

Lecture Notes in Networks and Systems 379

Manuel Ignacio Ayala Chauvin
Miguel Botto-Tobar
Angela Díaz Cadena
Sergio Montes León *Editors*

Sustainability, Energy and City

Proceedings of CSECity'21



Springer

Lecture Notes in Networks and Systems

Volume 379

Series Editor

Janusz Kacprzyk, Systems Research Institute, Polish Academy of Sciences,
Warsaw, Poland

Advisory Editors

Fernando Gomide, Department of Computer Engineering and Automation—DCA,
School of Electrical and Computer Engineering—FEEC, University of Campinas—
UNICAMP, São Paulo, Brazil

Okyay Kaynak, Department of Electrical and Electronic Engineering,
Bogazici University, Istanbul, Turkey

Derong Liu, Department of Electrical and Computer Engineering, University
of Illinois at Chicago, Chicago, USA

Institute of Automation, Chinese Academy of Sciences, Beijing, China

Witold Pedrycz, Department of Electrical and Computer Engineering, University of
Alberta, Alberta, Canada

Systems Research Institute, Polish Academy of Sciences, Warsaw, Poland

Marios M. Polycarpou, Department of Electrical and Computer Engineering,
KIOS Research Center for Intelligent Systems and Networks, University of Cyprus,
Nicosia, Cyprus

Imre J. Rudas, Óbuda University, Budapest, Hungary

Jun Wang, Department of Computer Science, City University of Hong Kong,
Kowloon, Hong Kong

The series “Lecture Notes in Networks and Systems” publishes the latest developments in Networks and Systems—quickly, informally and with high quality. Original research reported in proceedings and post-proceedings represents the core of LNNS.

Volumes published in LNNS embrace all aspects and subfields of, as well as new challenges in, Networks and Systems.

The series contains proceedings and edited volumes in systems and networks, spanning the areas of Cyber-Physical Systems, Autonomous Systems, Sensor Networks, Control Systems, Energy Systems, Automotive Systems, Biological Systems, Vehicular Networking and Connected Vehicles, Aerospace Systems, Automation, Manufacturing, Smart Grids, Nonlinear Systems, Power Systems, Robotics, Social Systems, Economic Systems and other. Of particular value to both the contributors and the readership are the short publication timeframe and the world-wide distribution and exposure which enable both a wide and rapid dissemination of research output.

The series covers the theory, applications, and perspectives on the state of the art and future developments relevant to systems and networks, decision making, control, complex processes and related areas, as embedded in the fields of interdisciplinary and applied sciences, engineering, computer science, physics, economics, social, and life sciences, as well as the paradigms and methodologies behind them.

Indexed by SCOPUS, INSPEC, WTI Frankfurt eG, zbMATH, SCImago.

All books published in the series are submitted for consideration in Web of Science.

More information about this series at <https://link.springer.com/bookseries/15179>


Manuel Ignacio Ayala Chauvin ·
Miguel Botto-Tobar · Angela Díaz Cadena ·
Sergio Montes León
Editors


Sustainability, Energy and City

Proceedings of CSECity'21

Editors

Manuel Ignacio Ayala Chauvin
Universidad Tecnológica Indoamérica
Ambato, Ecuador

Angela Díaz Cadena 
Universidad de Guayaquil
Guayaquil, Ecuador

Miguel Botto-Tobar 
Eindhoven University of Technology
Eindhoven, Noord-Brabant, The Netherlands

Sergio Montes León 
Universidad de las Fuerzas Armadas (ESPE)
Quito, Ecuador

ISSN 2367-3370

ISSN 2367-3389 (electronic)

Lecture Notes in Networks and Systems

ISBN 978-3-030-94261-8

ISBN 978-3-030-94262-5 (eBook)

<https://doi.org/10.1007/978-3-030-94262-5>

© The Editor(s) (if applicable) and The Author(s), under exclusive license
to Springer Nature Switzerland AG 2022

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

The 1st Congress in Sustainability, Energy and City (CSECity'21) was held at Universidad Tecnológica Indoamérica, in Ambato—Ecuador during June 28–29, 2021, and it will be organized and supported by GDEON. CSECity'21 will bring together experts in sustainability, urbanism, energy and industry. This multidisciplinary group of researchers will allow the transfer of knowledge between academic institutions, raise research and analyze how intermediate cities and industries are likely to change and adapt in the coming months and years in a sustainable way. Presenting high-quality, peer-reviewed papers, the book discusses the following topics:

- Energy sustainability
- Information and knowledge management
- Information technologies.
- Innovation, technology and society
- Software and systems modeling
- Software systems, architectures, applications and tools
- Sustainable energy and the city

CSECity'21 received 142 submissions written in English by 710 authors coming from 15 different countries. All these papers were peer-reviewed by the CSECity'21 Program Committee consisting of 107 high-quality researchers. To assure a high-quality and thoughtful review process, we assigned each paper at least three reviewers. Based on the peer reviews, 17 full papers were accepted, resulting in an 12% acceptance rate, which was within our goal of less than 40%.

We would like to express our sincere gratitude to the invited speakers for their inspirational talks, to the authors for submitting their work to this conference and the reviewers for sharing their experience during the selection process.

June 2021

Ignacio Ayala Chauvin
Miguel Botto- Tobar
Ángela Díaz Cadena
Sergio Montes León

Organization

General Chairs

Ignacio Ayala Chauvin

Universidad Tecnológica Indoamerica, Ambato,
Ecuador

Organizing Committee

Ignacio Ayala Chauvin

Universidad Tecnológica Indoamerica, Ambato,
Ecuador

Miguel Botto-Tobar

Eindhoven University of Technology,
The Netherlands

Publication Chair

Miguel Botto-Tobar

Eindhoven University of Technology,
The Netherlands

Program Committee

Ken Yocom

Department Chair and Associate Professor in the
Department of Landscape Architecture, USA

Agustín Llorente

Department of Electronics and Communications
Engineering, Spain

Alejandro Egüez

Visiting Researcher at Umeå School of Business,
Economics and Statistics (USBE) Units:
Economics, USA

Carlos Medrano

Department of Electronics and Communications
Engineering, Spain

Acampa Giovanna

Kore University of Enna, Italy

Paolo Blecich

Senior Assistant/Postdoctoral Fellow, Croatia

Antonio Abreu	Professor (Associate), Department of Mechanical Engineering, Instituto Politécnico de Lisboa, Portugal
Azhar Abbas	Assistant Professor (Institute of Agricultural and Resource Economics) University of Agriculture Faisalabad: Faisalabad, PK, Pakistan
David Yechiam Aharon	Senior Lecturer at the Faculty of Business Administration, Ono Academic College in Israel, Israel
Elzbieta Antczak	Assistant Professor at the Department of Spatial Econometrics, Faculty of Economics and Sociology, University of Lodz, Poland
Michal Apollo	Assistant Professor (Department of Tourism and Regional Studies), Poland
Mohamed Alwaeli	Department of Technologies and Installations for Waste Management, Silesian University of Technology, Poland
Eduardo Gil	Department of Informatics and Systems Engineering, School of Engineering and Architecture, Universidad de Zaragoza, Spain
Elena del Val	Department of Informatics and Systems Engineering, Universidad de Zaragoza, Spain
Elena Ibarz	Department of Mechanical Engineering, Escuela Universitaria Politécnica de Teruel, Spain
Elliot N. Maltz	Atkinson Graduate School of Management, Willamette University, USA
Fernando Brandão Alvez	Department of Chemical Engineering, Universidad de Porto, Portugal
Guillermo Azuara	Department of Electronics and Communications Engineering, Telematics Engineering Area, Spain
Hassan Azad	School of Architecture, University of Florida, USA
Inma Plaza	Department of Electronics and Communications Engineering, Electronics Engineering Area, Spain
Jesús Gallardo	Department of Informatics and Systems Engineering, Universidad de Zaragoza, Spain
Jesús Lázaro	Signal Theory and Communications Area, School of Engineering and Architecture, Universidad de Zaragoza, Spain
Kaveh Khalilpour	School of Information, Systems and Modelling, University of Technology Sydney, Australia

María Abián	Aragon University Institute of Engineering Research, Universidad de Zaragoza, Spain
Maxim Dulebenets	Civil & Environmental Engineering, FAMU-FSU College of Engineering, USA
Mukaddes Darwish	Department of Civil, Environmental, and Construction Engineering, Texas Tech University, USA
Pedro Ramos	Signal Theory and Communications Area, Escuela Universitaria Politécnica de Teruel, Spain
Özgür Akkoyun	Mining Engineering, Dicle University, Turkey
Stephen M. Wheeler	Department of Human Ecology at U.C. Davis, USA
Raquel Lacuesta	Department of Informatics and Systems Engineering, Universidad de Zaragoza, Spain
Raúl Igual	Department of Electrical Engineering, Electrical Engineering Area, Spain
Mukaddes Darwish	Department of Civil, Environmental, and Construction Engineering, Texas Tech University, USA
Susan Paulson	Center for Latin American Studies, University of Florida, USA
Deb Niemeier	Civil and Environmental Engineering, University of Maryland, USA
Hassan Azad	University of Florida' School of Architecture, USA
Juan Pablo Chauvin	Research Department of the Inter-American Development Bank, USA
Irene Casas	Department: School of History and Social Science, Louisiana Tech University, USA
Ana Cabrera Tobar	Universidad Politécnica de Cataluña, Spain
Elena Blanco	Department of Mechanical Engineering, Universitat Politècnica de Catalunya, Spain
Sònia Llorens	Tecnocampus Enseñanza superior, Spain
Carles Riba Romeva	Centre of Industrial Equipment Design, Universitat Politècnica de Catalunya, 08028 Barcelona, Spain
Genís Riba Sanmartí	Centre de Disseny d'Equips Industrials, Spain
Patricia Borges	Industrial Equipment Design Center of the Universidad Politécnica de Cataluña, Spain
Oriol Travesset	Observatori de la Sostenibilitat d'Andorra, Andorra
Saravana Prakash	Universidad Tecnológica Indoamérica, Ecuador
Juan Carlos Solano	Universidad Nacional de Loja, Ecuador

Miguel Ángel Caraballo Núñez	Universidad Nacional de Loja, Ecuador
Orlys Ernesto Torres Breffe	Universidad de la Habana, Cuba
Holger Benavides	Universidad Técnica Particular de Loja, Ecuador
Esteban Fuente	Universidad Técnica de Ambato, Ecuador
Jorge Maldonado Correa	Universidad Nacional de Loja, Ecuador
Carlos Gordon	Universidad Técnica de Ambato, Ecuador
David Yechiam Aharon	Ono Academic College, Israel
Xiong (Bill) Yu	Case Western Reserve University, USA
José A. Aguado	Universidad de Málaga, Spain
Maria Fernanda León	Universidad Internacional del Ecuador, Ecuador
Ruxandra Stoean	University of Craiova, Romania
Roger Dargaville	Monash University, Australia
Pieter De Wilde	University of Plymouth, UK
Isabel Miño	Karlsruhe Institute of Technology, Germany
Agnieszka Aliska	Warsaw School of Economics, Poland
Luis Gutierrez	Universidad Adolfo Ibañez, Chile
Yasemin Didem Aktas	University College London, UK
Victor Andaluz	Universidad de las Fuerzas Armadas ESPE, Ecuador
Carlos Naranjo	School of Mechanical Engineering, Ecuador
Diego Vaca	Georgia Institute of Technology, USA
Richard Watkins	Lecturer, UK
Christopher Jensen	Lecturer in Construction Management, Melbourne School of Design, Australia
Yahua Bi	Pusan National University, South Korea
Robert Brecha	https://www.energy-transition-hub.org/ , USA
Beatriz Rivela	inViable, Environmental Services, Madrid, Spain
Fernando Andrade	MES, Climate Change Technical Specialist, Ecuador
Diego Cabezas	Regional Marketing Director, Russia
Francesc Peremiquel	Universidad Politécnica de Cataluña, Spain
Andrea Ordóñez León	Universidad Internacional del Ecuador, Ecuador
Gregorio Ridaura	Universidad Politécnica de Cataluña, Spain
Renata Priote	Universidad Paulista (UNIP), Brasil
Antonio di Campli	Politecnico de Torino, Italy
Sonia Cueva Ortiz	Universidad Tecnológica Indoamérica, Ecuador
Ignacio Ayala Chauvin	Universidad Tecnológica Indoamérica, Ecuador

Organizing Institutions






Contents

Statistical Analysis of Villonaco Wind Farm Annual Energy Production	1
Jorge Maldonado-Correa, Juan Solano, Marco Rojas, José Cuenca, and Marcelo Valdiviezo-Condolo	
Comparison of the Operating Parameters of an Internal Combustion Engine During Cold Start, by Applying Two Ecuadorian Fuels of Different Octane Numbers	14
Jorge Lema, Gerardo Arteaga, and Belén Ruales	
Hybrid Deep Learning Architecture Approach for Photovoltaic Power Plant Output Prediction	26
Myriam Cumbajin, Ruxandra Stoean, José Aguado, and Gonzalo Joya	
Automotive Crankcase Design Using Biodegradable Materials	38
Juan Cruz, Blanca Topon-Visarrea, and Lorena Caceres	
Use of Battery Energy Storage Systems to Enhance the Frequency Stability of an Islanded Microgrid Based on Hybrid Photovoltaic-Diesel Generation	48
Iván Pazmiño, Danny Ochoa, Edwin Ponce Minaya, and Hugo Pico Mera	
Guiding Principles of the Contemporary City	59
Sonia Cueva Ortiz and Amadeu Casals	
Understanding the Relation with Nature in the City: Biodiversity Knowledge and Environmental Awareness in a Periurban Area of Quito, Ecuador	70
Belén Morales-Espín, Flor Ortiz, Enmily Sánchez-Lara, Mónica Páez-Vacas, Kevin Muñoz-Lara, Erick Bravo-Vera, Daniela Franco-Mena, Natasha Baer, Nora H. Oleas, and Ibon Tobes	
Portable Electromagnetic Energy Harvesting System	81
Julio Cuji, Luis Mendoza, Giovanni Brito, and Carlos Gordón	

Design of an Equipment for the Treatment of Domestic Greywater	92
Pablo Ron-Valenzuela and Esteban Mauricio Fuentes Pérez	
Study of the Influence of Anthropogenic Sources on the Water Quality of the Ambato River, Tungurahua - Ecuador. A Growing Environmental Problem	101
Lander Vinicio Pérez Aldas, Scarlet Nathaly Guachamin Zambrano, Liliana Patricia Acurio Arcos, Dolores Robalino Martínez, and Esteban M. Fuentes	
Recommendation System Applied to Academic Resources for the Computer Networks Subject of the Software Degree	111
Alfonso A. Guijarro-Rodríguez, Judith E. Flores-Rivera, Steven F. Castillo-Ponce, and Lucrecia E. Sánchez-Holguín	
Motivation and Job Performance: Human Capital as a Key Factor for Organizational Success	123
Emanuel Bohórquez, William Caiche, Verónica Benavides, and Arturo Benavides	
Assessing the Needs of an Innovation Resource to Promote the Touristic Sector of a Small Andean City. Riobamba, Ecuador.	134
Luis Quevedo, Silvia Aldaz, Héctor Pacheco, and Danilo Quintana	
Effects of Virtual Education on Lateral Mastery, Auditory Sequential Memory and Rhythm During the Literacy Process.	146
Rocío Duque, Gladys Recalde, Nuria Galárraga, Santiago Ponce, and Alejandra Portilla	
Interactive Software for the Learning of Mathematics in Elementary School Students in the Province of Tungurahua.	156
Paulina Sánchez, Ligia Jácome, Cinthya Sancho, and Richard Sánchez	
ICT and Interactive Multimedia in Teaching 3D Sculpting Design	171
Richard Patricio Sánchez Sánchez, Diana Gabriela Flores Carrillo, María Cristina Paredes Morales, and Paulina Elizabeth Sánchez Sánchez	
Management Tools for Process Mapping and Modeling in Assembly Industry	185
Rodrigo Arcentales-Carrion, Eliezer Colina Morles, Dolores Sucozhanay, Regina Duran, and Lorena Siguenza-Guzman	
Author Index.	199



Statistical Analysis of Villonaco Wind Farm Annual Energy Production

Jorge Maldonado-Correa^(✉) , Juan Solano , Marco Rojas,
José Cuenca, and Marcelo Valdiviezo-Condolo 

Facultad de Energía, Universidad Nacional de Loja, Av. Pío Jaramillo Alvarado,
La Argelia, Loja 110150, Ecuador
jorge.maldonado@unl.edu.ec

Abstract. The Villonaco Wind Farm is located between coordinates 693030 E 9558392 N and 693526 E 9556476 N in the province of Loja in southern Ecuador. It is the first wind farm in continental Ecuador, with a capacity of 16.5 MW and a location of roughly 2720 m above sea level in rugged terrain, which is especially relevant compared to others wind farms in the global context. This paper presents a statistical analysis of the Annual Energy Production of the Villonaco Wind Farm in the period from 2014 to 2018. In this analysis, actual wind speed and active power values were used, outliers and missing data were identified, and a new methodology was used to complete the missing data. With the complete dataset, an analysis of variance was performed to compare the means of the annual energy production. The results obtained in this study show an error of $\pm 4\%$ compared to the information available on the website of the Agency for Regulation and Control of Energy and Non-Renewable Natural Resources of Ecuador.

Keywords: Statistical analysis · Annual Energy Production · Villonaco Wind Farm

1 Introduction

Global warming has prompted scientists to look for new energy sources, and renewable natural resources are being promoted as a viable alternative to traditional energy generation from fossil waste fuels.

Among renewable energy sources, wind energy has demonstrated outstanding characteristics that have attracted the attention of the scientific community. With an average annual growth rate of 30% over the last two decades, the wind energy has been dubbed “the world’s fastest-growing renewable energy source” [1].

In this context, the wind industry has experienced in recent years a dizzying growth worldwide, as stated by the Global Wind Energy Council (GWEC) in its latest annual report published, which shows that the installed wind power in the world at the end of 2017 reached 546.38 GW, and by the end of 2019 it will increase to approximately 651 GW [2].

For wind farm investors and operators, it is of great importance to know precisely what the energy yield of the wind farm is. In this respect, it is important to mention that

the Annual Energy Production (AEP) of a wind farm is influenced by a variety of factors, including the availability of wind resources, the number and capacity of wind turbines installed, and the structure and design of the wind farm, among others [3].

This paper presents a statistical analysis of the Annual Energy Production of the Villonaco Wind Farm (VWF) for the period from 2014 to 2018. Descriptive and inferential statistical techniques were used for the data processing, and the MATLAB toolbox Statistics and Machine Learning was used for the analysis of variance.

The structure of this document is as follows: the second section of this article is dedicated to the materials and methods used in the research, the methodological procedure to complement the missing data (*NaN*) is described here, in the third section the results obtained are presented and discussed, and finally, in the fourth section the conclusions are presented.

2 Material and Methods

For this study, wind speed and active power data are available from the VWF, which have been provided by the public company (GENSUR-EP) to the authors of this study using a confidentiality agreement. In order to complete the missing values, the authors propose a methodology based on the following criteria:

i) *Spatial interpolation*

The procedure is based on the method called *Inverse distance weighting*, which is an approach that uses a linear weighted average of data from known points to approximate a value at an unknown place [4].

The reference anemometric station with the required data should be as close as possible to the study site (wind turbine with missing data). The method applies to a site with similar physical-geographical characteristics and is calculated by the following equation:

$$z(x) = \sum_{i=1}^n (\lambda_i \cdot z_i) \quad (1)$$

where:

$z(x)$ is the value of the wind speed at the point to be interpolated

z_i is the value of the wind speed at the known point i

λ_i is the weight of station i

n is the number of stations considered

ii) *Time interpolation*

It consists of finding the average wind speed value employing Eq. 2, using the available wind speed data of the immediate next years in the same time window.

$$\bar{x} = \frac{\sum_{i=1}^n x_i}{n} \quad (2)$$

where:

\bar{x} is the mean wind speed value

x_i is the value of the wind speed for the known station i

Missing wind speed data can be replaced based on the above-mentioned criteria by applying the flowchart of Fig. 1.

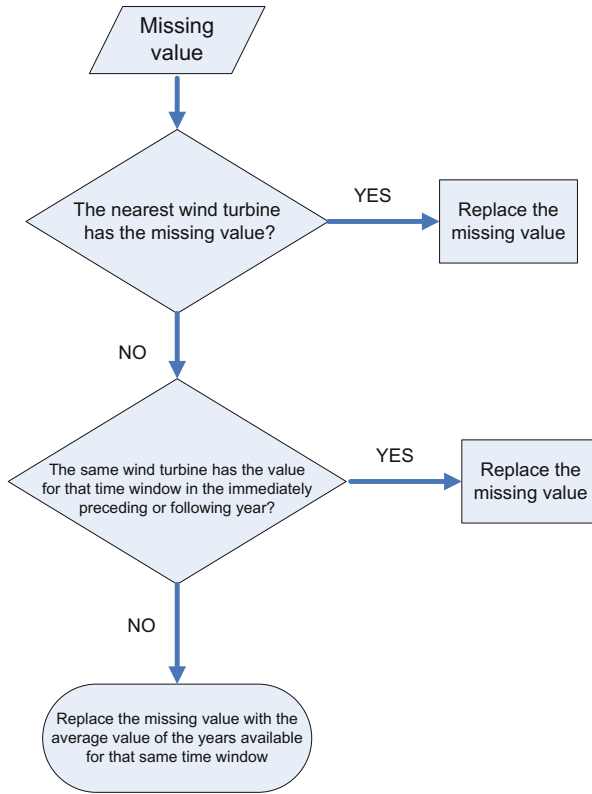


Fig. 1. Flow chart for filling in missing data.

2.1 Study Area

Since 2013, nine hydroelectric power plants have been built and commissioned in Ecuador, to change the country's energy matrix and achieve energy sovereignty. The hydroelectric power plants are: Coca Codo Sinclair, Delsitanisagua, Minas San Francisco, Manduriacu, Mazar Dudas, Quijos, Sopladora and Toachi Pilatón, which represent an installed capacity of 2589.5 MW, and the Villonaco Wind Farm [5].

The VWF started its operations in 2013 and is located in a mountainous area of the province of Loja in the southern region of Ecuador, between UTM coordinates 693030 E and 9556476 N. (Fig. 2). The VWF has an installed capacity of 16.5 MW, is located in the mountainous region of complex orography at 2720 m.a.s.l., in an area with average annual wind speeds of more than 10.5 m/s [6].

The VWF is composed of 11 wind turbines of 1.5 MW nominal unit power, GOLDWIND, type GW70, class “S”, equipped with *Direct Drive technology* and a permanent magnet synchronous generator [7].



Fig. 2. Panoramic view of Villonaco Wind Farm [8].

The Electric Public Company Corporation of Ecuador (CELEC-EP), is the entity in charge of the operation of the VWF through their business unit called GENSUR-EP [8].

2.2 Description of the SCADA Data Used

Most modern wind turbines record more than 200 variables in 5 to 10 min intervals using their SCADA system (Supervisory Control and Data Acquisition), which generates a wealth of historical data [9].

According to [10], the SCADA system records some monitoring variables related to the parameters: wind, energy conversion and temperature.

The data used in this study were obtained from the VWF SCADA system and correspond to the wind speed and active power variables recorded during the years 2014–2018 with a sampling frequency of 10 min. Table 1 shows the structure of the dataset used for wind turbine 1.

Table 1. The data format used in the study.

Data	Time	Wind speed (m/s)	Power active (kW)
01-01-2014	00:00	3.78	33.72
01-01-2014	00:10	3.13	15.59
01-01-2014	00:20	4.12	51.24
...
12-31-2018	23:50	16.38	1562.32

2.3 Data Analysis

Since not all speed data were available, the algorithm described in the Materials and Methods section was used to fill in the missing data. Figure 3 (a) shows a colour map indicating the missing wind speed data blocks, both for each wind turbine and for the data collection period. On the other hand, Fig. 3 (b) shows the wind speed colour map with the complete samples of the data set. The missing data represent 9.91% of the total data set.

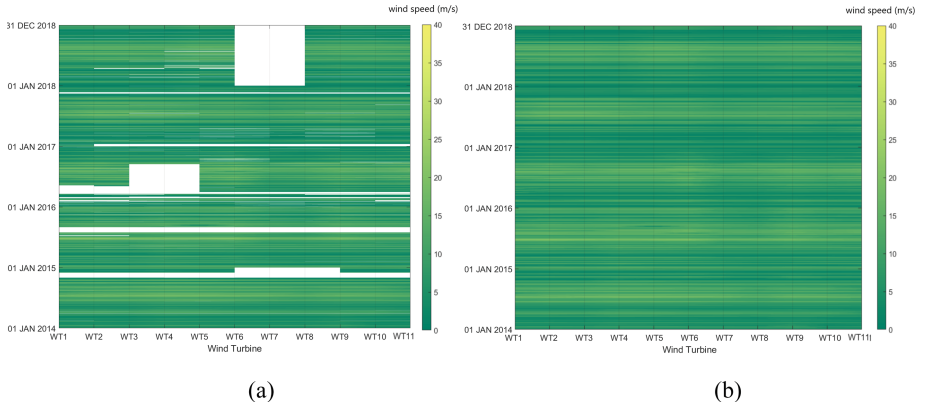


Fig. 3. Matrix of wind speed data at each wind turbine versus data collection period: (a) unfilled data, (b) filled data.

The most important factor in the power generated by a wind turbine is wind speed [11]. The theoretical wind power that can be extracted is stated by Eq. 3.

$$P = \frac{1}{2} \cdot \rho \cdot A \cdot Cp(\lambda, \beta) \cdot v^3 \quad (3)$$

where:

P is theoretical wind power

ρ is air density

A is the area of the wind turbine rotor

$C_p(\lambda, \beta)$ is the power coefficient, indicates the efficiency of a turbine capturing the wind energy; and

v is the wind speed

From the valid data and using Eq. 3, the model shown in Fig. 4 was obtained, whose coefficient of determination $R^2 = 0.9958$ indicates that the model to obtain the dependent variable (power of each wind turbine) is mostly explained by the independent variability of wind speed, as shown in Fig. 5.

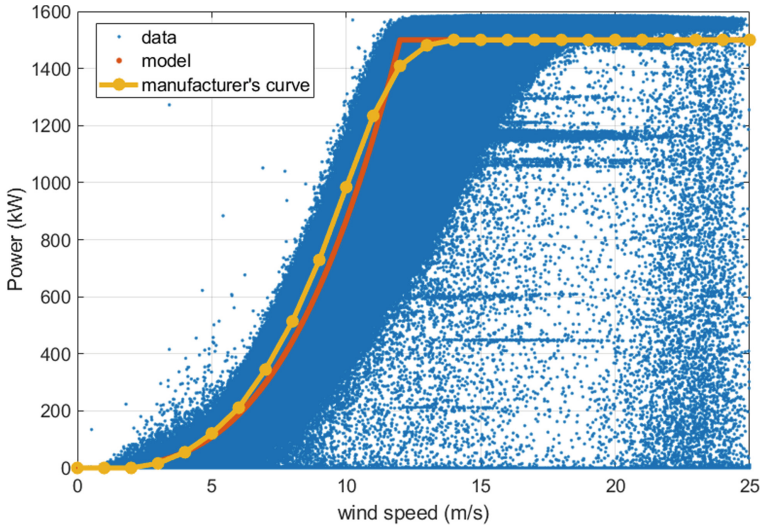


Fig. 4. Wind speed vs. wind power (blue dots). Raw data (10 min data) was obtained from the eleven wind turbines, from 01 January 2014 to 31 December 2018. The model obtained (red line) and the manufacturer's curve (yellow dash and dot line) are compared.

As can be seen in Fig. 4, in the slope of the sigmoid curve, the model does not fully fit the curve guaranteed by the manufacturer, mainly because the curve guaranteed by the manufacturer (GOLDWIND) considers a standard air density of 1.22 kg/m^3 and the air density at the project location is 0.89 kg/m^3 .

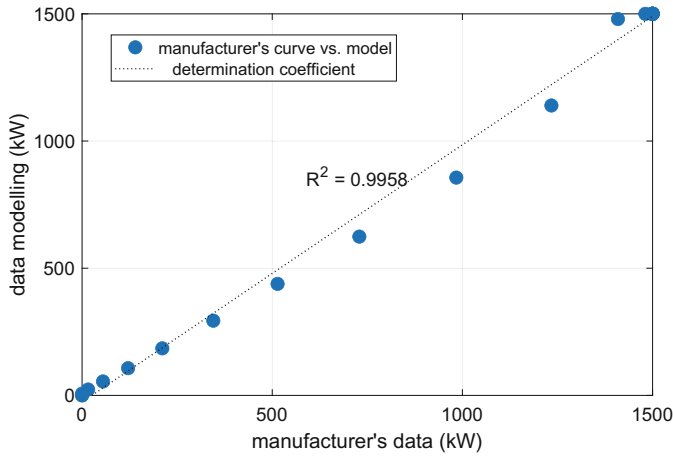


Fig. 5. Coefficient of determination when comparing the manufacturer's curve with the model presented in Eq. 3.

After obtaining 100% wind speed data, the model described in Eq. 3 was used to complete the power data and then calculate the annual energy produced by each wind turbine. Figure 6 shows the ordered pairs (wind speed, power) of each wind turbine after completing the data series.

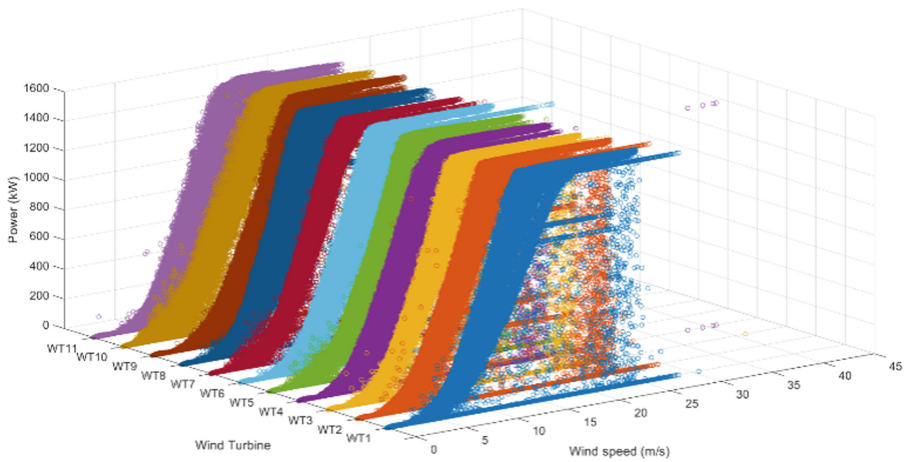


Fig. 6. Ordered pairs plot (wind speed vs. wind power) of each wind turbine.

2.4 Analysis of Variance (ANOVA) to Compare the Annual Average of Energy Production of the VWF

The statistical method of analysis used was “One-way analysis of variance”. To perform this analysis the Matlab Toolbox called Statistics and Machine Learning was used. The purpose of this analysis is to determine whether the annual averages of energy production of each of the wind turbines of the VWF have a common average. In this case, the independent variable is each of the wind turbines and the response variable is the average annual energy production measured between 2014 and 2018.

In this study, ANOVA was used to test the hypothesis that all wind turbines’ annual energy production (E_n) are equal, against the alternative hypothesis that at least one wind turbine has different averages than the others.

$$H_0 : \overline{E_1} = \overline{E_2} = \dots = \overline{E_{11}} \quad (4)$$

The procedure performed in Matlab® is as follows:

i) *Entry of the data is shown in Table 2.*

```
>>energy=[ annual averages of wind turbines] ;
```

Table 2. Annual averages of wind turbines in MWh.

Year	WT1	WT2	WT3	WT4	WT5	WT6
2014	6390.69	7693.93	7777.51	7778.01	7681.31	7507.19
2015	8473.30	9108.61	9211.99	8895.64	8744.44	8931.09
2016	6804.02	7128.88	7395.43	7617.10	7306.70	7100.86
2017	6334.43	6719.87	6689.21	6677.17	6581.42	6621.41
2018	6898.92	7402.10	7295.40	7329.21	7231.50	7051.66
Year	WT7	WT8	WT9	WT10	WT11	
2014	7270.20	6976.40	7044.45	6455.15	5980.07	
2015	8375.47	8403.55	8513.77	7845.52	7613.24	
2016	6491.83	6623.28	6826.68	6303.51	5964.94	
2017	6198.72	6018.76	6056.70	5543.53	5214.57	
2018	6800.16	6495.85	6548.20	5994.21	5599.31	

ii) *Obtain the standard ANOVA table and the box plot of data per wind turbine.*

```
>>[ p,tbl,stats] = anoval (energy) ;
```

Table 3. ANOVA analysis results.

Source	SS	df	MS	F	p-value
Columns	1.37765e + 07	10	1377654.2	1.77	0.0944
Error	3.41861e + 07	44	776957.4		
Total	4.79627e + 07	54			

3 Results

According to Fig. 7 and the ANOVA (Table 3), the $p\text{-value} = 0.1033$ is obtained, which indicates that the counts of the annual averages of the different wind turbines are approximately equal. Therefore, the null hypothesis that all annual average energy production of the wind turbines are equal is accepted.

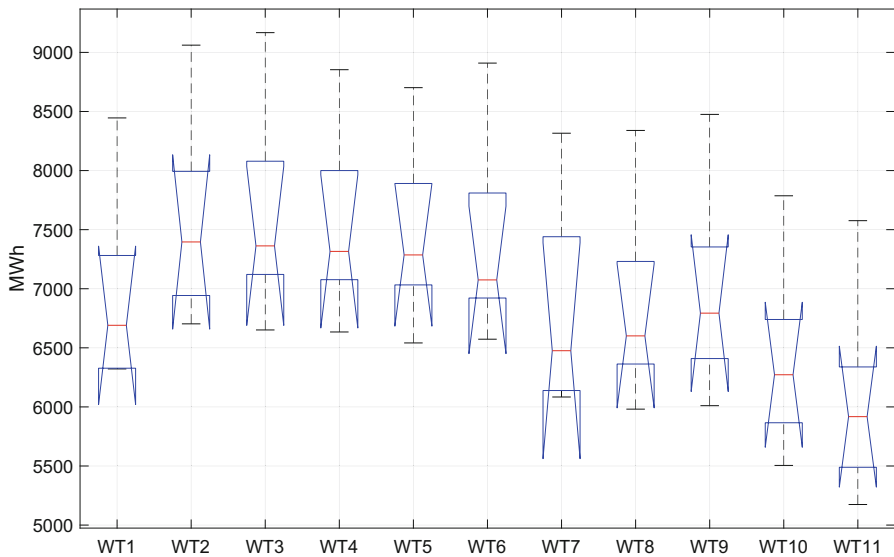
**Fig. 7.** Analysis of variance of the annual averages of each of the wind turbines.

Figure 8 illustrates that no wind turbine has averages significantly different from the rest. The coloured bars show the comparison interval for the average of each of the groups, and as can be seen, no bars overlap with each other. Therefore, all annual averages of energy production are not significantly different from each other.