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Review Article

An Overview of Wind Energy Potentials in Palestine

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Abstract: This study represents an overview on the possibility of using wind energy to fulfill the increasing demand on energy and the lack of supplied energy in the Palestinian territories, by analyzing and discussing former studies in this field. All previous studies mainly depended on historical data, and data from automated meteorological stations for some of the main cities in Palestine. However, the previous researches depended on data collected between 1991 – 2013, and used Weibull distribution function to analysing it. Moreover, all these studies agree about the possibility of exploiting wind energy, especially in high areas in Hebron in West Bank and Gaza city in Gaza Strip, to solve both the crisis of shortage electricity and the increase demand on energy. The highest wind energy is in Hebron, and the average month wind speed is between 3 m/s – 7.5 m/s, and the lowest wind energy is in Jericho, and the wind speed there is less than 2.5 m/s in most time. Some studies pointed that wind energy potential can be more efficient by using the hybrid PV / Wind system. At the same time, it can minimize the cost of generated energy from using each system independently. However, there are many obstacles of using wind energy to generate electricity in Palestine.

Keywords: Renewable Energy, Wind Energy Potential, Hybrid System, Palestine

1. Introduction

In recent decades, the world has developed rapidly in all life aspects. Because of this, an undoubtedly accompanied by a huge increase in energy demand. In fact, consumption of energy has risen by 2.3% all over the world in 2018, which is twice average rate of growth since 2010. As a consequence of the higher consumption of energy, global energy-related CO_2 emissions has grown by about 1.7% in 2018 to get to a high of 33.1 Gt CO_2. Actually, coal-fired power plants were the largest and single contributor to the increase in emissions detected in 2018. And also, the demand of global electricity has grown in 2018 by 4% to reach more than 23,000 TWh [1, 2].

Renewable energy (RE) is the solution to fulfil the madly increase in energy demand, as well as to save the environment by reducing CO_2 emissions, which increases in 2018 by more than 4%, thus avoiding 215 Mt of emissions. The generated electricity from the sources of RE has increased by more than 7% in 2018. And about 45% of the growth in the generated electricity round the world is now fulfilled by RE, and it also accounted for more than 25% of the world's power output. Apart from this, the generated electricity from wind has grown by about 12% in 2018, and the generated electricity from solar PV has risen by about 31% [1, 2].

Most of the increase in the consumption of global energy came from the developing countries, they are accounting for approximately 80% of the expansion [3]. Jalilvand stated that by 2035 Middle East will consume about 70% more energy [4]. In the same time, Middle East and North Africa bear the world's greatest potential for renewable energy, but right now, renewable energy contributes only a fraction of total energy consumption in the region [5]. In the Arab world, 6% of total power in the region was generated by RE, mainly in the form of hydropower 4.7%, 0.9% from wind and 0.4% from solar [6]. However, in these countries, the utilization of RE is increasing in more efficient ways and new RE (solar, wind and biomass) projects are being implemented [7]. Therefore, the countries in these developing regions can depend on themselves to fulfil the energy demand in the future by

developing RE infrastructure [8].

Palestine, like other developing countries in the world, is continuously developing. Thus, increasing the demand for all energy sources. According to PCBS data, during 2017 the imported energy to Palestine is increasing by 1.89% and quantity of electric power available in Palestine is increasing by 1.87%. Palestine depends entirely on imported energy, especially from Israel [9-13]. Palestine has a difficult and complex political situation because of the Israeli occupation, which negatively affected all life aspects in Palestine. Because of the full dependence on imported energy and the political situation, Palestine has the highest price for energy in the region [12, 14].

The Increasing demand on energy in Palestine accompanied by a lack of the quantity of the available energy. Sources of RE as their technologies have the possibility to provide solutions to the problems of energy [15]. Palestine has good potential for renewable energy, chiefly solar, wind, and biomass.

This paper presents a full grasp of using the potential of wind energy; to solve the problems of lack of energy sources in Palestine through an overview of previous literature on the same subject.

2. The Geographical, Demographic and Political Situation of Palestine

Palestine lies on the western edge of the Asian continent, between 34°20`-35°30`E and 31°10`-32°30`N [16]. Palestine has two separate geographical regions as presented in figure 1. The first is Gaza Strip, which lies on the western side of Palestine near the Mediterranean, it has an area of 360 Km^2. The second, is West Bank which lies on the west of the Jordan River [17]. The total area of these two regions is 6,020 Km^2 [10].

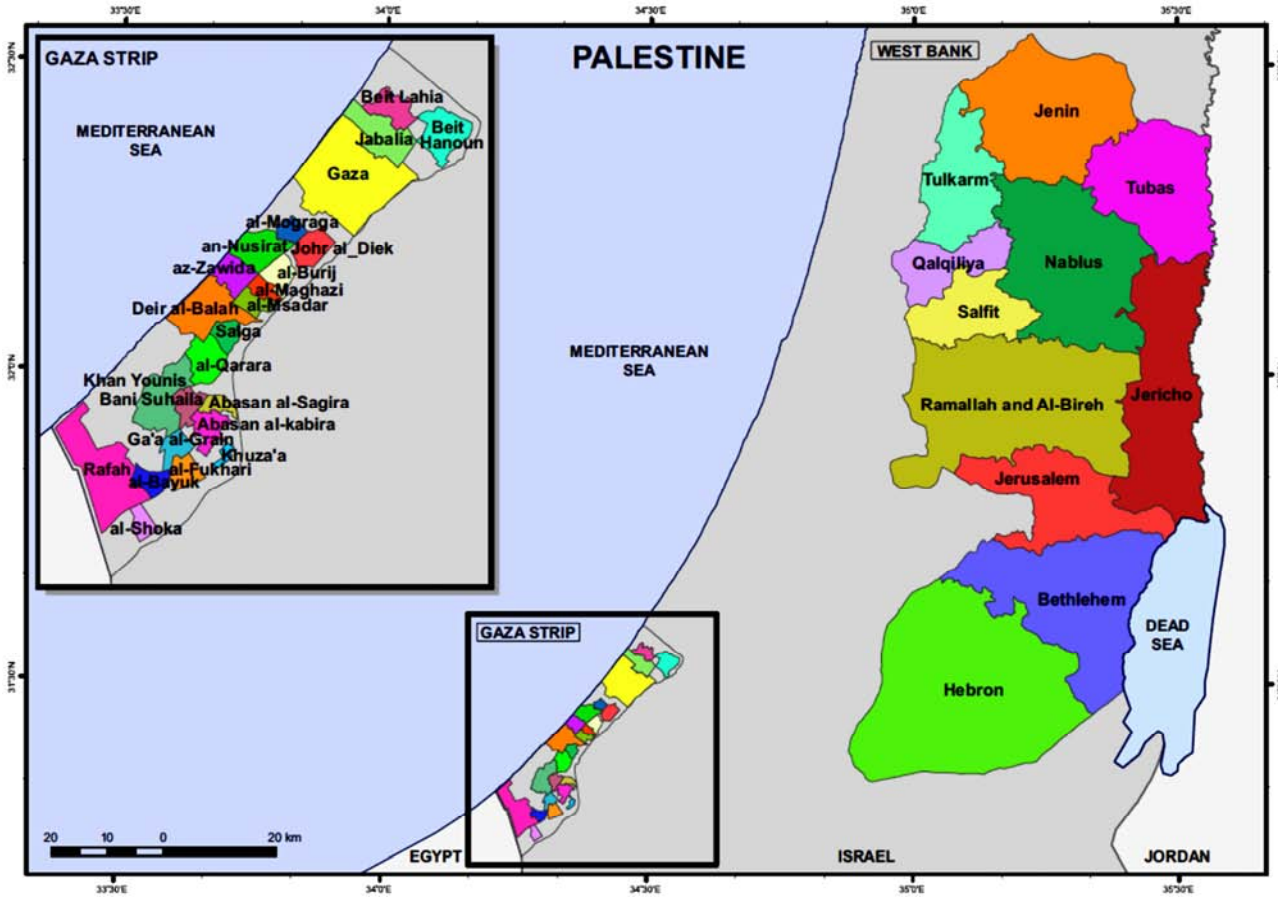

Figure 1. *Regions of Palestine [10].*

The climatic conditions, topography and the area's height are highly varied, despite the small geographical area of Palestine. In West Bank, the elevation of the land surface varies from 1,020 meters above sea level to 420 meters below sea level in the Dead Sea. However, in Gaza Strip, the elevation of the land surface varies from the sea level to 107 meters above sea level [18]. As a result, Gaza Strip is characterized by the coastal climate of the Mediterranean, with humidity, hot during summer and mild during winter [19].

According to PCBS data; In mid-2018, the total population in Palestine was 4,854,013 inhabitants, divided as follows: 2,921,170 in West Bank and 1,932,843 in Gaza Strip [9]. This means that Palestine, particularly Gaza Strip, is one of the most densely populated areas in the world, with about 3.0% population growth rate [16].

The political situation of Palestine is too complex, and the Israeli occupation has the control over West Bank and Gaza Strip. According to the Oslo Accords, West Bank was divided into three different zones; Area A, B, and C. Area A is under the Palestinian civil and security control. This area is about 17.7% of West Bank. Area B is under the Palestinian control and joint Israeli and Palestinian security control. This area is about 18.3% of the West Bank. Area C is under Israeli civil and security control. However, this area makes up to 61% of West Bank [18, 20]. According to the same accords, Palestinian energy authority and electricity companies in Palestine are only responsible for energy distribution to Palestinian's areas, whereas, the Israeli electricity companies are responsible for generating electricity and transmission. Therefore, any expansion of power station in Palestinian's area needs the Israeli approval, and nothing can be implemented in this field without collaboration with the Israeli electricity companies [21].

3. Energy Status in Palestine

Palestine is one of the developing countries, which is constantly evolving. And there is no doubt that this development is accompanied with a growing demand for energy. However, researchers, who conducted their researches about Palestine, should look at Palestine in another point of view because of the Israeli occupation and its special conditions. According to PCBS data during 2017, the imported Energy to Palestine and the quantity of electric power available in Palestine are increasing by 1.89% and 1.87% respectively [9]. Figure 2 represents the energy balance in Palestine in recent years.

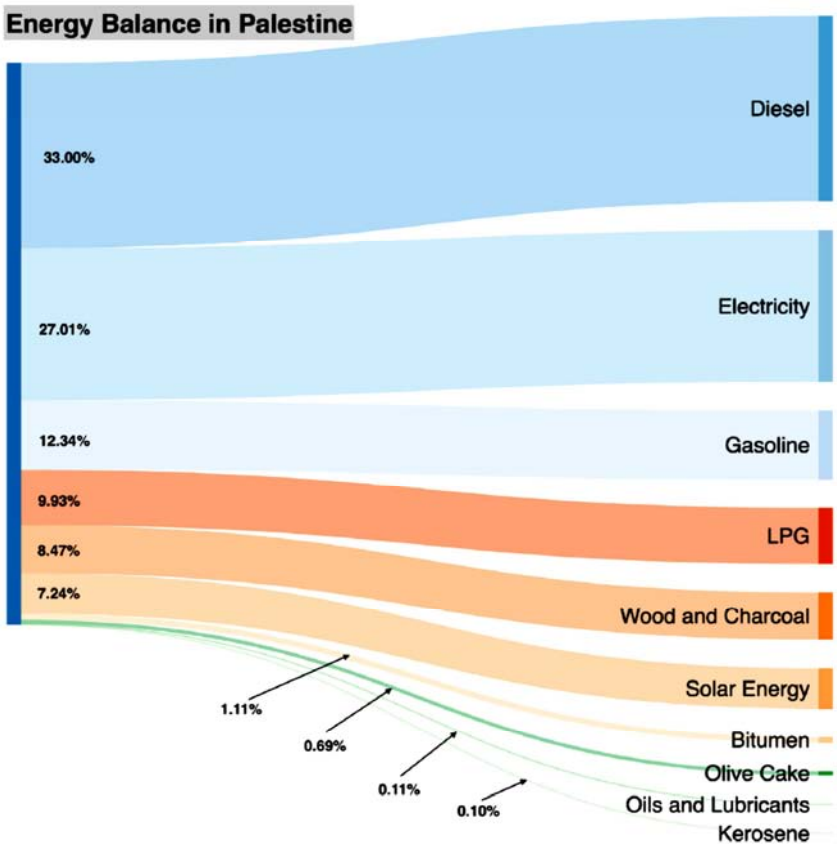

Figure 2. *Energy Balance in Palestine [10].*

In Palestine, 89% of electric energy and 100% fossil fuels is imported from Israel [10], while the rest of the electrical power needs are supplied from the power stations in Gaza Strip by 7%, Egypt by about 3% and from Jordan by 1% [22, 23]. Table 1 shows the imported energy, and table 2 shows the imported electricity. Ouda and Yassen asserted that because of the Palestinians' total reliance on conventional energy, the Palestinian territories have become more expensive, and at the same time less energy consumption per capita compared to neighboring countries [12, 14, 24, 25]. The Annual Electricity Consumption Per Capita in 2017 was 1138.3 KWh per Capita [9]. In fact, Palestinian household spent about 10% of their income on energy [24]. Surprisingly, Israel has collected about 12 million shekels monthly from the Palestinians consumers of electricity to finance the Israeli renewable energy activities. However, these funds could have been invested in the Palestinian territories' energy sector [26].

Electricity is not always available to many Palestinians, especially in Gaza Strip. According to a research performed by Oxfam in April 2010, it showed that houses across Gaza Strip were without power for about 35-60 hours per week [27, 28]. According to PCBS 2013 data, 99.8 % households in West Bank have a 24-hour access to power, and the daily power service for 97.2 % of households in Gaza Strip is

barely 16 hours [12]. The electricity crisis in Gaza Strip has become one of the notable problems that affects different aspects of the Palestinian citizens lives [11, 15]. Based on a UN report, in Gaza Strip the demand for energy was about 450 megawatts in 2017, while 120-142 megawatts were only supplied. That means; the deficit amount in Gaza Strip reached about 68% [29]. Moreover, about 24% of the electrical power is lost somewhere between the source and final destinations. The loss is from either technical issue, such as; worn-out grids and bad transmission lines, or the power was theft [12].

Table 1. *Imported Energy in Palestine by Type of Energy and Region, 2017 (Source: Palestinian Central Bureau of Statistics, 2018).*

Region	Type of Energy							
	Wood and Charcoal (Tons)	Bitumen (Ton)	LPG (Ton)	Kerosene (Thousand Liter)	Fuel Oil (Thousand Liter)	Diesel (Thousand Liter)	Gasoline (Thousand Liter)	Electricity (MWh)
Palestine	3,407	23,584	189,537	1,393	5,440	730,643	314,765	5,576,864
West Bank	3,300	23,352	124,208	1,279	4,769	496,146	274,716	4,801,564
Gaza Strip	107	232	65,329	114	671	234,497	40,049	775,300

Table 2. *Quantity of Electricity available (Imported and Purchased) in Palestine, 2017 (Source: Palestinian Central Bureau of Statistics, 2018).*

Sources						
Purchased from Palestine Electric Company (MWh)	Imported (MWh)	Jordan (MWh)	Egypt (MWh)	Israeli Electricity Company (MWh)	Other Sources	Total (MWh)
369,007	5,576,864	54,229	61,480	5,461,155	176,845	6,122,716

Renewable energy is the optimum solution energy security problem in Palestine, which will improve living and the economic conditions [23, 30]. It will also create energy security by using RE for electricity production. This will reduce the imported electricity and thus creating more energy sustainability with less cost [31], as well as it will reducing CO_2 emissions [10, 31]. In fact, the carbon emissions in 2016 is amounted to 4,645.5 tons according to PCBS [9].

Several studies have pointed out that the potential of renewable energy in the Palestinian territories is promising. Abu Hamed stated that 25% of energy demand and more than 36% of the current Palestinian electricity demand can be provided through renewable energy generation. Among the three major available resources available in the Palestinian territories, such as solar, wind, and biomass [30]. Juaidi stressed that Palestine has high solar energy potential about 3,000 sunshine hours per year, and high annual average of solar radiation which is amounting to 5.4kWh/m^2/day [10].

Renewable energy production contributes only 1.9% of the total energy [17]. Only 8% of solar energy is used, despite its high potential. However, this percentage has declined over the last years, and most of this energy is used for heating water. According to the Palestinian Central Bureau of Statistics, approximately 66% of households in the Palestinian territories use renewable energy (solar and Biomass) to heat water in residential buildings [14]. However, there are many studies pointed out to the potential of wind power in Palestine which is not utilized at all.

RE development needs researching on RE sources, making national laboratories internationally accredited for RE technologies, and increasing the professional skills related to the RE sector [32].

4. Wind Energy in Palestine

Currently, wind energy in Palestine is not exploited, as there is no project based on the exploitation of wind energy. There are studies that confirmed the potential of wind energy and stressed that wind energy has a promising future. However, only few studies related to wind energy potential were performed in the past, and these studies mainly depended on historical data and data from automated meteorological stations.

Palestine lies in a region characterized by low wind speed of the Middle East. Shawon mentioned that in some areas in the Palestinians Territories a small wind turbine can be used to generate energy from wind [33]. Furthermore, Ismael stated that these small wind turbines are especially attractive for supplying energy in the areas located far from the electrical grid [34]. Whereas, others argued that despite of the small potential of wind energy in Palestine, it has a future outlook on mountains (elevation of about 1000 m); regions of Nablus, Ramallah and Hebron where the speed exceeds 5 m/s have a potential of about 600 kWh/m^2 [17, 24]. Some hilly regions in West Bank, such as Nablus, Ramallah, Jerusalem and Hebron, have an average annual wind speed varied in the range of 4–8 m/s [16]. Shabbaneh and Hasan found that the highest wind potential areas in West Bank are in Hebron and northern Ramallah [35].

Depending on daily wind speed data from the Palestinian Metrological Authority in year 2006 [36], the average wind speed In Nablus and Ramallah cities were 4.346 m/s and 5.521 m/s, respectively. Qader has analysed these data using Weibull distribution function, and has calculated the power density which was 2,008.014 KWh/m^2 in Ramallah [37]. Since this study was published 10 years ago, it is hard to highly depend on it to have information a bout this topic. Also, climate changes slightly every year. Moreover, it took wind speed data for only one year (2006), and for only two cities. On other hand, it gives us some hope a bout wind energy potential in some West Bank areas.

Tahboub found that the average wind speed at 10 m could be as high as 6.2m/s in Al-Ahli Hospital, which is in the south-western of Hebron at about 1,000 m above sea level.

According to the wind speed measurements in 2007 obtained from the weather authority, the maximum average wind speed was in September of about 7.5 m/s. A study was done on the possibility to reduce the hospital electricity bill by installing wind turbines, the results of the study were very positive, but the political issue was a big obstacle, and it prevented the project implementation and it was cancelled [38]. Previous results confirmed the high potential of wind energy in the high areas in Hebron.

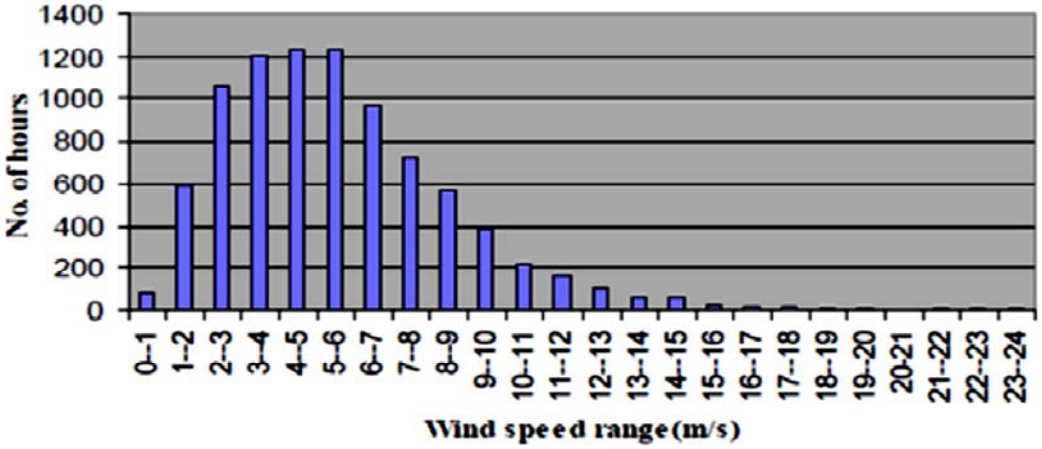

Figure 3. *Histogram showing hours that the wind blows at each wind speed range/Ramallah-2006 [37].*

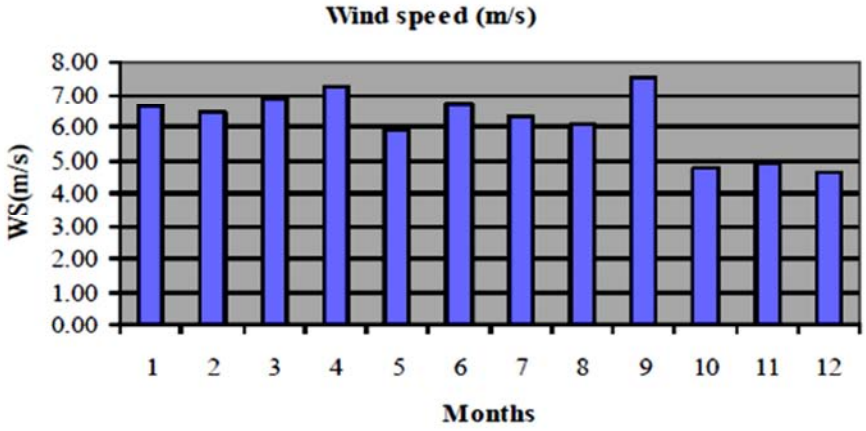

Figure 4. *Monthly average wind speed in Hebron/ Al-Ahli Hospital, during 2007 as provided by the weather authority [38].*

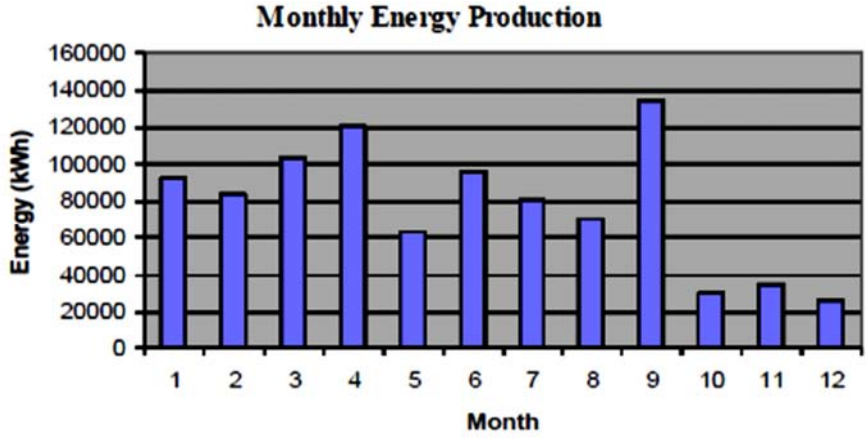

Figure 5. *Annual Wind Energy Production (AWEP) in Hebron/ Al-Ahli Hospital during 2007 [38].*

Ketaneh's study was more thoroughly than Qader and Tahboub, in term of number of cities the study covers, and the data of wind speed was for 5 years. He collected the daily wind speed data for four cities in Palestine (Nablus, Jenin, Jericho and Hebron), which were obtained from the Palestinian meteorological station network office for the

period 1997–2001. Then he analysed these data using Weibull distribution function, to get the results in table 3 [17]. In the months of summer, Nablus, Jenin and Jericho wind speed was noticed to be higher. However, in Hebron, wind speed was higher in the winter months. The highest mean power values were in July for Nablus 37.85W/m^2 and then in January for Hebron 32.98W/m^2. While the lowest mean power was 1.66 W/m^2 in January for Jericho [17].

Table 3. *Wind speed averages and wind power density in the period (1997–2001) for four cities in West Bank [17].*

Months	Hebron		Jenin		Jericho		Nablus	
	Wind speed (m/s) (at 10 m high)	Wind power density (W/m2)	Wind speed (m/s) (at 6 m high)	Wind power density (W/m2)	Wind speed (m/s) (at 6 m high)	Wind power density (W/m2)	Wind speed (m/s) (at 6 m high)	Wind power density (W/m2)
January	3.78	32.98 **	1.57	4.86	1.27	1.66 *	2.13	6.92
February	3.70	32.21	2.08	7.77	1.43	2.32	3.01	18.17
March	3.05	25.66	2.12	7.50	1.95	5.57	2.81	14.90
April	3.70	29.65	2.13	6.42	2.27	8.10	3.06	17.87
May	3.44	22.57	2.55	10.95	2.44	9.63	3.52	26.55
June	3.24	19.86	3.06	17.60	2.56	10.34 **	3.81	31.53
July	3.30	19.67	3.22	18.90 **	2.40	8.42	4.05	37.85 **
August	3.24	18.55	2.74	12.59	2.28	7.37	3.67	28.15
September	3.33	20.56	2.07	5.92	1.94	4.60	3.52	25.01
October	3.14	18.03	1.85	4.34	1.65	2.81	2.24	6.69
November	2.28	15.23 *	1.55	3.05 *	1.29	1.73	2.10	5.83 *
December	3.19	19.91	1.75	4.79	1.33	1.77	3.66	32.67

**: Max. values.
*: Min. values.

Table 4. *Climatology of the monthly mean wind speeds (based on 2000–2011), together with standard deviation [16].*

Months	Climatology Hebron (m/s)	St. dev (m/s)	Climatology Gaza (m/s)	St. dev (m/s)
January	4.71 **	2.25	4.43	2.20
February	5.06	2.38	4.52	2.40
March	4.18	2.18	4.18	2.11
April	4.76	2.10	3.89	1.95
May	4.58	2.05	3.26	1.97
June	4.49	1.80	2.73	1.76
July	4.27	1.71	2.52	1.67
August	4.01	1.53	2.40 *	1.67
September	3.80	1.47	2.52	1.67
October	3.39	1.47	2.67	1.57
November	3.43	1.62	3.16	1.54
December	4.02	1.94	3.85	1.90
Average	4.22	1.87	3.34	1.87

**: Max. values.
*: Min. values.

De Meij managed to conduct thoroughly study that covered West Bank and Gaza Strip, by analysing the climatology of the Palestine wind profile based on WRF simulations for the period 2000–2011 (12 years), and power density at 40 m height, it is clearly that most of the territories is highly suitable for wind development. De Meij found that the highest monthly average wind speed was calculated in February for Hebron 5.06±2.38m/s and the lowest value is 2.40±1.67 m/s for Gaza City in August [16]. whereas, Ketaneh asserted the highest monthly average wind speed is calculated in July for Nablus.

De Meij calculated the annual energy density from wind speed for the Palestinian regions, and classified them into three groups. Then, he put it on the map of Palestine [16]. At 80 m, the eastern zone of Hebron seems the most suitable area in West Bank.

Table 5. *Wind speed averages in 2013 for five cities in West Bank (ERC).*

City	Wind speed average in 2013 (m/s)
Tubas	4.97
Salfeet	4.26
Ramallah	3.09
Hebron	2.90
Jericho	1.32

Based on the data of wind speed and direction, which measured by Energy Research Centre (ERC) for Tubas, Ramallah, Hebron, Jericho and Salfeet in 2013, wind speed in these cities was found to be higher in summer months except for Salfeet which found that wind speed is higher in winter months. This result corresponds to the results Ketaneh was found. The wind speed averages for these cities are ranging from 4.97 m/s in Tubas to 1.32 m/s in Jericho. As a result of these wind speed values, the situation is encouraging

to use small wind turbines for generating electricity in the areas that suffer from power shortages, and in the areas located far from the electrical grid. In addition, it can be used as an alternative choice to diesel engines in water pumping [10].

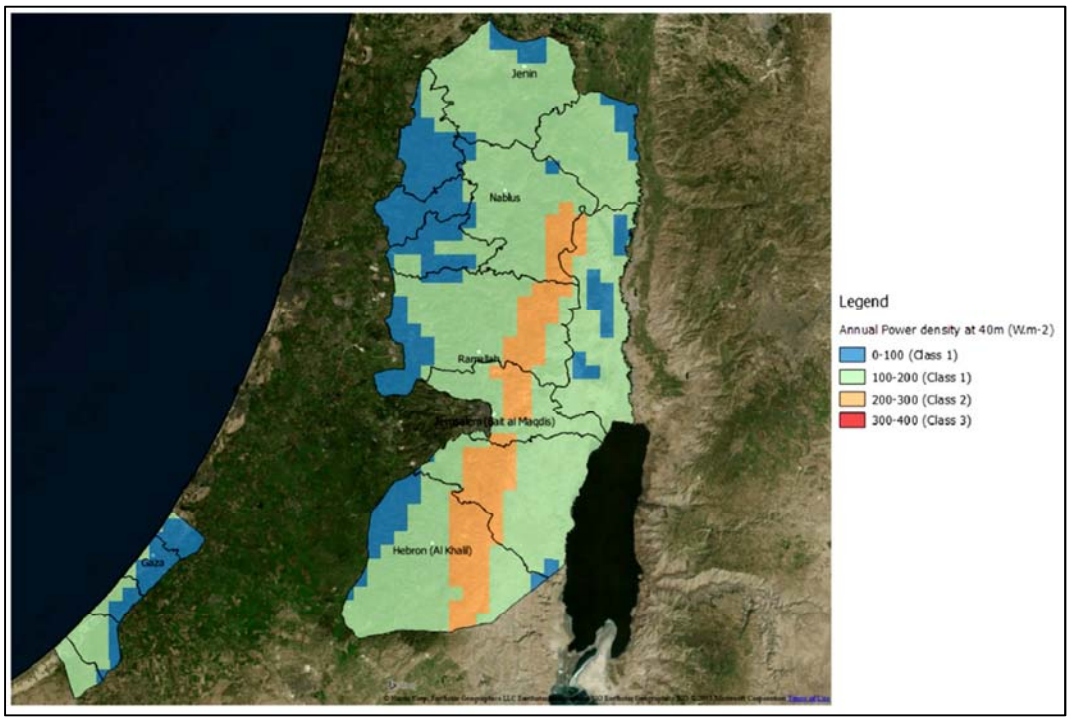

Figure 6. *Annual Power density at 40 m for the Palestine region [16].*

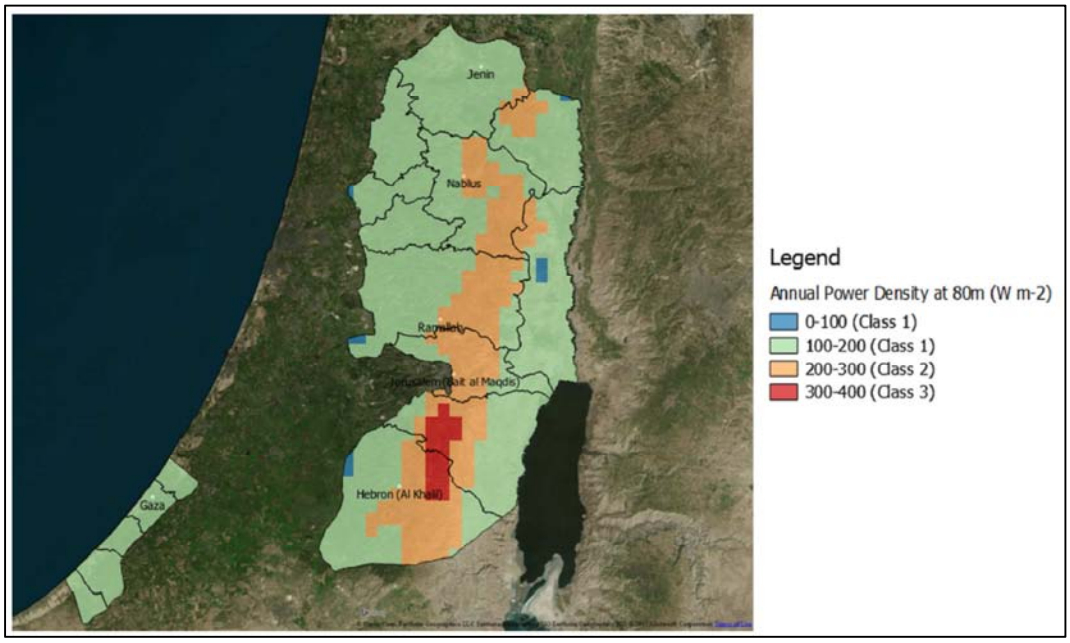

Figure 7. *Annual Power density at 80 m for the Palestine region [16].*

De Meij in his research declared that Gaza strip is characterized a very low wind speed with an average of about 2.5–3.5 m/s. Unfortunately, the potential of wind in Gaza is considered not enough to generate energy [16]. However, Elnaggar confirmed, depending on the data for a typical meteorological year from 1991 to 2010, that the average monthly speed in Gaza at 10 m high, mostly exceeds 4 m/s, except for October and November [29]. This result is very close to Badawi's result [39]. The expected annual energy output in Gaza from a small wind turbine of 5 kW at a height of 10 m amounts to 2695 kWh. The power generated by these turbines can be risen by increasing the height of the turbines [29].

Alaydi affirmed that Gaza city has the highest wind energy

potential compared to the other cities in Gaza strip, with an annual wind speed average of 4.2 m/s at a 50-meter height, and with wind speed higher than 5.0 m/s for about 60% of the time. This result corresponds to the results Elnaggar was found. Alaydi concluded that the annual highest attainable wind power potential per unit area of the wind stream is about 0.5 MWhr/m^2/year [27, 28, 39].

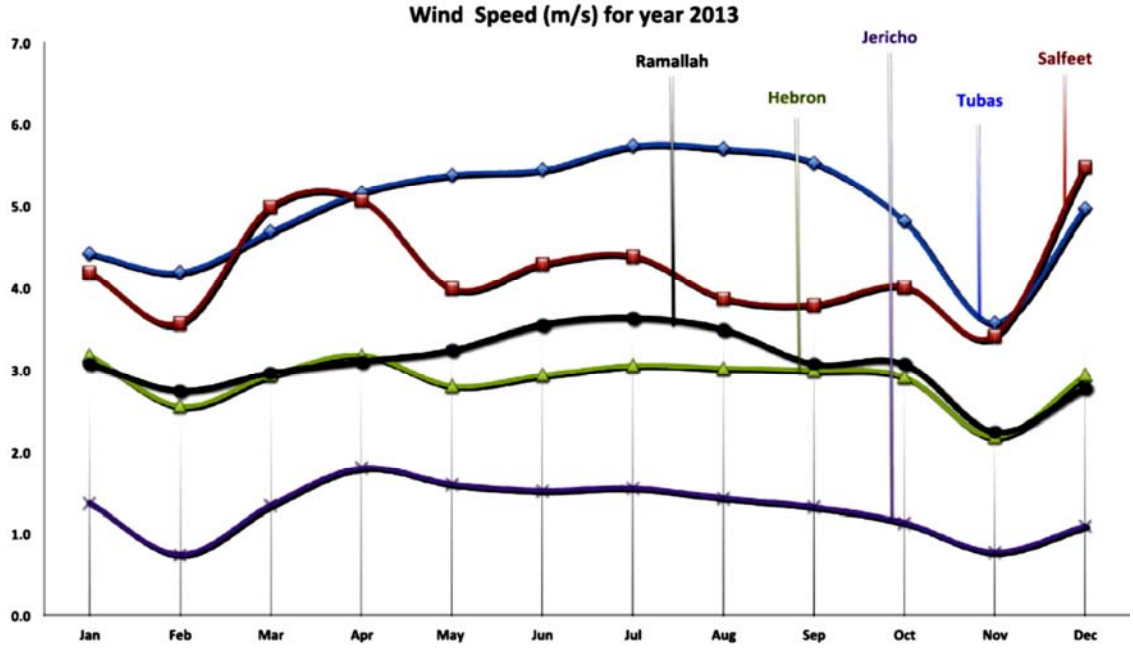

Figure 8. *Monthly wind speed in different cities in West Bank in year 2013 [10].*

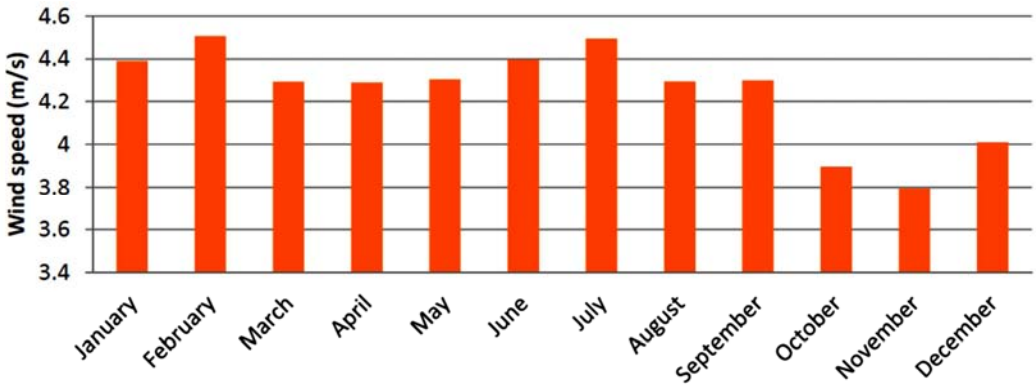

Figure 9. *Monthly average wind speed in Gaza in a typical meteorological year (height 10 m) [29].*

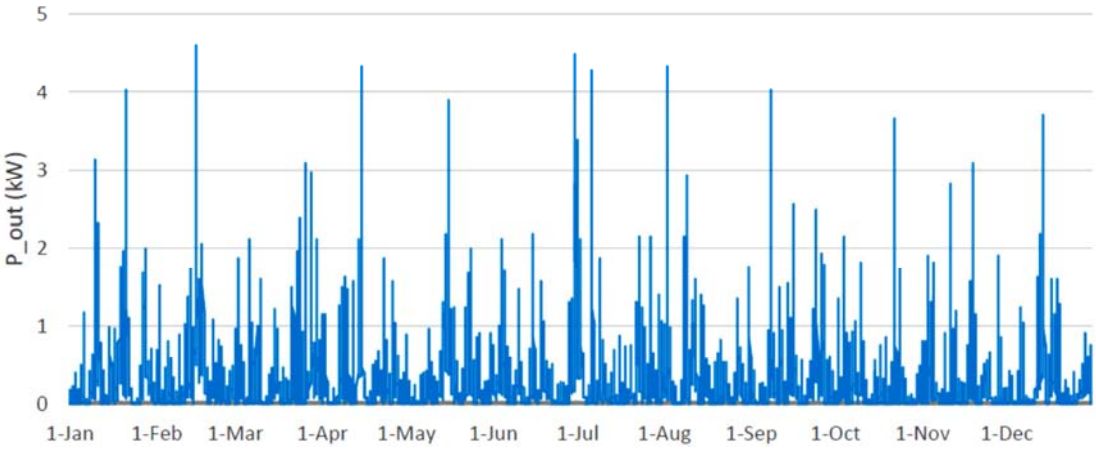

Figure 10. *Hourly distribution of power output for the typical meteorological year in Gaza [29].*

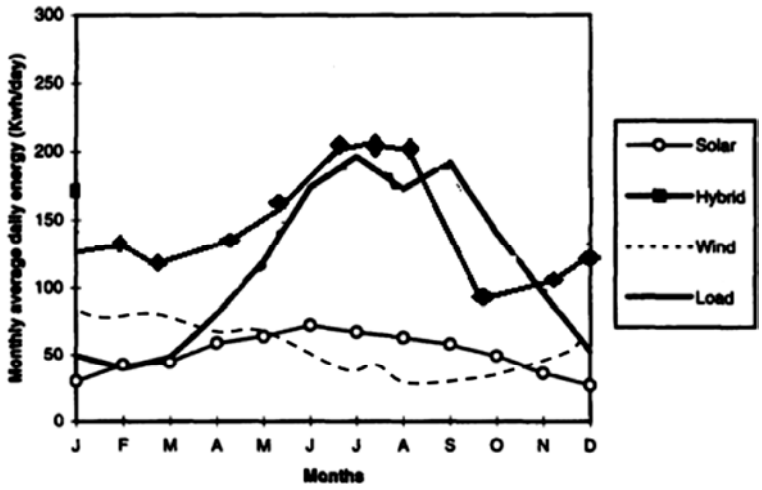

Figure 11. *Monthly distribution of solar, wind, and hybrid power in Gaza city at 50 m height (hybrid systems consisting of 3 kW WECS and 25 m^2 of photovoltaic solar) [27].*

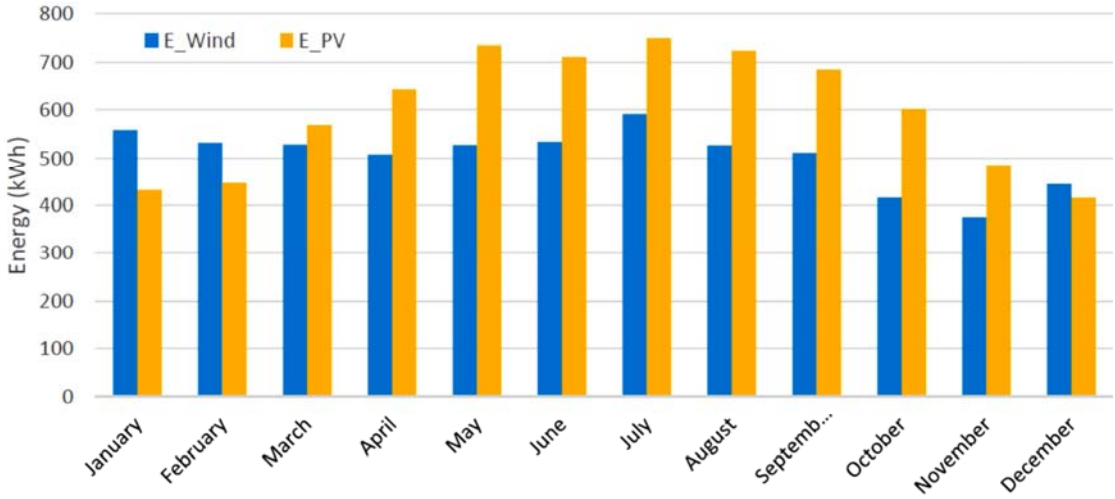

Figure 12. *The monthly energy output for a wind turbine (5 KW) at 70-meter height and a comparable photovoltaic system (5 KW) in Gaza [29].*

4.1. Hybrid System

Palestine is one of the countries that has high solar energy, but solar energy decreases in the winter months. On the other hand, the potential of wind power in Palestine is somewhat acceptable and increases in winter months. However, using wind power conversion systems (WECS) or PV system independently will be unreliable and costly. Therefore, wind energy that is harvested could compensate for the weakness in the harvested photovoltaic energy in the winter months and vice versa. PV/Wind hybrid system is the key solution to reduce their individual fluctuations, and raise the overall energy output [27, 40]. Moreover, using a hybrid system can lower the cost of energy generation, thus solving the problem of high cost of RE projects in Palestine [40, 41, 42].

Depending on the PV Watts Calculator, in Gaza, the annual photovoltaic energy output from a 5 KW photovoltaic system is about 7196 kWh. Consequently, the harvested annual energy of the small wind turbine at a 10-meter height is about 37% of the solar energy, but at 70-height and above the annual energy is about 84%. Based on a household energy survey performed by the Palestinian Central Bureau of Statistics in January 2015, a hybrid system that consists of one wind turbine (5 KW) and one comparable photovoltaic system (5 KW) can provide enough energy for about 3.7 households (with on average 5.7 persons) [29]. The maximum estimated output energy from PV/Wind hybrid system will be in the months of June and July.

4.2. Barriers Facing Developing Wind Power in Palestine

According to [10, 22, 24, 26], developing wind power in Palestine suffers from the following obstacles:

a) The main obstacle is the Israeli occupation, which prevents any Palestinian efforts to generate electricity by using RE, especially in Area C, which shapes 62% of the Palestinian territories. Also, by dominating the import and export trade movements and forcing a costly tax system which increase the cost of clean, reliable, efficient technologies.
b) Lack of technical and human capabilities, and the absence of professional training on the modern applications and designs.
c) The costly investment in this area, as well as the low

income of the Palestinian families. Also, the PNA does not provide any support or incentives for projects like these.

d) Lack of awareness of the importance of energy conservation and green technology.

4.3. Palestine RE Targets – By 2020

The Palestinian government aims to get 130 MW of the generated electricity from renewable energy sources, which is equivalent to 10% of electrical power produced locally by the year 2020 [6].

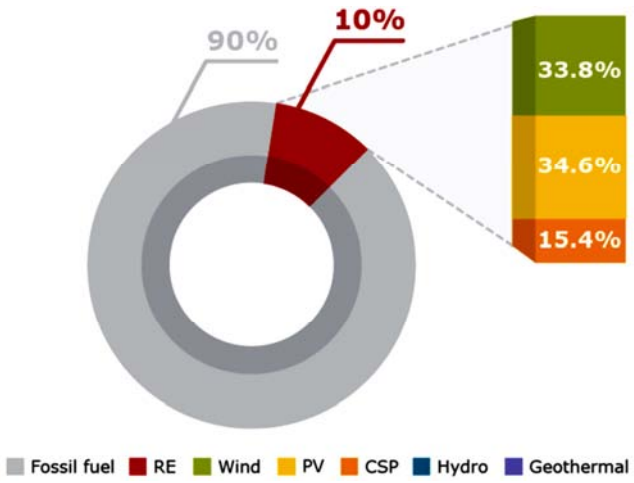

Figure 13. *RE Targets - Year 2020 [22].*

4.4. Future Prospects for Wind Power in Palestine Strengths and Drawbacks

a) Good average wind speeds in some highlands in West Bank are up to 6.2 m/s.
b) Small land surface availability especially in Gaza Strip. And wind turbines (WT) require less area, therefore, WT is the right solution for the lack of the available area.
c) Small wind turbines can totally be manufactured locally, so wind turbines can have lower cost.
d) Awareness of the Palestinian authority about renewable energies.
e) The Palestinian government is on the way to promote the renewable energy law and making a wind map.
f) Cover the increasing in the electrical demand annually by about 6%.
g) Drawbacks:
h) The low wind speed in most Palestinian areas, especially in the Gaza Strip.
i) There is no new data about wind energy. All previous studies depended on data collected between 1991 and 2013.
j) High project costs compared to income of most Palestinian families.
k) PNA does not provide any support or incentives to encourage implementing wind energy projects.
l) Poor infrastructure in the Palestinian Territories.
m) The political conditions in Palestine, and the Israeli occupation does not promote any foreign investment.
n) Palestinian government does not have any plans to resolve the electricity problems of increasing demand neither have solutions to solve the short-cuts problems.

5. Conclusion

Wind power clearly have a promising future, although most of Palestine is located in areas with moderate wind speeds. The lowest wind energy in Jericho since wind speed there less than 2.5 m/s in most times. And the highest wind energy in Hebron particularly in (Al-Ahli Hospital) since the average month wind speed is about 6.2 m/s, which can be used to cover the increase in demand for electricity annually for about 6%. It can be more efficient by using the hybrid PV/Wind system, at the same time it minimizes the cost of generated energy from using each system independently. On one hand, there are lots of barriers facing developing Wind Power in Palestine. On the other, the majority of these challenges can be resolved by manufacturing wind turbines locally.

6. Recommendations

Developing suitable financing and creating a national fund with the Palestinian government participation, the private sector and the external financial aid to support the development actions of renewable energy, and give incentives to encourage investing and using the renewable technologies. Also, paying attention to small-scale projects in this field and creating a wind map. Moreover, developing bilateral collaboration agreements with a sight to establish wind energy projects. New data about wind energy must be collected in recent years, to make more reliable studies, that can be used to build efficient projects.

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