

METHODOLOGY FRAMEWORK FOR PRIORITISATION OF RENEWABLE ENERGY SOURCES IN PORT AREAS

SOFIA AGOSTINELLI¹, MEHDI NESHAT², MEYSAM MAJIDI NEZHAD¹,
GIUSEPPE PIRAS¹ & DAVIDE ASTIASO GARCIA³

¹Department of Astronautics, Electrical and Energy Engineering, Sapienza University of Rome, Italy

²Center for Artificial Intelligence Research and Optimization, Torrens University Australia, Australia

³Department of Planning, Design, and Technology of Architecture, Sapienza University of Rome, Italy

ABSTRACT

Ports play a crucial role in increasing the decarbonisation of urban environments to mitigate the environmental impacts of maritime transport and promote sustainable intermodal mobility. Various efforts have been made to increase energy self-sufficiency using renewable energy sources (RESs) in different ports worldwide. However, the ports played an essential role in the pollution process of the nearest cities due to the short distance and merging with urban areas. In this case, solar and wind were measured using the Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) data of four Lazio province ports. Each RES was evaluated using 10 years of monthly data for mapping and 1 year of hourly data for potential assessment and energy converters installation. Furthermore, the time series method has been considered to design and develop better management of RESs for decision making monitoring the energy needs of ports. This time series method has been applied to the generated energy source based on various parameters of the RESs used in port.

Keywords: renewable energy sources, decision making, geographic information system, MERRA-2, time series analysis.

1 INTRODUCTION

The Paris Agreement on climate change clarifies that significant step should be taken towards a 100% decarbonisation by 2050 [1]. The total electricity generating capacity for industrial ports could increase more than tenfold thanks to renewable energy sources (RESs) by 2050. However, current activities in the port are significant contributors to CO₂ emissions and require drastic rethinking. Ports present a prominent energy source as crucial locations for energy production from RESs: an awareness that inspired the recent European Green Deal (EGD), in which ports are conceived as possible energy poles and engines of the blue economy next generation EU Program. These considerations are the main impetus for this kind of study, aiming to present efficient methods and models in European ports of technology to improve the energy efficiency of port areas. A port can provide RESs and support vessels with clean electricity. Different approaches of alternative energy for ports were proposed, such as Antwerp, Genoa, Venice, San Diego [1].

Some studies were carried out to evaluate the applying of RESs for the decarbonisation of the Italian ports, for example applying wind and solar energy [2], [3] in the European ports [4]–[6]. Of course, reducing greenhouse gas (GHG) and pollutant emissions are directly linked with energy efficiency interventions, electrification of equipment, and the use of RES or alternative fuels. These aspects, along with increasing operational efficiency, are crucial for increasing ports' energy and environmental sustainability in the next generation. Ports can be classified into six types by considering various factors such as location, water depth, purpose and size of ships [3]: (a) domestic ports, (b) fishing ports, (c) hot water ports, (d) dry ports, (e) seaports, and (f) cargo ports. Each cargo port has three functional areas, namely quayside, yard side and landside. The study is aimed to design, develop, test and validate a replicable multidisciplinary approach that includes method for identifying and quantifying



the potential of RESs interventions in ports. Finally, a method has been designed and developed to enhance network intelligence to better manage RESs for decision making monitoring the energy needs of ports. This study uses reanalysis data and dataset has been designed, developed, and launched by the NASA, which has high datasets. These reanalysis dataset source has been used for discovering, extracting, processing and mapping of RESs potential analysis to better understand ports as a preferred area with very high time resolution.

2 CASE STUDY

In this article we have studied the four ports of Lazio: Anzio (41°26'52.61"N 12°37'44.59"E) is a city and commune on the coast of the Lazio region about 51 km south of Rome. Formia (41°16'N 13°37'E) is situated on the Gulf of Gaeta on the west coast of Lazio. Formia port is a general cargo port formed by a breakwater and a jetty, accommodating fishing vessels only. Terracina (41°17'N 13°15'E) is an Italian city and located on the coast 56 km southeast of Rome. Ventotene (40°47'N 13°25'E) is one of the Pontine Islands in the Tyrrhenian Sea.

3 MATERIAL AND METHODS

In this paper, wind speed and solar radiations potential of the Lazio province ports have been analyzed using more than ten years of monthly data for mapping and one year of hourly data for time series analysis from the MERRA-2 reanalysis dataset. This long-term analysis has been done to evaluate and identify different ports with the exciting potential of Lazio ports' wind speed and solar radiations for micro wind turbines and PV installations. Furthermore, the priority decision-making of suitable potential ports is examined based on the following parameters.

3.1 Long term wind speed and solar irradiation mapping

Firstly, more than 10 years (2010–2021) of monthly data from the MERRA-2 reanalysis dataset have been used to evaluate and identify wind speed and solar irradiation potential classification ports. This data has been used to better understand the wind speed and solar radiation of Lazio ports to install micro wind turbines and PV facilities in one interval.

3.2 Port's analysis using hourly wind speed and solar irradiation data

Secondly, 1 year of hourly data from the MERRA-2 reanalysis dataset has been used to monitor and assess wind speed and solar potential time series analysis of ports areas with exciting potential to better understand the wind speed and solar irradiation assessment wind turbines and PV installations and make better decision-making. Furthermore, this year (2020–2021) hourly data from the MERRA-2 reanalysis dataset relative with ports areas outputs has been used as input of the next step, which means 3.3.

3.3 Statistical analysis of wind speed

In order to design and evaluate wind energy systems, wind speed parameters play a significant role. The interval of the recorded wind speed time series is hourly were acquired from the MERRA-2 in Lazio port across 12 months period from 2020 to 2021. In this study, we apply a Pearson's linear correlation coefficient test in order to analyse the level of correlation between the wind speed data of four ports. The correlation coefficient of the population between two sets generated randomly; X and Y is defined as follows:

$$px, y = \text{corr}(x, y) = \text{cov}(x, y) / \sigma_x \sigma_y = E[(X - \mu_X)(Y - \mu_Y)] / \sigma_X \sigma_Y, \quad (1)$$



where μ_X and μ_Y are the expected values of X and Y and both σ_X and σ_Y are the standard deviations. First and foremost, observation is a positive association among all ports in terms of wind speed data. Secondly, the highest positive correlation can be noticed between Ventotene and Formia port. In the third step of the wind speed data statistical analysis, an autocorrelation test is used. In order to define an autocorrelation coefficient lag k (r_k) for a sequential time series s_1, s_2, \dots, s_k as follows:

$$r_k = \frac{1}{T} \sum_{t=1}^{T-k} (S_t - \bar{S})(S_{t+k} - \bar{S}) / c_0, \quad k = 0, 1, \dots, L, \quad (2)$$

where c_0 denotes the sample variance of the sequential time series data. T is the effective sample size of S_t , and also \bar{S} is the average of time series S_t . Generally, $L = \frac{T}{4}$ and depends on the time series data length.

Indeed, autocorrelation regards the correlation strength of the corresponding variables between two consecutive time intervals. This analysis is generally applied to indicate that how the lagged version of the variable values is described as the primary variant of it in sequential data. The standard range of autocorrelation is between -1 and 1 . A negative autocorrelation is imposed where the value is from -1 to 0 . Inversely, we can see a positive autocorrelation with a value between 0 and 1 [7].

4 RESULTS

4.1 Long term wind speed assessment and mapping

In the Lazio ports, the highest wind speed values can observe in the Ventotene port near 5.5 m/s. The Anzio and the Terracina port with wind speeds of more than 5 and 4.5 m/s, also Formia port areas have wind speeds of about 4 m/s in the same period (Fig. 1). Fig. 1 shows wind speed analyzed using the MERRA-2 reanalysis dataset for the four case studies of Lazio and Fig. 2(a) and (b) shows a monthly and seasonality wind speed using hourly time series from 2020 to 2021 for the four Lazio ports.

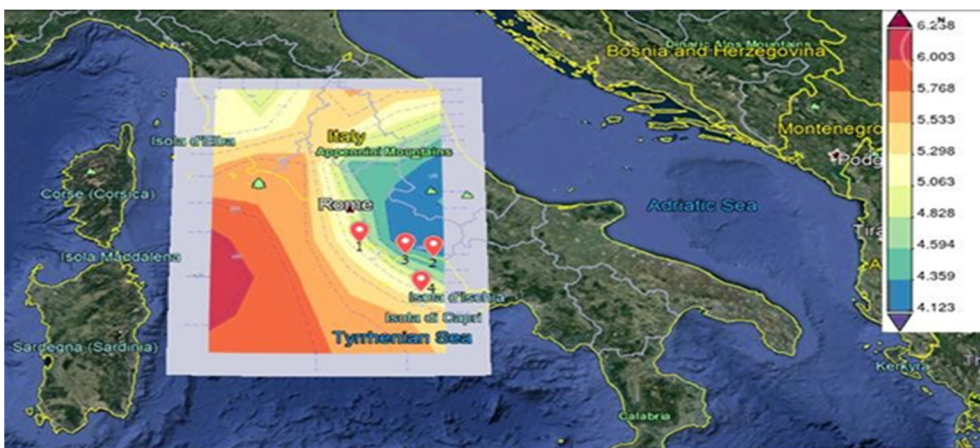


Figure 1: Surface wind speed monthly 0.5×0.625 deg. m s^{-1} from May 2011 to March 2021. Region 10.0707E , 39.6929N , 14.3334E , 43.648N .

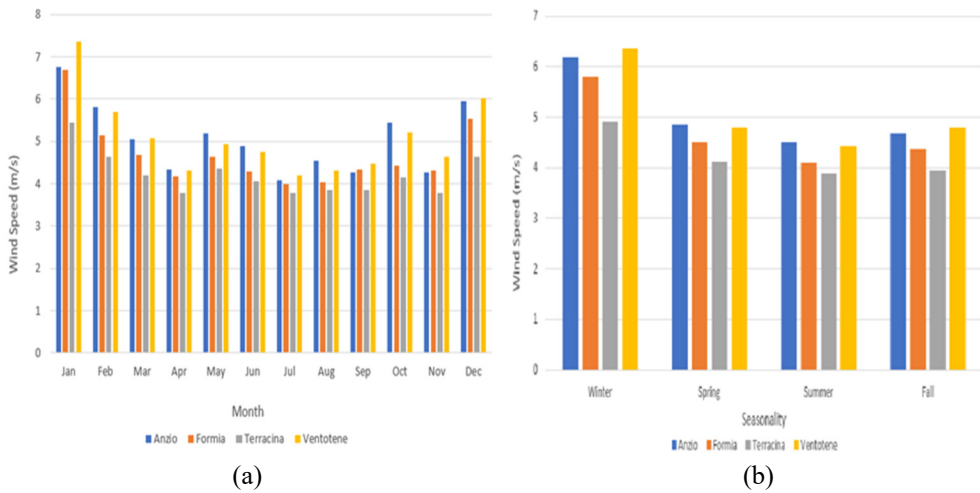


Figure 2: (a) Monthly; and (b) Seasonality wind speed using hourly time series from 2020 to 2021.

4.2 Long term solar radiation assessment and mapping

In the Lazio ports, the highest solar radiation values can observe in the Ventotene port near 3.169 W m^{-2} . The Anzio and the Terracina port with solar radiation of more than 3.2 and 3 W m^{-2} (between 2011 to 2021), also several Formia port areas have solar radiation of about 2.5 W m^{-2} in the same period (Fig. 3). Fig. 3 shows solar radiation analyzed using the MERRA-2 reanalysis dataset for the four case studies of Lazio. Fig. 4(a) and (b) shows a monthly and seasonality solar radiation using hourly time series from 2020 to 2021 the four Lazio ports.

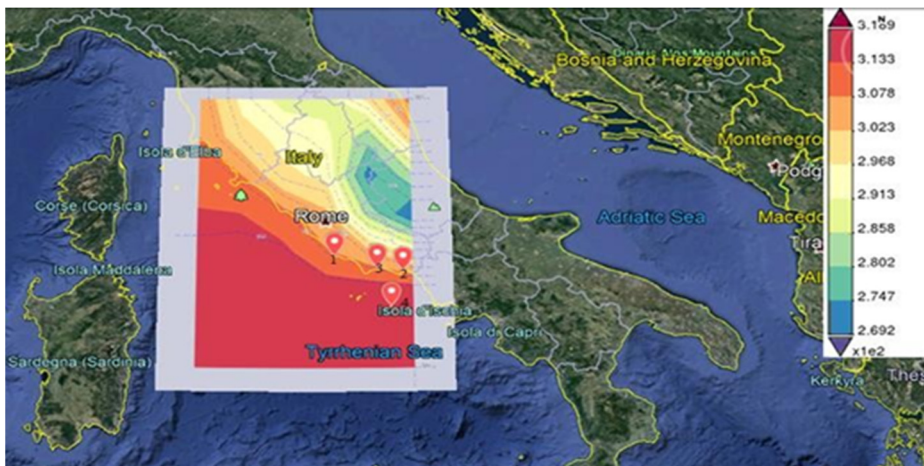


Figure 3: Surface absorbed longwave radiation assuming clear sky monthly 0.5×0.625 deg. W m^{-2} from May 2011 to March 2021. Region 10.0707E, 39.6929N, 14.3334E, 43.648N.

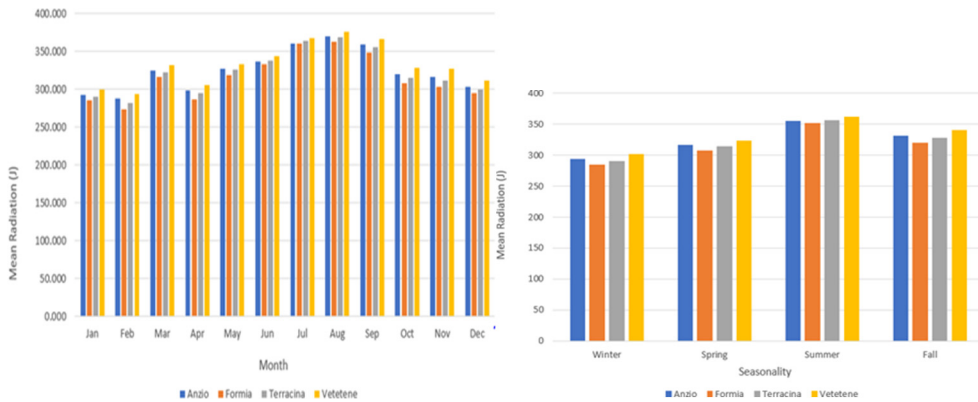


Figure 4: Monthly and seasonality solar radiation using hourly time series from 2020 to 2021.

4.3 Statistical analysis of wind speed

In the first step, to present and compare the wind characteristics at each particular ports, we present the stochastic behaviour of the recorded wind speed in Fig. 5.

Three different time resolutions (hourly, daily and monthly) are applied to compare the detailed relationship among the four ports and can be seen in Fig. 5(a)–(c), respectively. From Fig. 5(c), the principal observation is that the general models of wind speed in four ports are relatively comparable. However, as the details of wind direction data are not available and have a direct influence on the performance of the forecasting model, it is hard to compare the wind pattern in these locations. The frequency, mean, and standard deviation of 1-year wind speed values calculated for the available time-series data for four ports, and also are exhibited in Fig. 6(a)–(d). Furthermore, the probability distribution fitting is applied in order to fit a normal probability distribution to the wind speed time series regarding the repeated measurement of the variable wind data. The distribution fitting aims to predict the probability or the occurrence frequency of the wind speed magnitude in a certain interval [8]. It can be seen that the minimum and maximum average wind speed recorded is related to Terracina and Ventotene port at 4.175 and 5.065 (m/s), respectively.

In the following, we performed the correlation coefficient test that is an indicator of the linear relationship strength between both various variables. Where this coefficient is greater than zero designates a positive relationship between two applied time-series data. On the other hand, a rate that is less than zero implies an inverse or negative relationship. Conclusively, when the correlation coefficient is equal to zero, it shows no relationship between the two variables.

Fig. 7 shows the scatter, histogram and correlation coefficients of each pair location. The autocorrelation function of the measured wind data at four ports can be seen in Fig. 8. Interestingly, in all locations, there is the same pattern of the autocorrelation function. It shows that the wind speeds are strongly autocorrelated at the initial 15 lags. In the following, we can observe that less fully autocorrelated are at longer lags, and in most cases, the autocorrelation tends to the negative values. Another important point is that there is almost no daily pattern among the observed wind speed data of the ports.

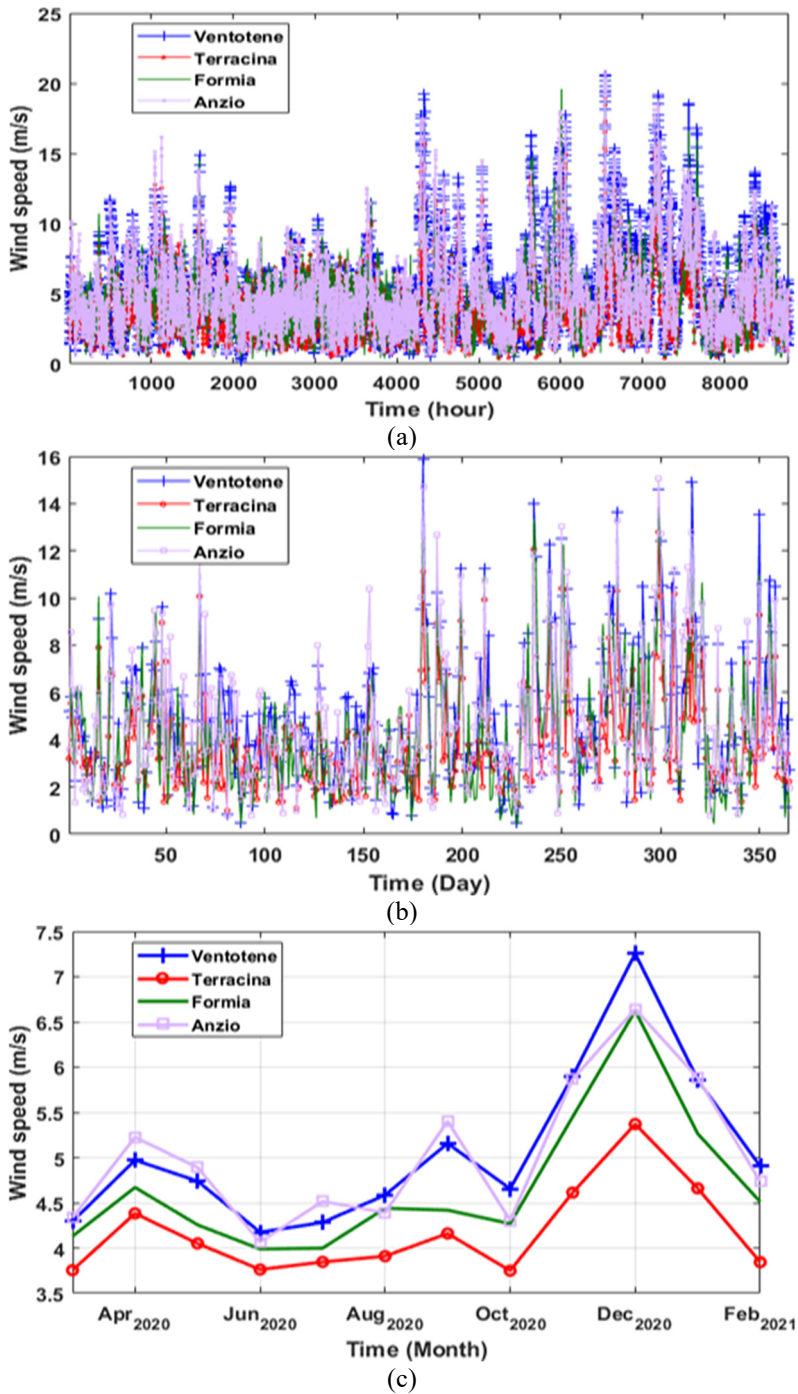


Figure 5: Sequential wind centre, Sapienza Lazio ports: Ventotene, Terracina, Formia and Anzio. (a) Recorded per hour; (b) Recorded per day; and (c) Recorded per month.



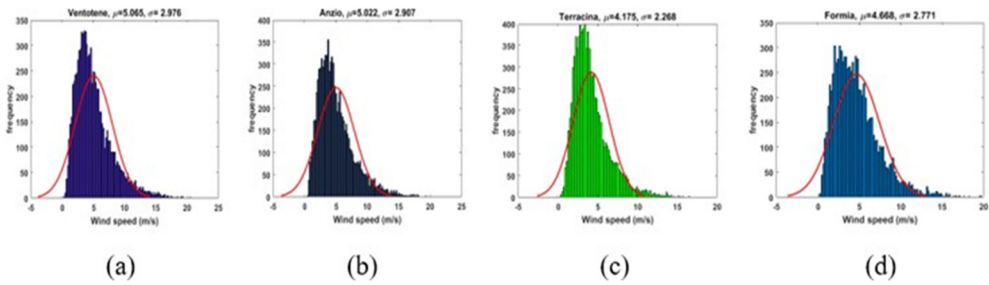


Figure 6: The histogram with a normal distribution fit of the wind speed data for Lazio ports. (a) Ventotene; (b) Anzio; (c) Terracina; and (d) Formia. The estimated fittest normal distribution parameters: mean and variance are shown per each port.

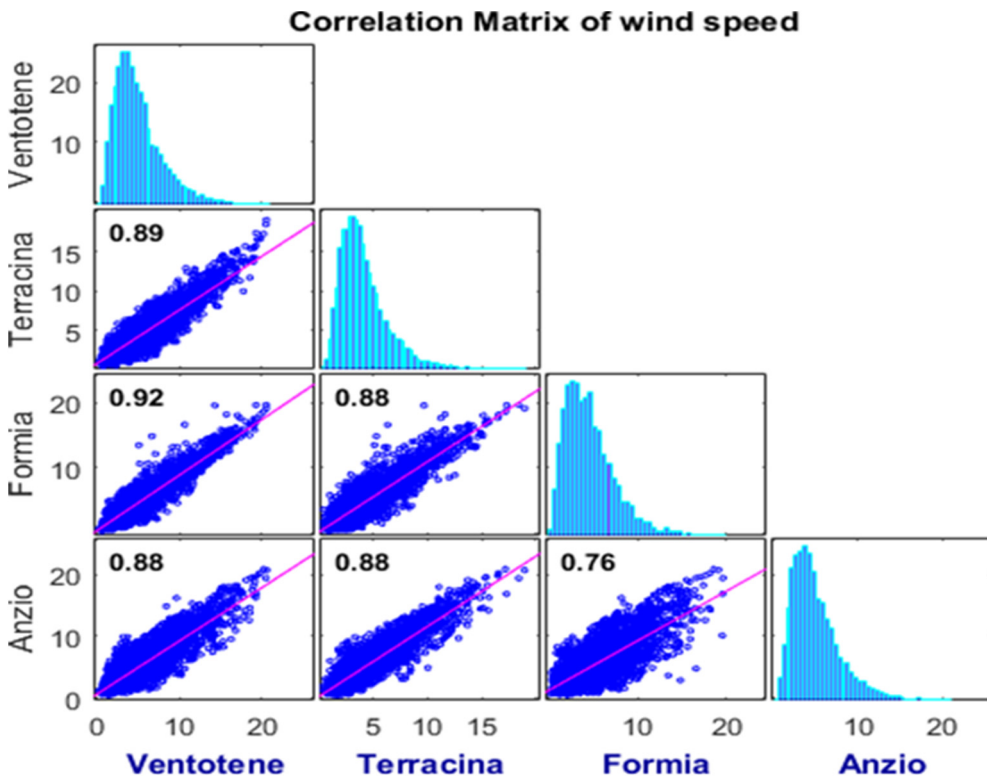


Figure 7: The Pearson's linear correlation coefficients of pairs ports wind speed data are depicted using scatter plots of variable pairs (Ventotene, Anzio, Terracina, and Formia) in the off diagonal. The slopes of the lines in the scatter plots notify the represented correlation coefficients

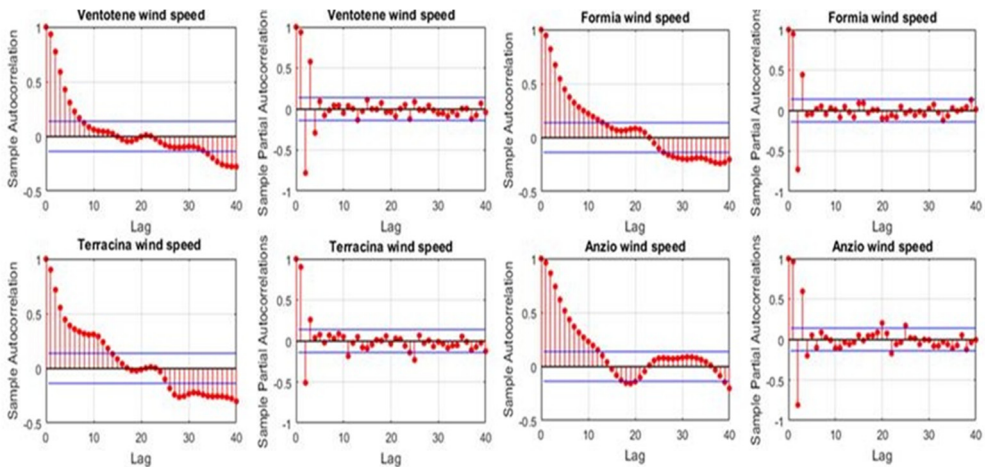


Figure 8: The sample autocorrelation function (ACF) and partial autocorrelation of the univariate, stochastic wind speed time series with confidence bounds for four ports (Ventotene, Anzio, Terracina, and Formia).

5 CONCLUSIONS

In recent years, due to the rapid growth of science and technology on RESs analysis in ports, there are still significant research gaps that need to be addressed in future research. RESs analysis is one of the hot topics of research that advances existing technology directly affecting future research prospects. Investing and developing RESs is a big project, and such investments require careful statistical and economic analysis. In this case, next-generation ports use automation, power and intelligent energy management systems. It is important to note that further research in the early stages must be of high data quality to succeed in the analysis. Managing sustainable energy development using RESs is an emerging issue for ports.

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