. *Renewable Power Generation Costs in 2014*. International Renewable Energy Agency, 185 p.

[8] MoEWRI, 2019. *National Energy Efficiency Strategy 2018.* Ministry of Energy, Water Resource and Irrigation, Government of Nepal, 14 p.

[9] Laudari R., Sapkota B., and Banskota K., 2018. Wind farming feasibility assessment in 16 locations of Nepal. *Invertis Journal of Renewable Energy* 8(4): 179–191.

[10] SWERA, 2008. *Solar and Wind Energy Resource Assessment in Nepal, Final Report (GIS PART)*. Alternative Energy Promotion Centre, Government of Nepal, 47 p.

[11] GoN, 2016. *Renewable Energy Subsidy Policy 2016.* Government of Nepal, 13 p.

[12] Tegen S., Hand M., Maples B., Lantz E., Schwabe P., and Smith A., 2012. 2010 Cost of Wind Energy Review: *Technical Report.* National Renewable Energy Laboratory, 96.
[13] Clark R. 2013. Small wind: Planning and building successful installations, 224. Retrieved from the World Wide Web: https://www.sciencedirect.com/book/9780123859990/small-wind .
[14] IRENA, 2012. Energy Technologies: Cost Analysis Series (wind energy). *Volume 1: Power Sector Issue* 5/5, 56 p.
[15] Kim H. and B. Kim. 2016. Wind resource assessment and comparative economic analysis using AMOS data on a 30 MW wind farm at Yulchon district in Korea. *Renewable Energy* 85: 96–103.
[16] [Dixon J.A., 2012. Economic Cost-Benefit Analysis (CBA) of Project Environmental Impacts and Mitigation Measures: *Implementation Guideline.* Inter-American Development Bank, 28.
[17] Pearce D., 2001. Energy Policy and Externalities: An Overview. *Paper prepared for OECD Nuclear Energy Agency Keynote address to Workshop on Energy Policy and Externalities: The Life Cycle Analysis Approach*, 19.
[18] Zerrahn A., 2017. Wind power and externalities. *Ecological Economics* 141: 245-260.
[19] Timilsina G., Van Kooten, C., and Narbel P., 2013. Global wind power development: Economics and policies. *Energy Policy* 61: 642–652.
[20] Couture T. and Y. Gagnon. 2010. An analysis of feed-in tariff remuneration models: Implications for renewable energy investment. Energy Policy 38(2): 955–965.
[21] Moreira Chagas C.C., Pereira M.G., Rosa L.P., da Silva N.F., Vasconcelos Freitas M.A., and Hunt, J.D., 2020. From megawatts to kilowatts: A review of small wind turbine applications, lessons from the US to Brazil. *Sustainability* 12(7): 1-25.
[22] ADoFA, 2006. *Handbook of cost-benefit analysis. Financial management reference material no. 6.* Commonwealth of Australia, 164 p.
[23] ADB, 2017. Guidelines for economic analysis of projects. Asian Development Bank, 189.
[24] World Bank, 2001. Economic analysis of investment operations: Analytical tools and practical applications. The World Bank, Washington D. C., 292.
[25] Zhuang J., Liang Z., Lin T., and De Guzman F., 2007. Theory and practice in the choice of social discount rate for cost-benefit analysis: A survey. *ERD Working Paper Series No. 94*, Asian Development Bank, 40.
[26] Willenbockel D., 2011. *A Cost-Benefit Analysis of Practical Action's Livelihood-Centred Disaster Risk Reduction Project in Nepal.* Brighton: IDS, 21.
[27] De Rus G., 2010. Introduction to Cost-Benefit Analysis: Looking for Reasonable Shortcuts. Book Chapter, 22.
[28] Sen A., 2000. The discipline of cost benefit analysis. *The Journal of Legal Studies* XXIX(S2): 931–952.
[29] Dreze J. and N. Stern, 1987. *The Theory of Cost-Benefit Analysis*. Chapter 14, 80.
[30] Banskota K., Sharma B., Shrestha B., and Dorman P., 2005. Costs and benefits of eliminating child labour in Nepal. International Labour Office, International Programme on the Elimination of Child Labour (IPEC), 49.
[31] EU, 2014. Guide to Cost-benefit Analysis of Investment Projects: Economic Appraisal Tool for Cohesion Policy 2014-2020. European Commission Directorate-General for Regional and Urban policy, 364.
[32] Arshad A., 2012. Net present value is better than internal rate of return. *Interdisciplinary Journal of Contemporary Research in Business* 4(8): 211–219.
[33] Drew D., Barlow J., Cockerill T., and Vahdati, M., 2015. The importance of accurate wind resource assessment for evaluating the economic viability of small wind turbines. *Renewable Energy* 77: 493–500.
[34] Khambalkar V., Gadge S., Dahatonde S., Kale M., and Karale D., 2007. Wind energy cost and feasibility of a 2 MW wind power project. *International Energy Journal* 8(4): 285–290.
[35] IWEA, 2019. Life-cycle of an Onshore Wind Farm. Irish Wind Energy Association, 20.
[36] IRENA, 2016. Wind power - technology brief. *Energy* 16, 1–24. https://doi.org/10.1049/ep.1976.0231.
[37] María Isabel B., 2009. The economics of wind energy. *Renewable and Sustainable Energy Reviews* 13(6–7): 1372–1382.
[38] Mone C., Smith A., Maples B., and Hand M, 2015. 2013 Cost of wind energy review. *Technical Report*. National Renewable Energy Laboratory, 91.
[39] Akdag A. and O. Guler, 2010. Evaluation of wind energy investment interest and electricity generation cost analysis for Turkey. *Applied Energy* 87(8): 2574–2580. https://doi.org/https://doi.org/10.1016/j.apenergy.2010.03.015.
[40] EWEA, 2009. The economics of wind energy. A report by the European Wind Energy Association, 156.
[41] WEC, 2016. World Energy Resources 2016. World Energy Council, 1028.
[42] IRENA, 2020. *Renewable Power Generation Costs in 2019.* International Renewable Energy Agency. 144 0.
[43] Ningxia Tianjing Shenzhou Wind Power Ltd., 2010. Ningxia Tianjing Shenzhou 30.6MW Wind-farm Project. Project design document form (CDM PDD)- Version 03, 50 p.
[44] Lalpur Wind Energy Private Limited Host, 2020. Wind project by LWEPL-2. Project design document form (CDM PDD) Version 11, 36.
[45] IEA, 2009. IEAWind Energy Annual Report 2008. International Energy Agency, 316.

[46] Belabes B., Youcefi A., Guerri O., Djamai M., and Kaabeche A., 2015. Evaluation of wind energy potential and estimation of cost using wind energy turbines for electricity generation in north of Algeria. *Renewable and Sustainable Energy Reviews* 51: 1245–1255.

[47] Nor M., Shaaban M., and Rahman A., 2014. Feasibility assessment of wind energy resources in Malaysia based on NWP models. *Renewable Energy* 62: 147–154.

[48] Couture T., Cory K., Kreycik C., and Williams E., 2010. *Policymaker's guide to feed-in tariff policy design.* National Renewable Energy Laboratory of the U.S. Department of Energy, 144.

[49] Burer M. and R. Wustenhagen. 2009. Which renewable energy policy is a venture capitalist's best friend? Empirical evidence from a survey of international cleantech investors. *Energy Policy* 37(12): 4997–5006.

[50] Greer M., 2012. *Electricity Marginal Cost Pricing, Applications in Eliciting Demand Responses*. Oxford: Butterworth-Heinemann publications.