



Techno-Economic Analysis of Wind Energy Resources Based on Real Measurements in West Bank – Palestine

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ABSTRACT

The wind resource assessment in Palestine is one of the main issues necessary for achieving our renewable energy target in Palestine by 2025. In this paper, wind energy potential assessment of West Bank was investigated, focus on wind site assessment of using small wind turbine in different cities in West Bank. A wide variety of data types and analysis techniques will be presented, were utilized in performing the national wind energy assessments. Most of the data used in the assessments were collected at anemometer 10m heights and locations that chosen for wind energy assessment purposes, and many of these have been located in areas chosen by energy research centre thought to have high wind resource. The techno-economic analysis of collected wind data at different cities in West Bank also will be presented.

Keywords: Wind Resources Assessment, Wind Power Density, Techno-economic Analysis

JEL Classification: Q4

1. INTRODUCTION

The energy situation in Palestine generally is complicated due to the shortage of natural resources and the need importing energy from other countries. Thus, it has a high dependence level in the energy field since imported energy represented more 90% of the total energy requirement in Palestine in 2017, and in electricity in particular, the electricity demand have been increased over the last years (Adel et al., 2016).

This situation points out the immediate need of generating their own energy in order to not depend from the external supply from Israel. Furthermore, owing to the shortage of natural resources, one of the main ways is working in the renewable energy field that could be really effective in rural or isolated areas not connected to the grid as well as being environmentally friendly, but wind energy is an incipient field yet. The West Bank's geographical location presents several interesting features for an extensive use of wind power. Having into account that the domestic fossil fuel resources are extremely limited and that the Palestinian energy

sector is characterized by a low annual energy consumption per capita but a high electricity cost (Juma, 2011), (Almudena, 2014) wind energy appears to be one of the most efficient and effective solutions for a suitable energy development in the West Bank. The first step for the wind exploitation to be used as an energy source is an accurate assessment of the potential of the wind in the area, and the identification of the best areas to obtain this type of energy, therefore the Energy Research Centre (ERC) installed meteorological stations in different cities in West Bank to have good quality data in order to make a reliable assessment.

The objective of this work is to evaluate the techno-economic analysis of installing small wind turbine at different locations based on real collected wind data from different metrological stations (Berruezo et al., 2013), (Imad, 2011).

2. DATA COLLECTION

The ERC start measuring and analyzing wind data (wind speed and direction values) since 2001 in different locations, it is

recommended to have at least 1 year of data in order to get a reliable analysis (Energy Research Centre, 2017).

However, due to the fact that one of the goals of the paper to analyze the wind in West Bank in particular, only data collected by ERC weather stations located in this area was used. Specifically, the data was gathered in different locations, obtaining data from different sensors (two of the stations, Salfeet and Tubas, are measuring data at two heights). In all the stations the data transfer is done manually and these data are sent periodically to the ERC. The location of some weather stations is shown in Figure 1, the elements of stations presented in Figure 2.

Tubas: This station, located in Tubas (32° 19.160'N, 35° 21.373'E) at 570 m altitude, as the one in Salfeet was installed in

Figure 1: Weather stations' location



Figure 2: Elements of metro station



2010 (the first data was measured on 5th June 2010) and financed by the It has two sensors, at 10 and 16 m high (the second one it was planned to be at 20 m) which take wind speed and direction values each 10 min. Moreover, the station has a hygrometer, solar radiation sensor, barometer and thermometer that register values of humidity, solar radiation, atmospheric pressure and temperature. The data transfer is done remotely to the Energy Research Center.

- **Mkahal:** This station is located in the area of Mkahal (32°25, 132' N 35°7, 657' E), also called Yaabad. Financed by the Public University of Navarra and it was installed in 2011 (the first data analyzed was taken on the 24th May 2011). On this station the wind speed and direction values are measured each 10 min using a sensor installed at 10 m high. The data transfer is done manually, so a member of the Energy Research Center goes from time to time to the station to download the data
- **Altarim:** This station has two anemometers at 10 and 20 m height, which record wind speed values each 10 min, but the wind direction values are taken only in the highest sensor
- **Salfeet:** The station in Salfeet (32°04'07, 5" N 35°13'23, 82" E), located at 815 m altitude, was installed in 2010.

In all the cases the wind speed were measured in m/s and the direction in degrees using the Campbell Scientific 03002 model, which includes a three cup anemometer (the cup wheel diameter is 12 cm) for the wind speed and a potentiometer which uses a 22 cm vane to sense the direction. The measuring range is from 0 to 50 m/s, and the accuracy of the value is ± 0.5 m/s for the speed, and $360 \pm 5^\circ$ for the wind direction.

The main objective of measuring wind data is oriented towards assessing wind energy resources in the West Bank and evaluates their potential for electric power generation in order to supply local communities with green electricity, the average of wind speed in some locations are shown in Figure 3.

These measuring stations measures wind speed and wind direction at 10 m height. These wind parameters are being measured at a scanning rate of 2 seconds then an average over an integration period of 5 min will be calculated and stored. The stored measured data is periodically collected and processed at ERC.

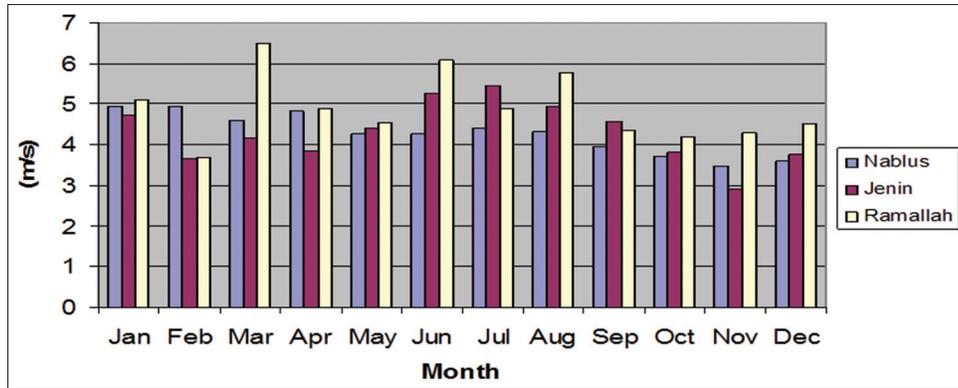
3. WIND-POWER MODELING AND ELECTRIC-POWER SIMULATION

The power available in the wind is derived from the kinetic energy available in a stream tube passing through a given area (Arslan, 2010). The most important part of wind resource assessment is the fact that the available power is proportional to the cube of the wind speed, the wind power entering the turbine blades P_{in} is calculated from the following equation:

$$P_{in} = 1/2 \times \rho \times A \times V^3 \quad (1)$$

P = Power available (W)

ρ = Density of air (kg/m³: approx. 1.2 kg/m³ at sea level and 15°C)

Figure 3: Monthly average wind velocity in different cities in Palestine

A = Swept area of wind energy conversion device (m^2 : $= \pi r^2$ for conventional horizontal axis rotors)

V = Wind velocity (m/s).

The efficiency of the wind turbine is referred to as power coefficient C_p , which is a measure that is often used by the wind power industry. The efficiency is a ratio of the actual electric power produced by a wind turbine divided by the total wind power flowing into the turbine blades at a specific wind speed (Ibrik, 2011).

C_p = Actual electrical power produced/Wind power into turbine

$$C_p = P_{out}/P_{in} \quad (2)$$

$$P_{out} = C_p \times P_{in} \quad (3)$$

The power coefficient C_p can also be calculated from the following equation (Stevens and Smulders, 1979):

$$C_p = \eta_b \times \eta_m \times \eta_e \quad (4)$$

Where, η_b : Is the blade aerodynamic efficiency,
 η_m : Is the mechanical efficiency, and
 η_e : is the electrical efficiency.

This cubic relationship is the single most important point relating to the assessment of the wind resource, as a doubling of the wind speed yields an eight-fold increase in power! As a result, an accurate assessment of the wind resource at each proposed site is absolutely vital. Wind speed increases with height above ground, the estimated speed can be adjusted using the following equation (Krohn et al., 2009).

$$V_h = V_o \times (h/h_o)^\alpha \quad (5)$$

Where, V_h = Wind speed at hub height, h (m/s)

V_o = Wind speed at a reference height, h_o (m/s)

h = Hub height of wind energy conversion device (m)

h_o = Reference height (m)

α = Friction coefficient.

The friction coefficient, α , is from 0.1 to 0.4 depends on landscape type.

Table 1: Analysis of wind power in selected different cities in the West Bank

Site	Capacity (kW) at height (m)	10 (30 m)	100 (32.5 m)	200 (32.5 m)
Hebron	Wind speed (m/s)	5.5	5.6	5.6
	Power density (W/m^2)	171	177	179
	Produced power (MWh)	20.7	179.1	396.3
Jenin	Wind speed (m/s)	5.5	5.6	5.6
	Power density (W/m^2)	175	183	183
	Produced power (MWh)	21.3	182.7	412.8
Kardallah	Wind speed (m/s)	4.4	4.5	4.5
	Power density (W/m^2)	142	147	147
	Produced power (MWh)	15.1	126.8	288.9
Nablus	Wind speed (m/s)	5.3	5.4	5.4
	Power density (W/m^2)	159	166	166
	Produced power (MWh)	19.5	167.4	376.2
Ramallah	Wind speed (m/s)	6.6	6.7	7.0
	Power density (W/m^2)	520	538	593
	Produced power (MWh)	33.4	272.6	1289
Tulkarem	Wind speed (m/s)	3.5	3.6	3.6
	Power density (W/m^2)	49	51	51
	Produced power (MWh)	5.7	50.2	108.3
Tubas	Wind speed (m/s)	5.9	6	6
	Power density (W/m^2)	216	226	226
	Produced power (MWh)	26.2	222.2	509.9
Salfeet	Wind speed (m/s)	5.6	5.7	5.7
	Power density (W/m^2)	157	164	164
	Produced power (MWh)	20.3	176.5	390.5

4. WIND ENERGY POTENTIAL IN WEST BANK

The Wind Atlas Analysis and Application Program (WASP) software (which is available at the Energy Research Center) was used to estimate the potential of wind energy in different selected sites in the West Bank.

The analysis was carried out for small scale turbines 10, 100, 220 kW installed capacity of individual wind mills in order to determine different output scenarios of possible turbine sizes for the 8 aforementioned sites as in Table 1.

The preliminary analysis of available wind data showed that the wind potential in the West Bank is moderate, since average wind speeds lie between 3 and 7 m/s. Such wind speeds (at relatively high levels above the ground surface) may not be very attractive for developing wind farms. Two wind sites have very low wind

speed values (Tulkarem and Kardallah) which would not be good alternatives for a wind project for which were discarded. Four of the sites have similar output values (Hebron, Jenin, Nablus and Salfet) which will be considered as the representative average value. And two sites have considerably higher yields (Ramallah and Tubas) which could be considered as the best case scenario.

It can be seen in Table 1 that power produced increases significantly when the height above ground surface increases. This is attributed to the fact that at higher levels the average wind speed is higher which results in a net increase in the produced power by cubic wind speed (v^3). Equally important is that the amount of energy that can be abstracted from a wind stream is proportional to the swept area of the turbine.

5. ANALYSIS OF POSSIBLE INSTALLATION OF SMALL COMMERCIAL WIND TURBINES

5.1. Characteristics

Small wind turbines range usually from 10 kW up to 200 kW. Such are mainly used in industries, farms and even for residences. As well, small wind turbines have been used in off-grid electrification projects to power several households. In this analysis the following main characteristics shared by most 100 kW wind turbines were considered:

- Rated electric power 100 kW, 3 phase, 480 VAC, 60 Hz
- Hub height ranges 30–40 m
- Rotor diameter 20–25 m

- Cut-in wind speed 3.5 m/s
- No gearbox.

5.1.1. Analyses of installing wind turbine 100 kW in different cities

The program (WAsP) software was used to estimate the potential of wind energy “Wind Rose” in different selected sites in the West Bank. Based on the available data for these sites it looks that wind speed may reach 5 m/s in some sites, with relatively good potential of more than 200 W/m² (class 4 or more from the wind power density point of view), in some sites, as illustrated in the following Figures 4-9.

It is important to mention that all wind measurements were taken at 10 m above ground surface, but the ideal approach would be to measure the wind speed at the hub height of the wind power generation station that is to be installed.

The electricity generated from installing 100 kW wind turbine in different places in Palestine are illustrated in Table 2.

5.2. Costs

According to the American Wind Energy Association (AWEA) (AWEA, 2010) small wind turbines total investment costs (including installation, civil works, and other costs) tend to range from 3000 to 6000 US\$/kW while operation and maintenance costs average 0.01 to 0.05 \$/kWh. For this analysis a value of 3500 USD/kW is taken as a conservative estimate for Palestine. Table 3

Figure 4: Wind speed and frequency at Hebron wind measuring station (In Hebron city)

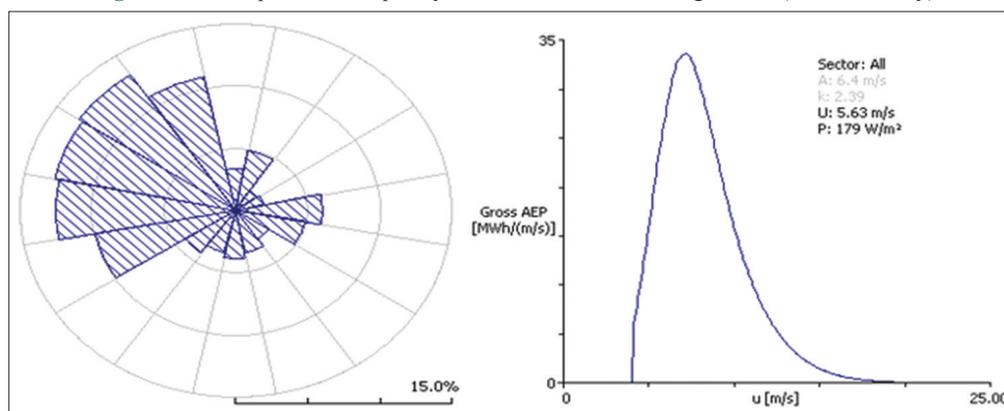


Figure 5: Wind speed and frequency at Kardala wind measuring station (In Kardala area)

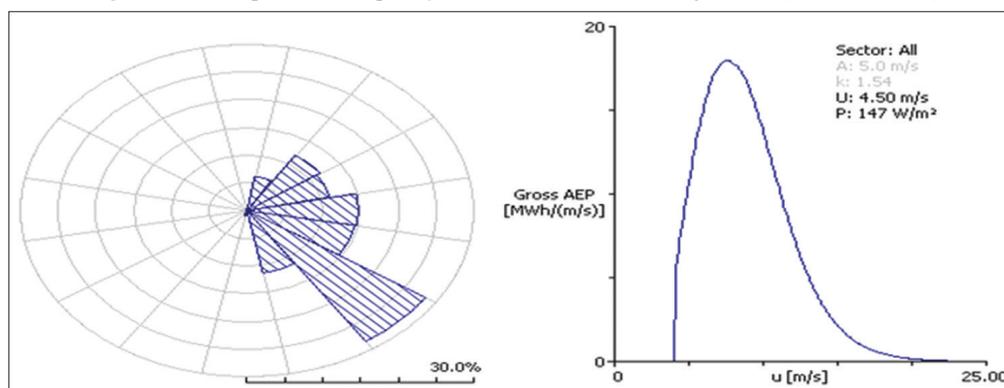


Figure 6: Wind speed and frequency at Nablus wind measuring station (In Nablus city)

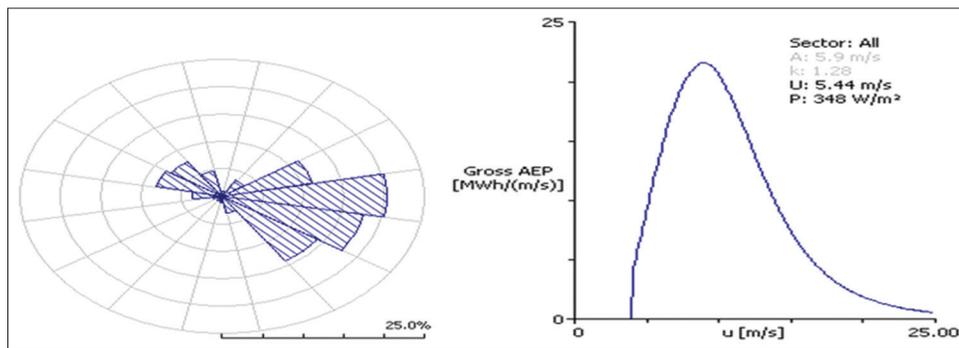


Figure 7: Wind speed and frequency at Ramallah wind measuring station (In Ramallah city)

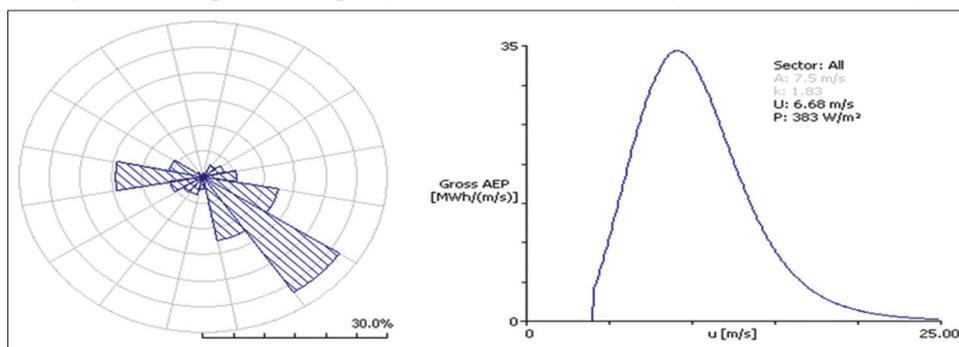


Figure 8: Wind speed and frequency at Tubas wind measuring station (In Tubas city)

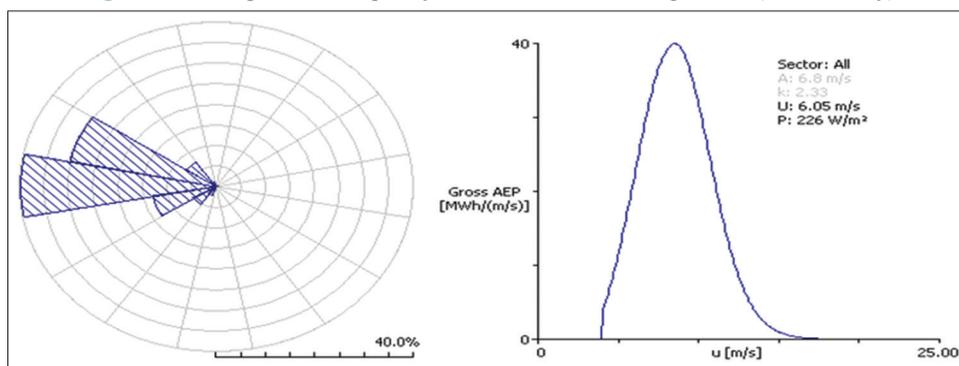
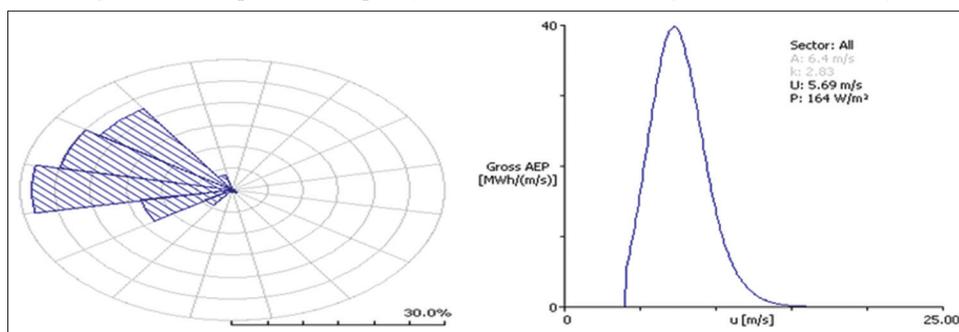


Figure 9: Wind speed and frequency at Salfet wind measuring station (In Salfet city)



present the total assumed costs for a 100 kW turbine including tower. Civil works (including engineering) and miscellaneous components (grid-tie controller and grid tie inverter) values were calculated as 17% and 7% of total costs respectively.

Moreover, the assumed O&M costs for this system were 0.02 USD/kWh and project lifetime is 20 years. The electricity generation assumed is 182.7 MWh/year, the LCOE for different cities presented in Table 4.

More optimistically, values could be as low as 0.22 USD/kWh in case we consider the highest wind values recorded in the Ramallah site (where the turbine would generate 272 MWh/year) and a 300 thousand price for the wind turbine.

5.3. Pre-feasibility Analysis

The techno-economic analysis looks specifically at the economical pre-feasibility of project development and its profitability. In such case in order for the previously analyzed

Table 2: Electricity generation from available wind stations

City	@32.5 m for 100 kW turbine (MWh/year)
Jenin	182.7
Kardallah	126.8
Nablus	167.4
Ramallah	272.6
Hebron	179.1
Tubas	222.2
Salfet	176.5
Average	189.6

Table 3: Small wind turbine capital costs

Items	Cost (USD)
Small wind turbine 100 kW	350.000
Civil works and installation	78.289
Miscellaneous components	32.237
Total	460.526

Table 4: Small wind turbine (100 kW) LCOE

% subsidy to initial investment	0%	25%	50%	75%	100%
Jenin	0.32	0.24	0.17	0.09	0.02
Kardallah	0.45	0.34	0.23	0.13	0.02
Nablus	0.34	0.26	0.18	0.10	0.02
Ramallah	0.22	0.17	0.12	0.07	0.02
Hebron	0.32	0.25	0.17	0.10	0.02
Tubas	0.26	0.20	0.14	0.08	0.02
Salfet	0.33	0.25	0.17	0.10	0.02
Average wind speed	0.305	0.234	0.163	0.091	0.020

Table 5: Small wind pre-feasibility analysis

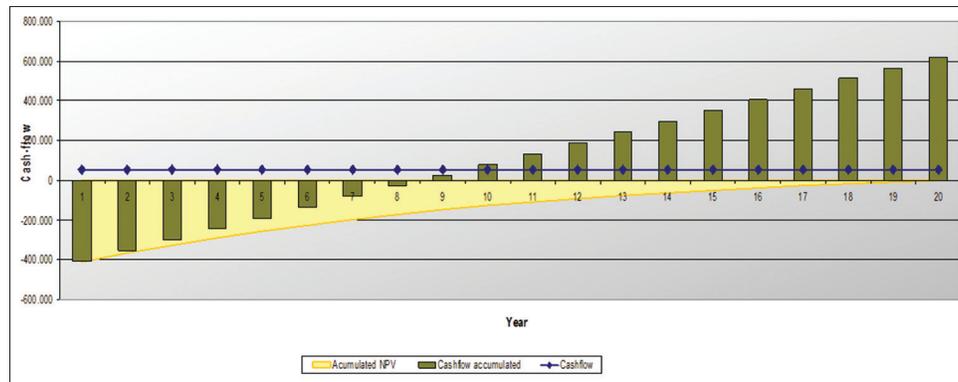
Year	0	1	2	3	4	5	6	7	8	9	10
Total costs	460.526	3.654	3.654	3.654	3.654	3.654	3.654	3.654	3.654	3.654	3.654
Total income		57.747	57.747	57.747	57.747	57.747	57.747	57.747	57.747	57.747	57.747
Cash flow	-460.526	54.093	54.093	54.093	54.093	54.093	54.093	54.093	54.093	54.093	54.093
Cash flow accumulated	-460.526	-406.433	-352.340	-298.247	-244.153	-190.060	-135.967	-81.874	-27.780	26.313	80.406
Present cash flow	-460.526	49.176	44.705	40.641	36.946	33.588	30.534	27.758	25.235	22.941	20.855
Present cash flow accumulated	-460.526	-411.351	-366.645	-326.004	-289.058	-255.470	-224.936	-197.178	-171.943	-149.002	-128.147
Year	11	12	13	14	15	16	17	18	19	20	
Total costs	3.654	3.654	3.654	3.654	3.654	3.654	3.654	3.654	3.654	3.654	
Total income	57.747	57.747	57.747	57.747	57.747	57.747	57.747	57.747	57.747	57.747	
Cash flow	54.093	54.093	54.093	54.093	54.093	54.093	54.093	54.093	54.093	54.093	
Cash flow accumulated	134.499	188.593	242.686	296.779	350.872	404.966	459.059	513.152	567.245	621.339	
Present cash flow	18.959	17.236	15.669	14.244	12.949	11.772	10.702	9.729	8.845	8.041	
Present cash flow accumulated	-109.187	-91.952	-76.283	-62.038	-49.089	-37.317	-26.614	-16.885	-8.041	0	

system to achieve a 10% internal rate of return a tariff of 0.316 USD/kWh would be required to achieve a net present value = 0. Table 5 and Figure 10. Show the detail lifetime costs of the small wind turbine project. Considering uncertainty of prices and wind speeds values can range from 0.175 to 0.401 USD/kWh. This highlights the importance of selecting most adequate wind sites and the importance to have reliable wind data to pursue higher energy yields (Krohn et al., 2009).

6. EXISTING BARRIERS AND RECOMMENDATIONS

One of the main characteristics of the Palestinian situation is political instability with direct and indirect consequences for the energy sector and the local economy. In addition, the high electric dependency on Israel can be considered as a major obstacle for economic development in the West Bank, the existing main barriers that preventing utilization of wind energy resources are as follows:

- Lack of availability and/or accessibility of land. According to the Oslo Peace Agreement, the West Bank is divided into three zones, A and B which are heavily populated, and zone C which constitutes most of the West Bank and considered as rural areas but under direct control of the Israeli armed forces. Thus, at present, there is no land available for developing a wind farm in the West Bank
- The electrical networks in the West Bank are all considered local distribution grids and there is no interconnected system, even in large cities. It is characterized by high electricity loss in addition to frequent power cuts. A major challenge for the power sub-sector as well as developing and utilizing wind energy sources is the construction of transmission network covering all parts of the West Bank. Until then, connecting wind farms or micro-turbine unites to the local grid could be a problem, in addition to the stability and control of the electrical system. (Radwan et al., 2011)
- Lack of adequate infrastructure in the West Banks in terms of paved roads, communications, etc.

Figure 10: Small wind pre-feasibility analysis. Net present value (NPV) = 0 USD, Internal rate of return (IRR) = 10%

7. CONCLUSION

This paper concludes that the most economical attractive areas for wind energy utilization, due to their special windy conditions, are the mountainous areas in the central and south of the West Bank where the average wind speed ranges between 5 and 7 m/s. The highest average wind speed values at these areas, around 7 m/s, are reached in summer. Flat areas of the West Bank are poorer regions for wind energy generation but still can provide significant wind energy potential, particularly in winter and autumn seasons. The potential of using small wind turbine applications are numerous and guarantee a prosperous future in different cities in Palestine. Small wind turbine implementation with capacity up to 100 kW can offer great possibilities to the energy consumers to benefit from clean energy source and reducing their energy bills. Therefore, energy demands of residential buildings, hotels and small businesses, farms and greenhouses etc. can be partly or fully covered with the use of small wind turbines.

8. ACKNOWLEDGMENT

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