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# Wind energy resource mapping of Palestine

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## ABSTRACT

This study presents the analysis of the climatology of the wind profile over the State of Palestine, together with the selection of the typical meteorological year, the wind power density and the annual energy production. This climatology is based on a 12-year simulation (2000–2011) using the numerical weather prediction model WRF. Our analysis of the wind profiles showed that the highest yearly average wind speeds are calculated for 2003, while the lowest yearly average wind speeds are calculated for 2008. For Gaza and West Bank region the highest wind speeds are observed during the winter period and the prevailing wind direction is westerly for both Gaza and West Bank.

An analysis of the statistics on the wind climatology showed that the year 2011 can be considered as a typical meteorological year. In general, the wind speeds for the Gaza region are the highest closest to the sea, while more inland lower wind speeds are found. Over the elevated terrain of the central part of the West Bank region the highest wind speeds are calculated. The analysis of the comparison of the calculated wind speeds with the observations shows that for 16 out of 20 stations the relation $RMSE_{mod} < STDEV_{obs}$ is valid, which is one of the conditions for good quality modeling results. The variations of wind power density and AEP over a 12-year period (2000–2011) are rather low in Gaza and West Bank. The AEP at 80 m shows that the zone east of Hebron is the most suitable area in West Bank. Wind potential all over Gaza is unfortunately not enough to be considered at any level.



**Contents**



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## 1. Introduction

Palestine lie on the western edge of the Asian continent and the eastern extremity of the Mediterranean Sea, between 34°20′–35°30′E and 31°10′–32°30N. Palestine elevation ranges from 300 m below sea level in the Jordan Valley, to sea level along the Gaza Strip seashore, reaching 1000 m above sea level in some locations in the West Bank. The total population is about 4.4 million (census 2012, Palestinian Central Bureau of Statistics) of which 2.47 million live in the West Bank and about 1.7 million in the Gaza Strip. The population growth rate is about 3.0% and the average household size is about 5.6 persons.

More than 90% of the Palestinian electric power is supplied by neighboring countries and renewable energy source represents about 27% of the total energy supply with 43% of solar energy and the rest from biomass energy [1]. In presenting possibilities to reduce this dependency on external energy sources [2] mentioned that since the fossil fuels resources are rather limited, the development of renewable energy sector is foreseen the most advantageous solution to meet the increasing energy demand. Moreover, Abu Hamed et al. [1] concluded that 25% of the energy demand could be provided by renewable energy generation. Within the three main available resources accessible in Palestinian territories, i.e. solar, wind and biomass, solar energy shows the most potential with high level of radiation high sunshine hours throughout the year. The horizontal yearly average daily solar radiation is about 5.6 kW h/m$^2$ with $\sim$3000 h of sunshine [3]. Even if grouping Palestine and Israel in the low wind speed region of the Middle East, Shawon et al. [4] mentioned the potential of specific locations and possible use of small wind turbines. Furthermore, Ismael et al. [2] states that these small wind turbines are particularly attractive to supply energy to sites located far from the grid.

Only a few studies related to wind energy potential were performed in the past. They are mainly focused on historical data and data coming from automated meteorological stations. Shabbaneh and Hasan [5] used measurements from 1940 to 1983 to investigate wind potential over Palestine. The data used for West Bank and Gaza were recorded in Beaufort Force scale and collected between 1940 and 1947. They calculated shape and scale parameters of a Weibull density distribution function for West bank in Palestine. They found the highest wind potential areas in West Bank, and in particular in the Hebron area and north of Ramallah.

Focusing on Gaza strip, Alaydi [6,7] used hourly wind-speed data recorded at automated meteorological station to investigate wind energy potential. The site of Gaza showed the highest potential with an annual wind speed of 4.2 m/s though extrapolated by a power-law to 50 m.

Recently, Badawi [8] proposed a new strategy based on an analytical approach to estimate wind potential. This strategy is based on building a Weibull curve for parts of the territories, e.g. Gaza strip, and then calculating the energy curve from it. Still this method is based on local measurements but it shows similar results in term of potential as previous studies.

Renewable energy (RE) resource mapping and geospatial analysis is increasingly being recognized as a crucial component to scaling up the deployment of RE in a way that is sensitive to environmental and social constraints [9,10]. Thus, the World Bank's Energy Sector Management Assistance Program (ESMAP) is supporting an initiative to support RE resource mapping activities in developing countries in recognition of the need for high quality, country-level resource mapping and geospatial planning.

In this paper, we present the wind atlas for the Eastern part of the Mediterranean focusing on the Palestine region, together with the power density and annual energy production for the Gaza and West Bank. For the first time a modeling approach based on a mesoscale model is used to estimate wind potential over Palestine. Moreover, since the methodology and result analysis are based on the recommendations set in the Best Practice Guidelines for Mesoscale Wind Mapping projects for the World Bank [9], this work can be of tremendous interest for decision makers and investors.

In Section 2 the tools and the method are presented. In Section 3 the results of the calculated climatology are discussed while the evaluation of the typical meteorological year is presented in Section 4. Wind power density and annual energy production are analyzed in Section 5. We finish in Section 6 with the conclusions.

## 2. Tools and methods

### 2.1. Model description and configuration

In this study we used the Advanced Research WRF system (WRF-ARW V3.3.1), which is in the public domain and is freely available for community use (http://www.wrf-model.org/index.php). A detailed description of the model can be found in Wang et al. [11]. WRF uses meteorological initial conditions and lateral boundary conditions from 6 h analyses from the NCEP Climate Forecasting System Reanalysis (CFSR); pressure levels 0.5 × 0.5° horizontal resolution and surface input parameters (e.g. specific humidity, temperature, $u$-component wind, $v$-component wind, ice-cover, land-cover, etc.) on ~0.3 × 0.3° horizontal resolution. Data produced during pre-processing and modeling simulations of WRF are in the Lambert conformal projection. The time step of output data has been set to 1 h. The vertical discretization involves 27 levels up to ~17.5 km. The parameterization schemes used to perform the simulations are described in Table 1.

### 2.2. Methodology

WRF operates on 12 × 12 km (D1) and 3 × 3 km (D2) resolution, see Fig. 1. Two simulations were performed with no nudging to the observations. The first simulation was performed on the 12 × 12 km resolution between 2000 and 2011 (12 years) to calculate the climatology and determine the typical meteorological year (TMY). The second simulation was performed on 3 × 3 km for the TMY. For the typical meteorological year we used the nesting capacities of the mesoscale model to allow a physical downscaling

**Table 1**
Specifications of WRF physical parameterization.

| | |
|---|---|
| Radiation | RRTM scheme |
| PBL Physics | Yonsei University (YSU) scheme |
| Microphysics | WRF single-moment 6-class microphysics scheme |
| Cumulus | Kain–Fritsch scheme |