# KM3NeT INFRADEV – H2020 – 739560

| | |
|---|---|
| **Report on the techno-economic study** | |
| **KM3NeT INFRADEV DELIVERABLE: 10.03** | |
| Document identifier: | KM3NeT-INFRADEV-WP10-D10.03 |
| Date: | 24/07/2019 |
| Work package: | WP10 |
| Lead partner: | NCSR-D |
| Document status: | Final |
| Dissemination level: | Public |
| Document link: | |


## Abstract

The document presents a techno-economic study for the two out of three installation sites of KM3NeT carbon neutral facilities using renewable energy technologies. It reports initially the theoretical background and the data that this study is based on and it analyses the methodologies that are used to obtain the results. Specifically, it uses the levelized cost of energy (LCOE) as a metric to express the techno economic prospects of various renewable energy technologies. The results have shown that the cost per generated kWh drops significantly as the system's lifetime is prolonged and that the LCOE value can change considerably for a wind turbine by changing the wind speed of the site even for the same scenario and system lifetime. Moreover, most of the systems in Capo Passero have lower LCOE values from the respective systems in Kalamata even for the cases where the life cycle cost is higher in Italy than Greece. The large-scale horizontal axis wind turbine LCOE range is € 0.045-0.070/kWh for Kalamata and € 0.034-0.052/kWh for Capo Passero (S2 case) while for PV plants it is € 0.030-0.046/kWh in Kalamata and € 0.027-0.041/kWh in Capo Passero.

# I. DELIVERY SLIP

| | Name | Partner/WP | Date |
|---|---|---|---|
| Author(s) | T. Georgitsioti, with contributions from G. Androulakis, C. Bagatelas, K.Pikounis | NCSR-D | 24/07/2019 |
| Reviewed by | C. Markou | NCSR-D | 29/07/2019 |
| Approved by | C. Markou | NCSR-D | 29/07/2019 |
| Reviewed by | S. Razzaque | KM3NeT / IB | 15/8/2019 |
| Approved by | S. Razzaque | KM3NeT / IB | 15/8/2019 |
| Endorsed by | KM3NeT IB | | 28/8/2019 |

# II. DOCUMENT LOG

| Issue | Date | Comment | Author/Partner |
|---|---|---|---|
| 1 | 29/07/2019 | Draft sent to IB reviewer, S. Razzaque | T. Georgitsioti/NCSR-D |
| 2 | 15/8/2019 | Comments received from IB reviewer | |
| 3 | 28/8/2019 | IB endorsement | |

# III. APPLICATON AREA

This document is a formal deliverable for the GA of the project, applicable to all members of the KM3NeT INFRADEV project, beneficiaries and third parties, as well as its collaborating projects.

# IV. TERMINOLOGY

A complete project glossary is provided below:

CM-SAF: Climate monitoring satellite application facility
EPW: EnergyPlus weather
GHI: Global horizontal irradiation
GOES: Geostationary operational environmental satellite
HAWT: Horizontal axis wind turbines
HNMS: Hellenic National Meteorological Service
IAM: Incident angle modifier
ISD: Integrated surface hourly database
ISH: Integrated surface hourly
IWEC2: International weather for energy calculations
LCC: Life cycle cost
LCOE: Levelized cost of energy
MPP: Maximum power point
MPPT: Maximum power point tracker
MSG: Meteosat Second Generation
NASA SSE: NASA Surface meteorology and solar energy database
NASA-Power: NASA- Prediction of worldwide energy resource
NCDC: National climatic data center
NCEI: National center for environmental information
NREL: National renewable energy laboratory
O&M: Operation and maintenance
PLC: Programmable Logic Controller
PV: Photovoltaic
PVGIS: Photovoltaic geographical information system
RES: Renewable energy sources
RET: Renewable energy technologies
SAM: System advisor model
STC: Standard test conditions
TMY: Typical meteorological year
VAWT: Vertical axis wind turbines
WECS: Wind energy conversion systems
WP: Work package
WT: Wind turbine

# V. LIST OF FIGURES

# VI. LIST OF TABLES

# VII. PROJECT SUMMARY

KM3NeT is a large Research Infrastructure that will consist of a network of deep-sea neutrino telescopes in the Mediterranean Sea with user ports for Earth and Sea sciences. Following the appearance of KM3NeT 2.0 on the ESFRI roadmap 2016 and in line with the recommendations of the Assessment Expert Group in 2013, the KM3NeT-INFRADEV project addresses the Coordination and Support Actions (CSA) to prepare a legal entity and appropriate services for KM3NeT, thereby providing a sustainable solution for the operation of the research infrastructure during ten (or more) years. The KM3NeT-INFRADEV is funded by the European Commission's Horizon 2020 framework and its objectives comprise, amongst others, activities on the preparation for establishing KM3NeT as a Zero Carbon Footprint research infrastructure (work package 10).

# VIII. EXECUTIVE SUMMARY

This report presents the techno-economic study for the two out of three installation sites of KM3NeT carbon neutral facilities using renewable energy technologies (RET). These sites are in the city of Kalamata, Greece and in the town of Capo Passero, Italy. The reason why the third site of KM3NeT was excluded from this techno-economic study is referred to the first delivered report of work package 10 titled “Report on contacts/discussions with power companies/local authorities/potential partners”. Moreover, the first report covers the subjects of various renewable energy generation technologies, the energy market in each of the three hosting countries and the possible synergies and collaborations that can be established for the installation of the RET systems. This deliverable, following the concluding points of the first, starts by providing an overview of the available weather databases and simulation tools. Continuing, it analyses the weather resources of the sites. Then, it presents the companies and the available products for the chosen renewable energy technologies (Solar photovoltaic and Wind energy conversion systems). After selecting the RET systems, a study is conducted for the technical and economic evaluation of their performance. More specifically, through the various types of the RET systems’ installation capacity, technical characteristics and weather data, the report examines and analyses the first year’s energy yield of the proposed configurations. A sensitivity analysis is conducted for the Wind energy conversion systems as they include the highest uncertainty in their energy yield prediction based on the acquired weather data of this study. Additionally, the lifetime energy yield of the systems is calculated incorporating a degradation rate for the systems’ degradation mechanisms. Moreover, the background for the economic assessment of the RET systems is analysed and their evaluation is made by using the levelized cost of energy (LCOE) as a metric. The LCOE, in this study, expresses the average cost of the systems' generated energy during a certain period of time. Hence, it combines the technical with the economic performance of the systems during this period. Finally, considering the whole analysis, it is recommended that the main RET for Kalamata area will be a fixed mounted grid-connected PV plant while for the region of Capo Passero is not clear yet whether the main RET will be a grid connected large-scale HAWT or a fixed mounted PV plant.

# Table of Contents

# Chapter 1: Introduction

The shortage of fossil fuels and the effect of climate change created the need for the utilisation of the renewable energy sources (RES). Worldwide, renewable energy technologies (RET) are considered as one of the main contributory factors to the reduction of the greenhouse gas emissions and a solution for satisfying the world's constantly growing energy demand. As it was mentioned in the first deliverable of the work package 10 (WP10), titled "Report on contacts/discussions with power companies/local authorities/potential partners" [1], one of KM3Net objectives is to feed the energy needed for its research infrastructures from renewable energy technologies. If the specific objective is achieved, it will provide a sustainable and environmentally friendly solution for KM3Net energy requirements while at the same time will promote the renewable energy technologies to the general public as the surplus energy will be supplied to local buildings.

A summary of the main conclusions of the first deliverable and the aim and objectives of this deliverable are presented below. The proposed RET installations for Greece and Italy will depend on the climatic conditions of the site, the economic constrains, the budgeting issues, and the collaboration with the local and/or regional authorities. Moreover, all the proposed systems will be grid-connected and an appropriate agreement in accordance with the policies and laws of each country will be made with the respective energy supplier. Additionally, the KM3Net sites will be connected to the normal electricity grid. Finally, small-scale Photovoltaic (PV) and Wind energy conversion systems (WECS) will be proposed to be installed in urban environment. These systems will cover a small percentage of the total energy needed for the KM3Net infrastructures because the local and/or regional authorities in Greece and Italy own a significant amount of real estate, which can be utilised. This provides two main advantages: 1) the generated energy on site can be directly consumed and reduces the amount of energy taken from the electricity grid, 2) it has been decided that the proposed urban RET installations will be in the form of an infrastructure of high aesthetic value; therefore, it will promote public awareness on the RET and the community's environmental perception.

This report provides a holistic study for the installation of solar PV and WECS in the KM3Net locations. The study for the RET installation is made for two out of the three locations of KM3Net; Kalamata, Greece and Porto de Capo Passero, Sicily. For the site in Toulon, France, it was decided that green energy will be bought from already existed RET installations. However, a reference in the cost of buying green energy in France is included. Despite the fact that the funding for the RET installation is out of the scope of this project and consequently of the WP10, at this point, it should be mentioned that in order for the RET to be installed in Greece and Italy, respective funding bodies must be found and collaboration with the local and/or regional authorities must be established.

## 1.1 Aim and Objectives

The aim of this deliverable is to present the techno-economic assessment of grid-connected PV and Wind energy technologies in the locations of Capo Passero, Italy and Kalamata, Greece.

The objectives are the followings:

- Review the available meteorological databases and simulation software programs
- Analyse the weather data that are used in this analysis for the two locations
- Present the technical characteristics of the systems and their designs
- Predict the annual and long-term energy yield of the systems
- Present the systems' life cycle cost and analyse their long-term finance
- Combine the systems' technical and economic results.

This report is divided in the introductory chapter, five main chapters and the concluding chapter. Chapter 2 presents the available meteorological databases and simulation software packages, which are used for the prediction of the RET systems' annual energy production. In Chapter 3, a comparison between the chosen weather databases is provided in order to demonstrate the uncertainty included in the main input parameter of the simulations. Chapter 4, initially, gives a brief summary on specific products in the RET market and later analyses the chosen products for the proposed RET systems. Chapter 5 presents the wind turbine (WT) annual energy prediction and PV monthly specific production, which have been acquired by the simulations conducted in this study. Moreover, the lifetime energy is calculated for all the systems including their degradation mechanisms. Chapter 6 provides the economical background for the economic analysis in this report and presents the lifecycle costs of the chosen RET systems. Additionally, Chapter 6 uses the levelized cost of energy (LCOE) as a metric to express the results of the techno-economic analysis. Finally, the concluding chapter presents the main conclusions of this study and few recommendations for further work.

# Chapter 2: Weather databases and simulation programs

Generally, in order to estimate accurately the energy production of a RET system, it is important to know the limitations and the uncertainties involved in the data and methods of calculation that are used for this estimation. Hence, this section presents a research for available meteorological databases and simulation programs, as they are the main tools for the RET systems' energy yield prediction.

## 2.1 Meteorological databases overview

As this study engages with both Wind energy conversion systems and Photovoltaic systems, the main climatic factors that affect the performance of these systems are the solar irradiation, the ambient temperature, the atmospheric pressure, the wind speed and wind direction. Some of the most popular meteorological databases and their data characteristics are presented below. In general, these databases acquire data from ground weather stations and/or geostationary satellites. They interpolate the data through algorithms and provide/generate monthly, daily and hourly averaged data, which can also be imported to simulation programs and/or used for the calculation of the systems' annual energy production. Moreover, their data are provided in various formats such as TMY (Typical Meteorological Year) data sets, which are hourly data for one year that combine the data of a long-term recorded period, actual series of data for one specific year and/or averaged long-term data. Finally, the file formats that these data are provided and can be imported to simulation programs also vary (i.e. EPW (EnergyPlus weather) comma-delimited (.epw), TMY3 a comma-delimited (.csv), TMY2,(.tm2), ASCII files etc.). The simulation programs are discussed in the following section (section 2.2) while the databases discussed in this section are: PVGIS [2], RETScreen[3], Meteonorm [4], NASA-Power [5], World Radiation Data Centre [6], Solargis [7], and White box technologies [8].

Meteonorm software provides a global coverage of weather data. It uses around 1700ground measurements and 5 geostationary satellites (interpolation at 4 x 4°grid per satellite)[9].Worldwide solar irradiation data exist from 1981 to 1990 and 1991 to 2010 (specifically for CH, D, and the UK from 1996 to 2015) while from 1961 to 1990 and 2000 to 2009 there are other meteorological parameters [10]. *Commercial*

World Radiation Data Centre (WRDC) provides every month, from 1964 to 1993, average irradiance data from 1195 locations [11]. Nevertheless, in many of these data the average is provided only for a few years and not for the entire period. Moreover, WRDC database does not provide temperature data and since 1993 its radiation data are issued four times per year [6]. *Web-free*

NASA-Power (Prediction of Worldwide Energy Resource) has satellite data from 1984 till 2013 (global coverage) [12]. In the beginning, the Power solar data were created on a 1° (≈111 km) latitude/longitude grid while later they were re-gridded through data replication to a 0.5°latitude, longitude grid cells. The cell has its latitude, longitude value at its lower left corner. The initial Power meteorological data were generated on a 1/2° by 2/3° global grid and they were bi-linearly interpolated by the Power project to a global 0.5° grid. The cell contains its latitude, longitude value at its centre [5]. (Relatively low spatial resolution) *Web-free*

Solargis provides historical time series and TMY solar data for a global coverage. The data are from Geostationary Operational Environmental Satellite (GOES) system starting in 1994 for Europe and Africa and covering the most part of the globe from 1999 till now [7]. They are regularly revised and developed from Meteosat MSG (Meteosat Second Generation) and ERA [11] data. Their spatial resolution is 250 x 250 m [7]. *Commercial*

RETScreen Canadian software supplies a complete database for any site in the world including a global database that contains climatic conditions acquired from ground-based stations and NASA satellite data [3]. This database contains the best available monthly averaged data for each site that come from around 20 sources; mainly from the WRDC and NASA [11]. *Web-free*

White Box Technologies created IWEC2 (International Weather for Energy Calculations) weather files via the ASHRAE Research Project RP-1477, "Development of 3012 Typical Year Weather Files for International Locations" [13]. These files are produced from meteorological reports of weather stations worldwide that are archived in the Integrated Surface Hourly (ISH) database preserved by the National Climatic Data Center (NCDC). For these selected sites, the ISH database includes climate observations that have been obtained on average at least four times per day and include wind speed and direction, sky cover, visibility, ceiling height, dry-bulb temperature, dew-point temperature, atmospheric pressure, liquid precipitation, and present weather. These observations have been recorded for a period of 12 years to 25 years [13].

1. ASHRAE IWEC2 "typical year" weather files concern 3,012 international locations, except the US and Canada.

2. Historical year weather files from 2001 through the current year concern over 10,000 stations worldwide, including more than 2,000 US and 400 Canadian stations (earlier years are also available upon request).

Both data sets are composed from actual recordings that come from official weather stations around the world. The recordings constitute a 25-year archive, the Integrated Surface Hourly Database (ISD), maintained by the (US) National Center for Environmental Information (NCEI). Wide processing with an equivalent scope to the TMY3 files has led to complete weather files with solar radiation, daylight illuminance, and precipitation, in addition to the standard parameters of temperature, humidity, pressure, wind speed and direction, etc. [14]. *Commercial*

PVGIS (Photovoltaic Geographical Information System) provided a map-based record of solar energy resource and evaluation of the electricity generation from photovoltaic systems in Europe, Africa, and South-West Asia. The PVGIS web application has changed throughout the years by improving the accuracy of its data especially for Europe. Currently, PVGIS version 5 contains five different solar databases. Three of them are based on satellite data (CM-SAF, SARAH, and NSRDB) while the other two give solar radiation estimates from Climate Reanalysis Data (ERA-5 and COSMO) [2].

PVGISCM-SAF (Climate Monitoring Satellite Application Facility) option is almost the same to the prior PVGIS version developed for Europe and Africa, as for example, the solar radiation has been calculated with the MAGIC algorithm. The key difference is that the data currently concern the period 2007-2016 while the prior PVGIS version was based on slightly older data, including data from first generation satellites of Meteosat[15]. The coverage has been also partially extended to South America. The data have hourly time resolution and their spatial resolution is 1.5 arc-minutes (≈3 km) [16].

The data set of PVGIS-SARAH has been calculated through SPECMAGIC and has been utilised in the prior PVGIS version in order to supply solar radiation data for Asia. However, the PVGIS-SARAH data set currently covers Europe, Africa and parts of South America. Moreover, its coverage to Asia will contain minor differences because its new version uses for the calculations only the period of 2007-2016 while its older version uses long-term averages that were calculated during the period 1999-2014 [15].

COSMO dataset covers Europe and Northern Africa. The spatial resolution is approximately 6km by using 3 arc-minutes while the data cover the years from 1995 to 2015 despite the fact that in PVGIS only the period 2005-2015 is currently used. In contrast, ERA-5 has global coverage with low spatial resolution (around 30 km) for the period 2010-2016. However, PVGIS 5 has currently released only the data for Europe in order to make the COSMO and ERA-5 databases available with the same extent [17].Finally, NSRDB data have been provided by the National Renewable Energy Laboratory (NREL) as it is a collaboration between the Joint Research Centre of the European Commission and NREL. These data are part of the National Solar Radiation Database. They cover North and South America with hourly time resolution and a spatial resolution of about4.5km. The time period used in PVGIS is 2005-2015 [15]. *Web-free*

After having identified a variety of meteorological databases and their characteristics, it has to be stated that at this point of the study there is no need of buying meteorological data. There are two reasons behind this decision; the first one regards the PV systems while the second the WECS. Regarding the PV systems, the main climatic parameter that influences their energy output prediction is the solar irradiation; PVGIS CM-SAF database is used as the solar database as 1) it is a recently updated database with a relatively high temporal and spatial resolution, 2) it is considered one of the most accurate solar databases for Europe as it has a uniform land coverage and its data have been validated and compared with high-quality solar radiation ground stations, and 3) its data can be imported in numerous simulation software. However, the disadvantages of the PVGIS CM-SAF database are the following: 1) The satellite image varies between 3 to 5 Km, hence, features such as narrow mountain valleys cannot be resolved, 2) the algorithms used to calculate the radiation on ground level may face difficulties to distinguish the difference between snow and clouds, and 3) the calculation of the radiation when the sun is in low altitudes consists a higher uncertainty [17, 18].Regarding the Wind energy conversion systems, the main climatic parameter that influences their energy output prediction is the wind speed. Since the exact location for the installation of wind turbines it is not known yet, an analysis from various meteorological sources takes place in Chapter 3 and concludes to the wind speed data that are considered for the simulations in the two locations.

## 2.2 Simulation software programs overview

The simulation software that is used for the system's annual energy prediction is directly related to the weather data that can be acquired for a specific location. The various software packages read the weather parameters in different formats. The compatibility of the data acquired to the input weather data that a software requires, have to be considered in the selection of the software.

There are many well-developed software programs, which calculate the RET system energy output by taking into account various parameters. The need of this study is to use software that can analyse PV systems and WECS. Hence, four well known software for RET projects' analysis are presented below. These software are: SAM (System advisor model), RETScreen Expert, HOMER and PVsyst. The first one is a free access software; the second is free only in viewer mode while the third and the fourth need a licence to be bought in order to use them. Additionally, the first three evaluate most of the RET systems while the fourth is a photovoltaic specialised software.

HOMER software is used for the design and evaluation of grid-connected and off-grid power systems for remote, stand-alone, and distributed generation applications. The user can evaluate the economic and technical feasibility of numerous technologies and account the insecurity in technology costs, energy resource availability, and other variables through the use of HOMER's optimization and sensitivity analysis algorithms [19].

RETScreen Expert is a comprehensive software platform that gives the ability to professionals and decision-makers to quickly recognise and determine the viability of potential energy efficiency, renewable energy and cogeneration projects. Moreover, it provides the ability to easily measure and confirm the actual and ongoing energy performance of buildings, factories and power plants at a global level [20].

The System Advisor Model (SAM) is a performance and financial model designed to assist individuals of the renewable energy industry in the decision making. SAM is used in performance prediction and cost of energy estimates for grid-connected power projects. These predictions and estimates are based on installation and operating costs and system design parameters that are indicated as inputs to the model. SAM embodies the cost and performance of renewable energy projects using computer models created by NREL, Sandia National Laboratories, the University of Wisconsin, and other organisations. Each performance model constitutes a part of the system while every financial model represents a project's financial structure. In order to describe the performance characteristics of physical equipment in the system and project costs, the models need input data. The description of the renewable energy resource and weather conditions at a project site requires a weather data file. Depending on the kind of system that is modelled, the weather data file can be either chosen from a list included in SAM, downloaded from the Internet, or created by the user.

SAM's performance models conduct hourly calculations of a power system's electric output, producing a set of 8,760 hourly values that constitute the annual electricity production of the system. The system's performance characteristics can be investigated by either observing tables or graphs of the hourly and monthly performance data or by using performance metrics such as the system's total annual output and capacity factor for more general performance evaluations [21].

PVsyst is one of the oldest photovoltaic software, which aims to be used by architects, engineers and researchers. It is known for its detailed PV system design and simulation. Its key features are: Full design of remote PV systems, full design of PV systems connected to the grid, complete database of PV panels, inverters, meteorological data, useful 3D application to simulate near shadings, import of irradiation data such as PVGIS, NASA etc, databases, import of PV modules data from Photon International, economic evaluation and payback, export of calculations to CSV files, and many tools to simulate the behaviour of PV modules and cells according to irradiation, temperature and shadings. Finally, PVsyst offers results through the form of a full report, specific graphs and tables, and data export that can be utilised in other software [22].

Apart from the simulation software presented above, some wind simulation software was examined in order to check if they are going to be used in this study. These software are specialised in wind data analysis and were the followings: WindRose [23], WindFarm [24], Windographer [25], WAsP [26], Qblade [27]. WindRose and Windographer are specialised in wind data analysis. This means that in order to make use of them, high quality data are required, usually acquired by on site measurements. WindFarm is used for the wind farms development potential. It calculates the energy yield of the wind turbines as WAsP, although they both need extensive sets of wind data. Finally, Qblade is mainly used for the wind turbine blade aerodynamic design and simulation. Hence, it is shown that these software are not compatible with the set of data that this study can obtain. Moreover, after a brief research for vertical axis wind turbines (VAWT) simulation software, it was found that none of the well-known wind simulation software is specialised in VAWT simulations. Hence, the VAWT annual energy prediction is acquired by using the standard model used in the simulation software packages for the energy prediction of a wind turbine.

Additionally, an example for computing the energy output of a wind turbine is given below [28]:

generally, the energy output ($E_{out}$) of a wind turbine can be calculated by multiplying the rated energy ($E_{rated}$) of the turbine with its capacity factor ($C_f$) (equation 2.1).

$$E_{out} = C_f \times E_{rated} \tag{2.1}$$

The rated energy is provided in the manufacturer specification's datasheet. Moreover, a formula to calculate the capacity factor is the following:

$$C_f = \frac{\exp[(-\frac{v_i}{c})^k] - \exp[(-\frac{v_r}{c})^k]}{(\frac{v_r}{c})^k - (\frac{v_i}{c})^k} - \exp[(-\frac{v_0}{c})^k] \tag{2.2}$$

where, $v_i$=cut in wind speed, $v_r$= rated wind speed, $v_0$= cut off wind speed, k=shape and c =scale of Weibull parameters at hub height. All the parameters of this formula are known apart from the Weibull parameters, which are dependent on the wind speed distribution. Parameter k is assumed to be independent from height, hence the k value for a wind speed distribution at height $z_1$ will have the same value at height $z_2$. Consequently, if the wind speed distribution is known, k will be constant for any height. On the other hand, c parameter is dependent on the height and it follows the seventh power law.

Seventh power law: $\frac{c_2}{c_1} = (\frac{z_2}{z_1})^{\frac{1}{7}}$ (2.3)

where, z=height, if the wind distribution is known for a certain height, c could be calculated for any height by using Equation2.3.

Considering the information provided by the simulation software research, it was concluded that HOMER and SAM software are going to be used as the simulation tool for the wind turbine simulations. HOMER is a well-developed software and its input data are compatible with the data acquired in this study.SAM software gives the option to import a wind data file in .srw format. This file contains hourly values, for a typical meteorological year, of wind speed, wind direction, ambient temperature and air pressure measured in four different heights from the ground (i.e. 50m, 80m, 110m and 140m). It is obvious that a file with this kind of data can be created either from long-term measurements on site or by using computational algorithms in order to generate the data. However, SAM gives the option to simulate the wind turbine by generating a wind speed Weibull distribution with three inputs; average annual wind speed, reference height for wind speed, and Weibull k factor. It was noticed that by using the specific option in SAM, the monthly energy prediction values were based on the sum of the days of each month, as it was the only monthly differentiation since there were no monthly wind speed values. Hence, in this study SAM is used only for the general performance evaluation of the horizontal axis wind turbine (HAWT) in the sensitivity analysis and in order to compare its results with HOMER software. Finally, due to its specialised characteristics, PVsyst software has been chosen for the PV system simulations and consequently for the annual energy prediction in this study.

### 2.2.1 PVsyst, SAM and HOMER input and output parameters

Generally, the input and output parameters of a software have to be identified in order to gain a clear view for the analysis of the obtained results. This section presents the most important inputs and outputs of the three software packages, which were chosen for grid-connected PV system and wind turbine simulations and for the annual energy yield prediction.

**Grid-connected PV systems: Annual energy estimation by PVsyst software**

PVsyst main input parameters [29]:

1) Geographical location and meteo data
2) Albedo value (default value 0.2 for an urban environment and grass)
3) Array operating temperatures: PVsyst uses default values but it also gives the choice to change them, these parameters are used for the design and are not involved in the simulation.
4) Orientation and field type of the array (fixed or tracking mounted)
5) Horizon and diffuse factor (the amount of the diffuse irradiation contributing in the simulation results): PVsyst does not include any horizon database but it gives the opportunity to the user to import a horizon file. For the diffuse factor its default value is 1.
6) Near shading (no shading, linear shading, according to the module strings)
7) System electrical design (choice of modules and inverters)

PVsyst main output parameters [29]:

1) Specific energy production (kWh/kW/year)
2) Normalized energy production (kWh/kW/day)
3) Performance ratio
4) Analytical collection losses and system losses
5) Array and system efficiencies

6) Electricity production values (kWh)
7) Global irradiation values (kWh/m$^2$)
8) Various graphs and tables.

**PVsyst calculations and losses treatment**

After identifying the inputs and outputs of the software, the way that the software calculates the outputs is examined along with the type of losses contained in the PV system performance calculations. This examination occurs in this section as it is crucial for analysing the simulation results.

PVsyst annual energy calculations are processed in the following way:

(1) The software corrects the horizontal global irradiation to the global incident irradiation on the collector plane.

(2) It corrects the IAM (Incident Angle Modifier) factor ($F_{IAM}$) on the global irradiance to calculate the effective irradiance on the collectors. Practically, this loss refers to the transmission and reflections of the incident irradiance that falls on the PV array. In PVsyst, this loss is calculated by the "ASHRAE" model that is dependant only on the parameter $b_0$. For crystalline modules, the default used value used is$b_0$ = 0.05.

$F_{IAM}$ = 1 - $b_0$ x (1/cos($i_\theta$) -1), where $i_\theta$ = incidence angle on the plane (2.4)

(3) It converts the irradiance to the PV system generated kWh depending on the module efficiency at the STC (Standard Test Conditions); array nominal energy at STC efficiency.

(4) It considers the subsequent losses and gives the array virtual energy at MPP (Maximum Power Point).

- PV loss due to irradiance level: The efficiency of the array is defined at the STC (1000 W/m²), but is reduced with irradiance based on the PV standard model.

- PV loss due to temperature: The thermal behaviour of the array is calculated at each stage of the simulation, by a thermal model. This model determines an energy balance between the ambient temperature and the cell temperature because of incidence irradiance. The model is presented in Equation 2.5 below:

$U_T$ x ($T_{cell}$ - $T_{amb}$) = α x $G_i$ x (1 - $\eta_{PV}$) (2.5)

where α is the absorption coefficient of solar irradiation, $\eta_{PV}$ is the PV module efficiency based on the operating conditions and $U_T$ is the thermal loss factor. $U_T$ can be divided into a constant component ($U_C$) and a factor proportional to the wind velocity ($U_V$) (equation2.6).

$U_T$ = $U_C$ + $U_V$ x v (W/m²*k), where v = wind velocity (m/s) (2.6)

This factor depends on the mounting position of the modules and its default value in the software is $U_T$= 20 W/m²*k. Therefore, the thermal model used by PVsyst establishes the instantaneous operating temperature, which is then used by the PV modules modelling.

- Soiling loss: Based on PVsyst, the soiling effect is almost negligible in middle-climate residential areas. However, it could become important in industrial environments, desert climates and areas with snow effects. The default value for the soiling loss by the software is 3% and its use is optional in the simulation.

- Module quality loss: This parameter conveys the matching of the real module performance to the manufacturer's specification. The default value is half the lower tolerance of the chosen module.

- Module/array mismatch loss: The real modules in the array do not present the same I/V characteristics comparing to the manufacturers' specification. In PVsyst, this loss acts as a continuous loss during the simulation and is divided into two default values; the first one is the energy loss at MPP and the second one is a loss factor for fixed voltage operation.

- Ohmic wiring loss: The loss between the available power from the modules and the power at the terminals of the array is caused by the ohmic wiring resistance (R) and is equal to R x I² (where I is the current). The software has a default system wiring loss of 1.5% by respect to the STC.

(5) Continuing its calculations, PVsyst considers the following losses and provides the available energy at inverter output (energy injected into the grid).

- Inverter loss during operation (efficiency)
- Inverter loss over nominal inverter power
- Inverter loss due to power threshold
- Inverter loss over nominal inverter voltage

- Inverter loss due to voltage threshold

It can be observed that PVsyst is a complicated simulation tool since it considers numerous aspects for the purpose of predicting the system's energy output. Moreover, there are some additional features that can be utilised in PVsyst simulation such as the partial shading [29].

**Grid-connected Wind turbines: Annual energy estimation by SAM software**

SAM main input parameters [21]:

1. Wind Resource
1.1 Wind Resource file
or
1.2 Wind speed Weibull distribution
- Average annual wind speed
- Reference height for wind speed
- Weibull k factor

2. Wind turbine
2.1 Select a turbine from the library
- Rated output
- Rotor diameter
- Hub height
- Shear coefficient (default value for onshore wind turbines 0.14)

or
2.2 Define turbine design characteristics
- User defined rated output
- User defined rotor diameter
- Maximum Cp (rotor's power efficiency)
- Maximum tip speed
- Maximum tip speed ratio
- Cut-in wind speed
- Cut-out wind speed
- Drive train design (3 stage planetary, single stage- low speed generator, multi-generator, direct drive)
- Blade design (advanced design, baseline)
- Tower design(advanced design, baseline)

3. Wind farm

3.1 System Sizing
3.1.1 Use a single turbine
or
3.1.2 Specify desire farm size

- Desire farm size in kW
- Number of turbines in farm
- System nameplate capacity in kW

or
3.1.3 Specify number of turbines

- Number of turbines in farm
- System nameplate capacity in kW

3.2 Losses and wake effects

- Wind farm losses
- Availability and curtailment

3.3 Turbine layout
3.3.1 Import wind turbine location data file
3.3.2 Define wind farm using layout generator

SAM main output parameters [21]:

1. Annual and monthly energy (kWh)
2. Capacity factor (%)
3. Specific energy production (kWh/kW/year)
4. Various graphs and tables

**SAM calculations and losses treatment**

SAM computes the wind farm's output for an entire year in hourly time steps. The algorithm steps for the calculation of the wind farm output are the following:

1. It determines the wind data height and changes the wind resource data to explain the differences between the turbine hub height and the wind resource data height.

2. It calculates the output of a single turbine, accounting for the turbine's height above the ground. On the Turbine page, the turbine's performance characteristics can be represented either as a turbine power curve from the turbine library or by specifying values for a set of turbine design parameters. For both options, a turbine hub height and shear coefficient are specified.

3. It calculates the output of wind farm, accounting for wake effects.

4. It calculates the electricity delivered to the grid. SAM adjusts the wind farm's output using the curtailment and availability factors or other operating losses.

Further, the value of the shear coefficient, on the Turbine page, is used through the wind power low to estimate the wind speed at the hub height. The wind power law equation to estimate the wind speed at the turbine height $v_{hub}$, using the wind speed $v_{data}$ and wind measurement height $h_{data}$ from the data file, and the turbine hub height $h_{hub}$ and shear coefficient a is:

$$v_{hub} = v_{data} \times (\frac{h_{hub}}{h_{data}})^a \qquad (2.7)$$

Additionally, when wind passes through a wind turbine rotor, its speed and turbulence features alter. Regarding wind farms with more than one turbine, the spacing of turbines influences the wind farm output since upwind turbines can decrease the energy in the wind available for downwind turbines. For this reason, SAM uses wake effect models. The Simple Wake Model makes the subsequent assumptions:

- All turbines in the wind farm have the same hub height and height above sea level.
- The wind farm terrain is uniform with a single ambient turbulence coefficient.

Finally, it has to be noted that it is preferable to use the Wind Resource Characteristics option when a wind turbine performance is examined under different wind speeds. However, by choosing this option, the Wind Farm page is disabled because there is no data to describe the wind direction [21]. This option is used in this study for the HAWT, as there is only one HAWT for each location and is examined under various wind speeds.

**Grid-connected Wind turbines: Annual energy estimation by HOMER software**

HOMER main input parameters [19]:

1. Geographical location
2. Resources
   - import from a time series data file
   - download from internet NASA's data

- enter monthly averages

2.1 Wind resource parameters

- Monthly average wind speed data (m/s)
- Altitude above sea level (m)
- Anemometer height (m)
- Wind speed profile (choice between power law and logarithmic)
- Weibull k parameter (default value 2)
- Diurnal pattern strength (default value 0.25, how strongly the wind speed depends on the time of day)
- 1 hr. autocorrelation factor (default value 0.85, hour to hour randomness of the wind speed)
- Hour of peak wind speed (default value 15, the time of day that tends to be windiest on average)

3. Design the system

Add a wind turbine from the library or define the wind turbine characteristics

- Name, model manufacturer
- Insert power curve
- Hub height
- Lifetime
- Percentage losses (optional)
- Insert economic factors (capital cost, operation and maintenance cost, replacement cost) (optional)
- Insert maintenance schedule (intervals, down time, cost) (optional)

Add the grid for the grid-connection

- Choose grid rates (simple rates, real time rates) (optional)
- Insert grid power price and/or sellback price (optional)

HOMER main output parameters [19]:

1. Sensitivity cases results (in case of different input values are added for one parameter)
Homer ranks the sensitivity cases according to the net present cost of the systems included in the design (from low to high).

2. Optimization results (the possible combination of the components added in the design)
The list of the components in the optimization results are updated according to the choice of the sensitivity case.For example, in the case of the grid-connected wind turbine simulation there are only two components; the wind turbine and the grid. The possible combinations

are to have the wind turbine connected to the grid or to have only the grid as a grid-connected wind turbine cannot stand alone and operate.

3. Various graphs and tables

Regarding the wind turbines, HOMER's outputs are the followings:

- Total Rated Capacity (the highest possible power amount from the wind turbine(s) (kW))
- Mean Output (the average power amount of the wind turbine over the year (kW))
- Capacity Factor (the average power output of the wind turbine(s) divided by the total wind turbine capacity (%))
- Total Production (the total power output of the wind turbine(s) over the year (kWh/yr))
- Minimum Output (the minimum power output of the wind turbine over the year (kW))
- Maximum Output (the maximum power output of the wind turbine over the year (kW))
- Wind Penetration (the average power output of the wind turbine(s) divided by the average primary load (%))
- Hours of Operation (the number of hours of the year during which the wind turbine output was greater than zero)
- Levelized Cost (the levelized cost of energy of the wind turbine(s), ($/kWh))

**HOMER calculations and losses treatment**

Regarding the wind turbines, HOMER calculates their power output in three steps:

1. It calculates the wind speed at the turbine's hub height by using the power or the logarithmic low. Further discussion on the power and logarithm laws is provided in Chapter 3, Section 3.2.

2. Afterwards, it calculates the power that the wind turbine would produce according to the turbine's power curve by considering the standard conditions of temperature and air pressure.

3.Then, it adjusts the power output to the actual air density by multiplying the predicted power output with the air density ratio using the following equation:

$$P_{WTG} = (\frac{\rho}{\rho_0}) \times P_{WTG,STP} \qquad (2.8)$$

where, $P_{WTG}$is the wind turbine power output (kW), $P_{WTG,STP}$ is the wind turbine power output at standard temperature and pressure (kW), ρ is the actual air density (kg/m$^3$) and $\rho_0$ is the air density at standard temperature and pressure (1.225 kg/m$^3$).

Finally, regarding the losses, HOMER gives the option to the user to insert individually the losses for each component used in the design.The wind turbine losses are insertedin a percentage format andare the followings:

- Availability losses (%)
- Turbine performance losses (%)
- Environmental losses (%)
- Other losses (%)
- Wake effect losses (%)
- Electrical losses (%)
- Curtailment losses (%).

The overall loss factor is combined multiplicatively [19].

# Chapter 3: Site specifications

Generally, there are three ways to obtain weather data for a specific region. The first and most accurate way would be to make long-term measurements on site. The second way would be to obtain long-term data from the local weather station while the third way is to obtain these data from available meteorological databases. Regarding the first way, this project does not have the means or the time to make long-term on-site measurements. This, however, will be noted during the analysis of the energy output results, as especially for the wind energy conversion systems, it might cause a great uncertainty in the energy prediction and consequently in their economic viability. Regarding the data from the local weather stations, they also contain some drawbacks as a certain weather station might not measure all the parameters, which are needed for a study. For example, the local weather station in Kalamata does not measure the solar irradiance. Finally, the third way has been analysed in Chapter 2 by presenting some of the available meteorological databases and their characteristics. In this study, both the second and third way are going to be used in the analysis in order to complement each other. Moreover, a comparison between the different weather sources is presented for validation purposes. For example, a comparison between RETScreen and PVGIS CM-SAF databases was made to demonstrate the discrepancies, which can be caused in the data for the same location just by the choice of database.

This study examines the weather data of four different sources; RETScreen [20], PVGIS CM-SAF [2], NASA SSE (Surface meteorology and Solar energy) database [19], and the data acquired from the local weather station of Kalamata [30]. These data (some of them have been processed) can be imported in the simulation software programs, which are used for the RET annual energy prediction.

NASA SSE database is a database used by HOMER simulation software. It is the previous version of NASA-Power database presented in Chapter 2, Section 2.1. Through HOMER software monthly averaged values over a 22-year period are provided for the global horizontal irradiation (GHI). The cell dimensions are 1x1 degree and the time period is from July 1983 to June 2005 [19]. Hence, the spatial resolution is low and the data fairly old. The same stands for the monthly average temperature data. For this reason, the GHI and temperature are not used in the simulations from this database. However, monthly average wind speed data are also provided in 50m above ground over a 10-year period and for a terrain similar to airports. This 10-year period is between July 1983 to June 1993 [19]. These data are quite old although they have two advantages; they are measured in 50m above ground and they give information regarding the terrain, which is also important for the wind analysis since the large-scale HAWT of this project might be installed in similar terrain in both locations. Hence, from this database the wind speed values are considered as the main dataset for the wind turbines' simulations.

## 3.1 Analysis of the climatic parameters

The weather could be determined by factors such as the solar irradiation, ambient temperature, air humidity, precipitation, wind speed and direction, and sky condition. The solar irradiation differs based on the location (geographical co-ordinates), the season, the time of the day and the atmospheric conditions. The ambient temperature depends on the location, the solar irradiation, the wind, and the presence of water. The air humidity is the amount of moisture in the air and it is frequently expressed as relative humidity. Relative humidity is expressed as a percentage and its definition is the ratio of the water vapour mass in a certain volume of moist air to the water vapour mass in the same volume of saturated air, at a given temperature. In addition, the transmission of solar radiation is decreased in locations with high humidity levels because of atmospheric absorption and scattering. The precipitation contains water in the form of rain, snow, hail or dew. The wind constitutes the movement of air because of the difference of atmospheric pressure. It is created from the differential heating of land and water mass on the surface of the earth surface by solar radiation and rotation of earth [31]. Finally, the sky condition is referred to the level of cloud cover in the sky and it is measured in okta. Usually, the irradiation augments when there are clear sky conditions while it is reduced when there is cloud cover.

The main climatic parameters, which are also compulsory for the simulation inputs, are the global horizontal irradiation, the ambient temperature and the wind speed. Below, an analysis of these parameters among the different weather sources is presented. The first example is given between the data of RETScreen and PVGIS CM-SAF databases. For comparison purposes and in order to minimise the differences among the input parameters, the locations that have been selected is where RETScreen software includes data from weather stations. Hence, for Kalamata the measurements are from a location near Kalamata Airport and not from inside the city while for Capo Passero are from a location fairly close to the town. Further, all the datasets in this study refer to these locations because even the values from the weather station in Kalamata are measured near Kalamata's Airport.

Tables 3.1 and 3.2 present the monthly averaged values for the daily global horizontal irradiation, the ambient temperature and the monthly averaged wind speed for the two sites. At this point, it should be mentioned that PVGIS CM-SAF (in its TMY series) and RETScreen databases provide various parameters apart from the aforementioned such as relative humidity, air pressure etc. However, the comparison focuses on the compulsory parameters for the simulations, so they are not presented here. Moreover, for this study wind direction data are not required as an input from HOMER software, which is used for the annual energy prediction of the wind turbines. In the specific stage of the study where the exact locations for installing the RET systems are not known yet, there is no need for wind direction data.

**Table 3. 1: Capo Passero meteorological data (RETScreen and PVGIS CM-SAF)**

***Capo Passero***

*Latutude:36.7 degrees N, Longitude:15.08 degrees E*

| Month | RETScreen | | | PVGIS CM-SAF | | |
|---|---|---|---|---|---|---|
| | Temperature (°C) | Daily solar radiation GHI (kW/m$^2$/d) | Wind speed (m/s) At 10m from ground | Temperature (°C) | Daily solar radiation GHI (kW/m$^2$/d) | Wind speed (m/s) At 10m from ground |
| *January* | 12.10 | 2.20 | 4.00 | 13.60 | 2.72 | 4.44 |
| *February* | 12.00 | 3.27 | 3.90 | 12.90 | 3.68 | 5.49 |
| *March* | 13.40 | 4.25 | 3.80 | 13.80 | 5.27 | 6.57 |
| *April* | 15.30 | 5.39 | 3.80 | 15.80 | 6.35 | 4.50 |
| *May* | 19.00 | 6.25 | 3.40 | 18.30 | 7.50 | 5.12 |
| *June* | 23.10 | 6.79 | 3.20 | 21.90 | 8.11 | 4.75 |
| *July* | 26.20 | 6.57 | 2.90 | 25.30 | 8.22 | 3.60 |
| *August* | 26.80 | 5.84 | 3.00 | 26.20 | 7.30 | 4.00 |
| *September* | 24.20 | 4.84 | 3.00 | 24.50 | 5.66 | 4.81 |
| *October* | 21.00 | 3.69 | 3.00 | 21.70 | 4.27 | 5.14 |
| *November* | 17.10 | 2.48 | 3.50 | 18.60 | 3.01 | 6.12 |
| *December* | 13.60 | 2.04 | 3.70 | 15.00 | 2.42 | 7.53 |
| *Annual* | 18.65 | 4.47 | 3.43 | 18.97 | 5.38 | 5.17 |

**Table 3. 2: Kalamata Airport meteorological data (RETScreen and PVGIS CM-SAF)**

***Kalamata Airport***

*Latitude:37.1 degrees N, Longitude:22.0degrees E*

| Month | RETScreen | | | PVGIS CM-SAF | | |
|---|---|---|---|---|---|---|
| | Temperature (°C) | Daily solar radiation GHI (kW/m$^2$/d) | Wind speed (m/s) At 10m from ground | Temperature (°C) | Daily solar radiation GHI (kW/m$^2$/d) | Wind speed (m/s) At 10m from ground |
| *January* | 9.30 | 2.11 | 2.60 | 13.7 | 2.32 | 2.75 |
| *February* | 9.40 | 2.77 | 2.80 | 14 | 3.00 | 4.78 |
| *March* | 11.40 | 3.92 | 2.50 | 15.2 | 4.84 | 2.77 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *April* | 14.30 | 5.15 | 2.40 | 17.5 | 5.83 | 2.54 |
| *May* | 18.80 | 6.08 | 2.60 | 20.8 | 7.02 | 2.69 |
| *June* | 23.10 | 7.29 | 3.00 | 24.8 | 7.87 | 2.86 |
| *July* | 25.40 | 7.21 | 3.00 | 27.8 | 7.55 | 2.40 |
| *August* | 25.50 | 6.41 | 3.00 | 28.7 | 6.79 | 2.16 |
| *September* | 22.20 | 4.98 | 2.70 | 26.3 | 5.51 | 2.49 |
| *October* | 18.80 | 3.46 | 2.50 | 22.2 | 4.04 | 4.64 |
| *November* | 14.10 | 2.23 | 2.50 | 19.2 | 2.77 | 2.51 |
| *December* | 10.70 | 1.74 | 2.70 | 15.6 | 2.08 | 2.74 |
| *Annual* | 16.92 | 4.45 | 2.69 | 20.48 | 4.97 | 2.94 |

Regarding PVGIS CM-SAF data, it can be noticed that Capo Passero and Kalamata Airport receive yearly almost the same amounts of solar irradiation while they have big difference in their wind resource. Even in RETScreen data where the difference in wind speed is smaller, still Capo Passero seems to have a better wind resource than Kalamata Airport.Further, Table 3.3 presents the percentage differences of the two databases based on PVGIS CM-SAF data.

**Table 3. 3: Percentage difference of the two databases based on PVGIS CM-SAF**

| | ***Capo Passero*** | | | ***Kalamata Airport*** | | |
|---|---|---|---|---|---|---|
| | Percentage difference based on PVGIS | | | Percentage difference based on PVGIS | | |
| *Month* | Temperature | Daily solar radiation GHI | Wind speed | Temperature | Daily solar radiation GHI | Wind speed |
| *January* | 11.03% | 19.12% | 9.91% | 32.12% | 9.05% | 5.45% |
| *February* | 6.98% | 11.14% | 28.96% | 32.86% | 7.67% | 41.42% |
| *March* | 2.90% | 19.35% | 42.16% | 25.00% | 19.01% | 9.75% |
| *April* | 3.16% | 15.12% | 15.56% | 18.29% | 11.66% | 5.51% |
| *May* | -3.83% | 16.67% | 33.59% | 9.62% | 13.39% | 3.35% |
| *June* | -5.48% | 16.28% | 32.63% | 6.85% | 7.37% | -4.90% |
| *July* | -3.56% | 20.07% | 19.44% | 8.63% | 4.50% | -25.00% |
| *August* | -2.29% | 20.00% | 25.00% | 11.15% | 5.60% | -38.89% |
| *September* | 1.22% | 14.49% | 37.63% | 15.59% | 9.62% | -8.43% |
| *October* | 3.23% | 13.58% | 41.63% | 15.32% | 14.36% | 46.12% |
| *November* | 8.06% | 17.61% | 42.81% | 26.56% | 19.49% | 0.40% |

| | | | | | | |
|---|---|---|---|---|---|---|
| *December* | 9.33% | 15.70% | 50.86% | 31.41% | 16.35% | 1.46% |
| *Annual* | 1.67% | 16.90% | 33.62% | 17.41% | 10.52% | 8.58% |

As it can be observed from Table 3.3, the biggest discrepancy between the two databases is for the wind speed data of Capo Passero (annual difference 33.62%). This will affect the annual energy yield predictions of the wind turbines as depending on the used data, their outcome will be different. Moreover, the percentage difference between the two databases of the daily global horizontal irradiation is higher in Capo Passero than in Kalamata Airport. Finally, it is obvious that the temperature data for Kalamata Airport have big discrepancies in the two databases while they are fairly similar for Capo Passero.

The maps of the locations pointing out the sites where these measurements were provided by the two databases are presented below. Moreover, graphical representations of the global horizontal irradiation, the wind speed and the temperature of therespective locations are also presented (figures3.1 and 3.2). The primary axis in the graphs depicts the global horizontal irradiation and wind speed while the secondary axis shows the average daily temperature for each month of the year.

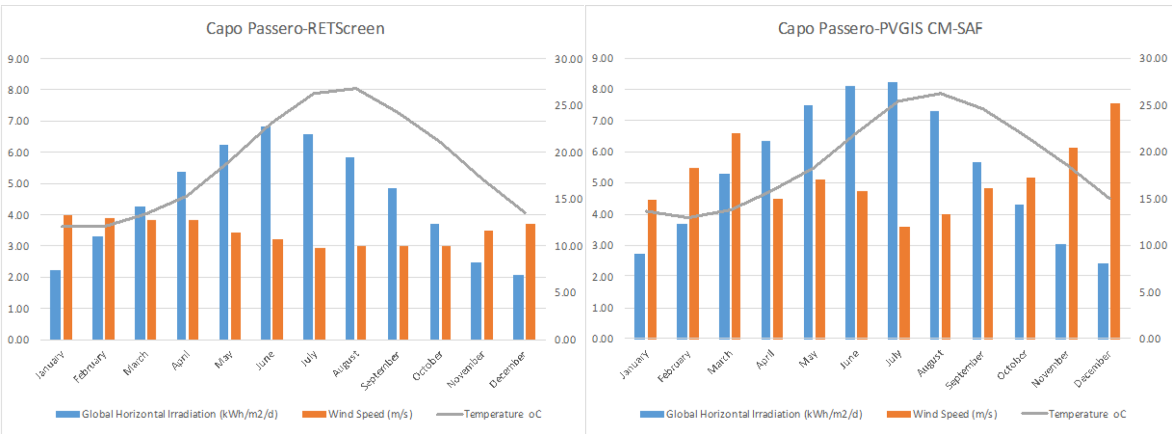



**Figure 3. 1: Meteorological data for Capo Passero (RETScreen& PVGIS CM-SAF)**

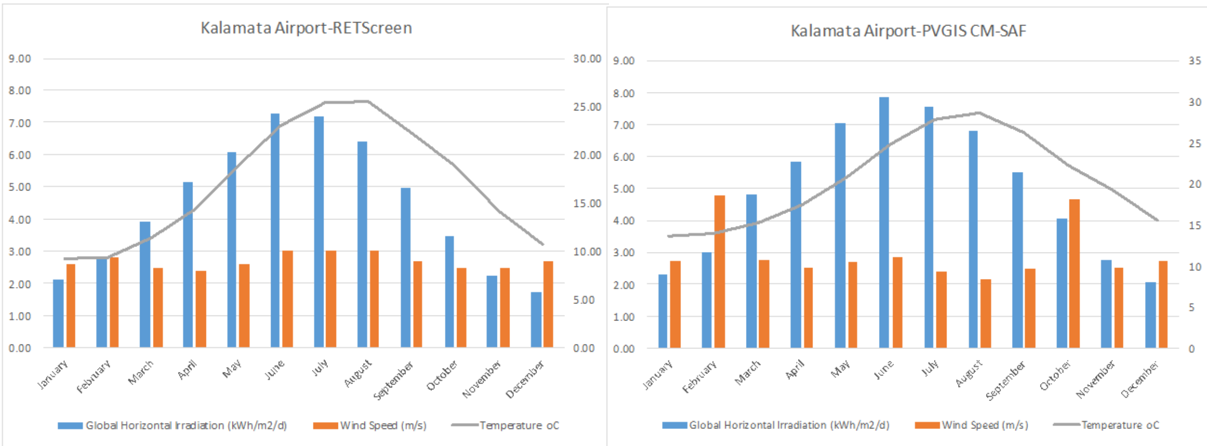



Figure 3. 2: Meteorological data for Kalamata Airport (RETScreen& PVGIS CM-SAF)

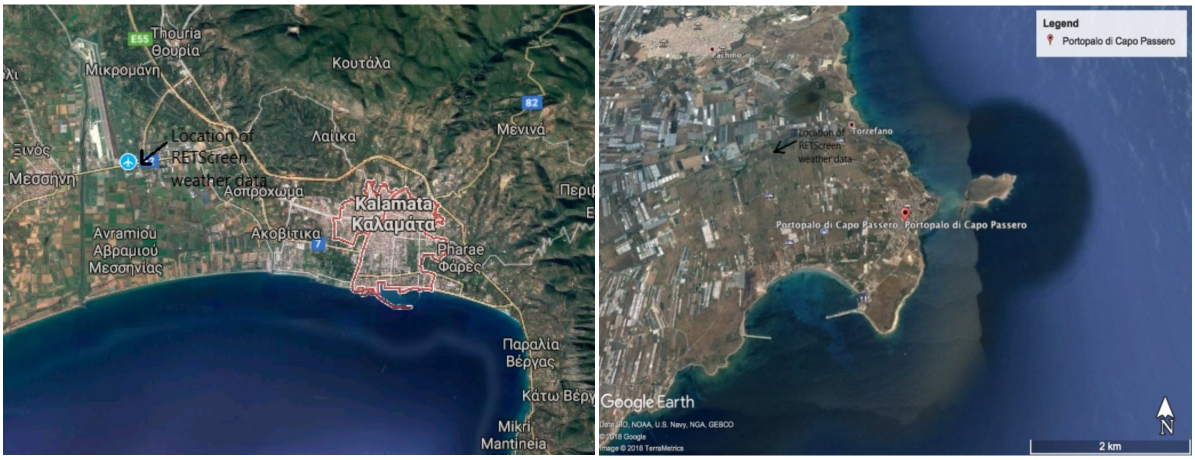



Figure 3. 3: Locations of the data acquired by RETScreen database

Below, the data from HOMER software are presented. The analysis of the data from the different sources as well as the wind speed data from the weather station in Kalamata are presented in the following section. The data from Kalamata's weather station have been obtained through communication with the Hellenic National Meteorological Service (HNMS). HNMS provided daily measured row data in 3-hour time step for wind speed, wind direction, temperature and air pressure for the period of 1997 to 2007[30].No data have been obtained from the respective local weather station in Capo Passero.

**Table 3. 4: Meteorological data from HOMER software**

| | *HOMER* | | | | | |
|---|---|---|---|---|---|---|
| | Capo Passero | | | Kalamata | | |
| *Month* | Temperature | Daily solar radiation GH ($kW/m^2/d$) | Wind speed (m/s) At 50m from ground | Temperature | Daily solar radiation GH ($kW/m^2/d$) | Wind speed (m/s) At 50m from ground |
| *January* | 13.92 | 2.47 | 6.79 | 7.84 | 2.11 | 5.97 |
| *February* | 13.45 | 3.42 | 7.05 | 8.20 | 2.77 | 6.20 |
| *March* | 14.42 | 4.69 | 6.65 | 10.86 | 3.92 | 5.42 |
| *April* | 16.22 | 5.92 | 6.43 | 15.32 | 5.15 | 4.82 |
| *May* | 20.16 | 6.95 | 5.71 | 20.87 | 6.08 | 4.35 |
| *June* | 24.30 | 7.68 | 4.86 | 25.68 | 7.29 | 4.11 |
| *July* | 27.35 | 7.78 | 4.59 | 28.41 | 7.21 | 4.44 |
| *August* | 27.80 | 6.88 | 4.75 | 28.08 | 6.41 | 4.42 |
| *September* | 25.08 | 5.29 | 4.67 | 23.86 | 4.98 | 4.16 |
| *October* | 22.20 | 3.92 | 5.39 | 18.89 | 3.46 | 4.78 |
| *November* | 18.69 | 2.65 | 6.35 | 13.38 | 2.23 | 5.47 |
| *December* | 15.49 | 2.14 | 6.78 | 9.20 | 1.74 | 6.02 |
| *Annual* | 19.92 | 4.98 | 5.84 | 17.55 | 4.45 | 5.01 |

## 3.2 Chosen weather data

This section continues the analysis from the different sources and presents the data as they are used in the simulation software. Regarding the irradiation and temperature, PVGISCM-SAF is a valid solar database that provides recent solar irradiation data and has a small uncertainty in its data for Europe [17,18,32,33].Hence, these data are used for the PV systems' simulations in both locations since they are also available in both locations. Regarding the wind speed data, which are more trivial and not straight forward to interpret, different combinations are made for the two locations. For Kalamata, the wind speed values from the local weather station and HOMER are used in this study. As mentioned, the row wind data from Kalamata's weather station have been measured in three-hour steps, in 6 m height above the ground between the period of 1997 to 2007. The data have been processed in order to compose the long-term monthly averaged values of the aforementioned period. For the area of Capo Passero, long-term monthly averaged wind speed data are used from RETScreen database measured at 10 m above the ground and HOMER measured at 50 m above the ground. Since the databases concern wind speed measurements at different heights, two models, which can extrapolate the wind speed values at the wind turbine's hub height, are presented below.

These two models are the “power law” and the “logarithmic law”, which are used to calculate the wind speed at various heights (i.e. in vertical heights from the location of the measurement). Both of them provide a wind speed estimation and not a certain value since the turbulence effects are not included in their calculations. Hence, if these models are used for a homogeneous flat terrain, the wind speed prediction will be more accurate [34]. Moreover, HOMER software gives the option to the user to choose betweenthese two models in order to extrapolate the wind speed at the turbine’s hub height from the height of the input data [19]. SAM also uses the power law model in order to calculate the wind speed at the turbine’s hub height and gives the option to the user to choose the value of the shear coefficient [21].

**Power Law**

The power low is defined by the Equation 3.1 below:

$$v_2 = v_1 \times (\frac{z_2}{z_1})^a \tag{3.1}$$

where $v_2$ is the wind speed at height 2, and $v_1$ the wind speed at height 1, $z_1$ and $z_2$ are the heights 1 and 2 while “α” is the wind shear exponent. Generally, the wind shear exponent and/or coefficient varies with the elevation, the temperature, the time of the day, the season, and the atmospheric stability [34] (i.e. the difference between the ground temperature and the air temperature [35]). However, in this calculation, as well as in the wind energy simulations, it is considered as a constant value.

**Logarithmic Law**

The logarithmic law can approximately be used for the first 100 m vertically from the ground as the wind speed is considered to follow a logarithmic expression in between this distance (equation 3.2).

$$v \approx v_{ref} \times \frac{ln\frac{z}{z_0}}{ln\frac{z_{ref}}{z_0}} \tag{3.2}$$

Where v the wind speed at height z and $v_{ref}$ the known wind speed measured at height $z_{ref}$while $z_0$ is roughness length in the current wind direction. “The term roughness length is really the distance above ground level where the wind speed theoretically should be zero.

The “Logarithmic” formula assumes so-called neutral atmospheric stability conditions, i.e. that the ground surface is neither heated nor cooled compared to the air temperature” [35].

Table 3.5 describes the roughness class and the respective roughness length (in meters) according to the landscape type [34]. Generally, “in the wind industry one distinguishes between the roughness of the terrain, the influence from obstacles, and the influence from the terrain contours, which is also called the orography of the area” [35].

**Table 3. 5: Roughness definitions according to the European Wind Atlas [34]**

| Roughness Class | Roughness Length (m) | Landscape Type |
|---|---|---|
| 0 | 0.0002 | Water surface |
| 0.2 | 0.0005 | Inlet water |
| 0.5 | 0.0024 | Completely open terrain with a smooth surface, e.g. concrete runways in airports, mowed grass, etc. |
| 1 | 0.03 | Open agricultural area without fences and hedgerows and very scattered buildings. Only softly rounded hills |
| 1.5 | 0.055 | Agricultural land with some houses and 8 metre tall sheltering hedgerows with a distance of approximately 1250 metres |
| 2 | 0.1 | Agricultural land with some houses and 8 metre tall sheltering hedgerows with a distance of approximately 500 metres |
| 2.5 | 0.2 | Agricultural land with many houses, shrubs and plants, or 8 metre tall sheltering hedgerows with a distance of approximately 250 metres |
| 3 | 0.4 | Villages, small towns, agricultural land with many or tall sheltering hedgerows, forests and very rough and uneven terrain |
| 3.5 | 0.8 | Larger cities with tall buildings |
| 4 | 1.6 | Very large cities with tall buildings and skyscrapers |

In this study, the power law is used to extrapolate the wind speed values at the turbine’s hub height. As it was mentioned, the wind shear coefficient depends on various parameters. Hence, two values have been chosen instead of one in order to demonstrate the effect of the wind shear coefficient to the wind speed calculations. It is known that “the larger the exponent the larger the vertical gradient in the wind speed. Although the power law is a useful engineering approximation of the average wind speed profile, actual profiles will deviate from this relationship” [34]. Moreover, it is better to obtain a range of wind speed values and consequently energy prediction values rather than an individual value. The two values that have been chosen for “α” are 0.16 and 0.24. Table 3.6 presents the typical values of the wind shear coefficient for various terrains. As it is shown, the 0.16 value is for an area with foot-high grass and occasional trees and the 0.24 value is for many trees and occasional buildings. Since the exact location of the wind turbines installation is not known yet, intermediate values of the shear coefficient were chosen.

Table 3. 6: Typical power law exponents for varying terrain [36]

| Terrain Description | Power law exponent, α |
|---|---|
| Smooth, hard ground, lake or ocean | 0.10 |
| Short grass on untilled ground | 0.14 |
| Level country with foot-high grass, occasional tree | 0.16 |
| Tall row crops, hedges, a few trees | 0.20 |
| Many trees and occasional buildings | 0.22 – 0.24 |
| Wooded country – small towns and suburbs | 0.28 – 0.30 |
| Urban areas with tall buildings | 0.4 |

Six figures are presented below, three for Kalamata and three for Capo Passero depicting the respective climatic parameters; averaged monthly wind speed (m/s), daily ambient temperature (°C) and daily global horizontal irradiation (kWh/m$^2$) for each location. The reason of these figures is to observe the patterns of the monthly averaged climatic parameters of each database.

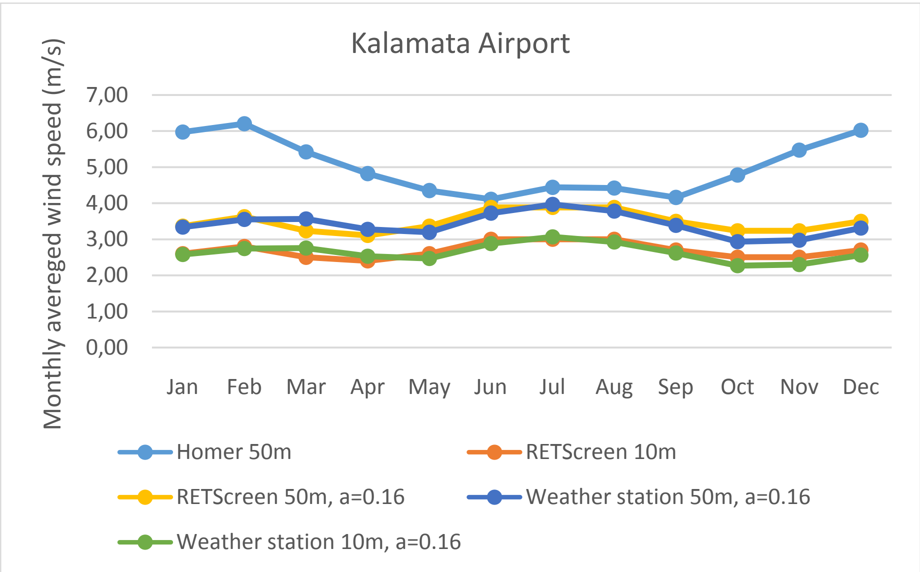



Figure 3. 4: Original and extrapolated wind speed data for Kalamata from various sources

Figure 3.4 shows the original and the extrapolated wind speed data for Kalamata. The wind speed data from Kalamata weather station are measured at 6 m height above the ground. Hence, by using the power low with a shear coefficient of 0.16, the monthly averaged wind speed values at 10 and 50 m height are extrapolated. The reason why the data have been extrapolated and not depicted in their original format is for comparison purposes among the databases. The extrapolation does not affect the pattern of the original data, only the wind speed value increases when the vertical distance from the ground is increased. Hence, the data from the weather station in Kalamata and from RETScreen have the same patterns at 10 and 50 m respectively. Regarding the patterns among the databases, it can be observed that the weather station in Kalamata and RETScreen have very similar patterns. Regarding RETScreen database, which was presented in Chapter 2, it was stated that it uses data from different sources both ground and satellite measurements and mainly NASA's satellite database. In this case, it is obvious that the measurement is taken from the ground station, as HOMER, which uses NASA's database, gives a different pattern in the monthly wind speed values. Moreover, it is observed that even if the wind speed values from the weather station and RETScreen are extrapolated to 50 m height, in most of the months, their values are sufficiently lower than the one provided by HOMER, resulting in a much lower annual average wind speed compared to HOMER dataset (Kalamata weather station and RETScreen annual averaged wind speed at 50 m and a=0.16 equals 3.41 and 3.48 m/s respectively while HOMER annual average wind speed at 50 m= 5.01 m/s). The same stands for the location of Capo Passero where the RETScreen annual average wind speed at 50 m and a=0.16 is 4.44 m/s while HOMER's is 5.84 m/s.

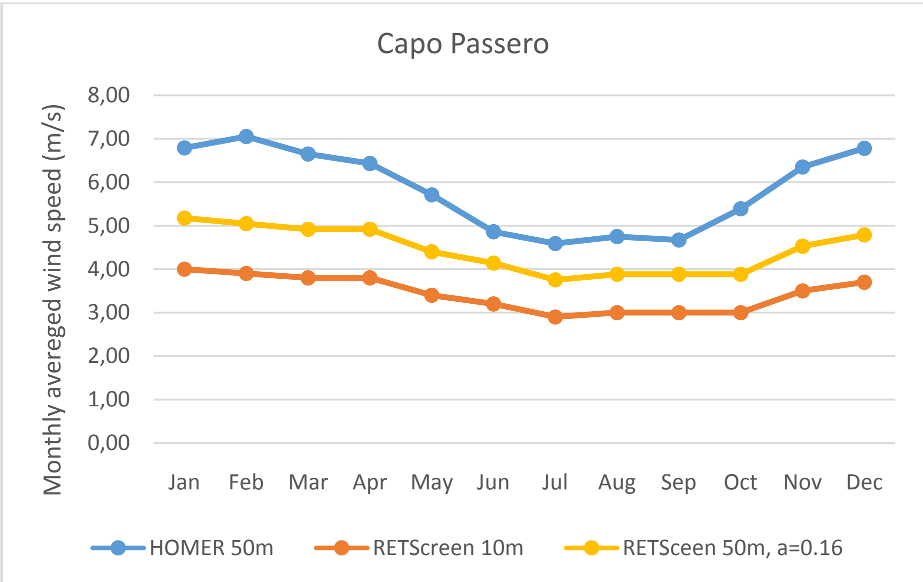



**Figure 3. 5: Original and extrapolated wind speed data for Capo Passero from various sources**

Note that PVGIS wind speed data where excluded on purpose from the wind speed graphs of the two locations as both their pattern and values seemed unrealistic, for a measurement and/or calculation at 10 m above the ground, compared to other databases. Regarding the ambient temperature data, the patterns among the databases in each location are quite similar with the patterns for Capo Passero to fit more among them compared to the patterns for Kalamata. The average temperature annual values are between 17-20.5 °C for Kalamata while they are between 18.6-19.9 °C. for Capo Passero Finally, concerning the global horizontal irradiation values, the patterns of the monthly values are quite similar among the databases in both locations. For the case of Kalamata, HOMER data cannot be depicted in the figure as they are exactly the same with RETScreen data, meaning that both sources use NASA's irradiation data for this location. In both sites, PVGIS gives the highest irradiation values while their annual irradiation values range from 4.5-5.4 kWh/m$^2$/day for Capo Passero and 4.5-5kWh/m$^2$/day for Kalamata.

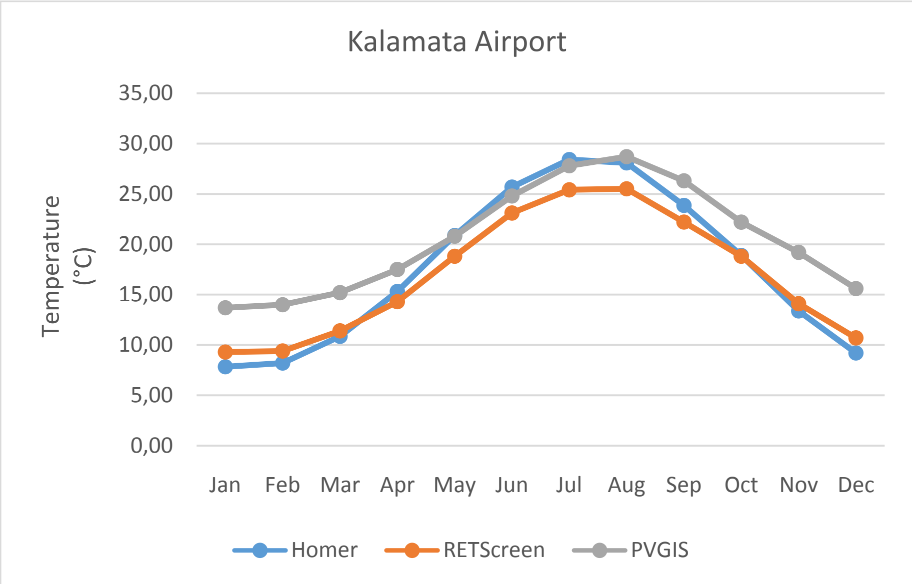



**Figure 3. 6: Original ambient temperature data for Kalamata from various sources**

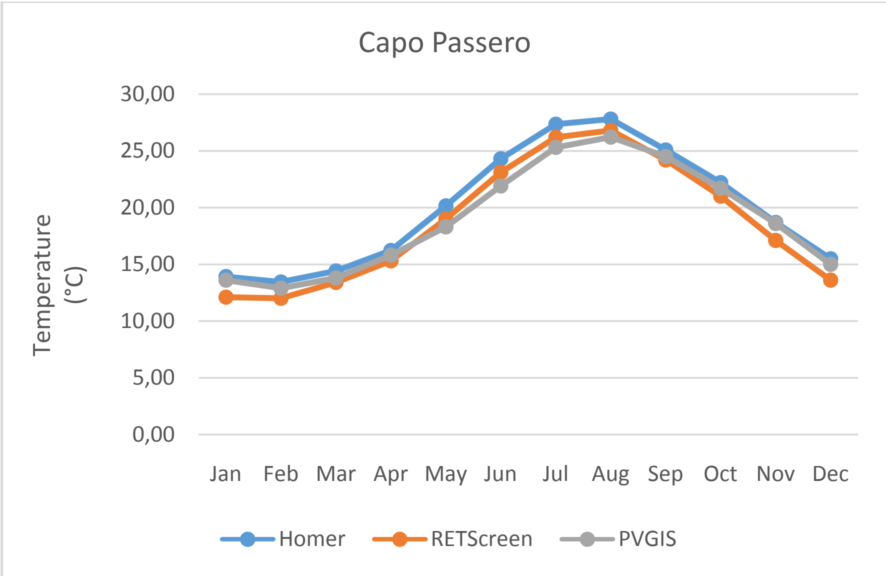



**Figure 3. 7: Original ambient temperature data for Capo Passero from various sources**

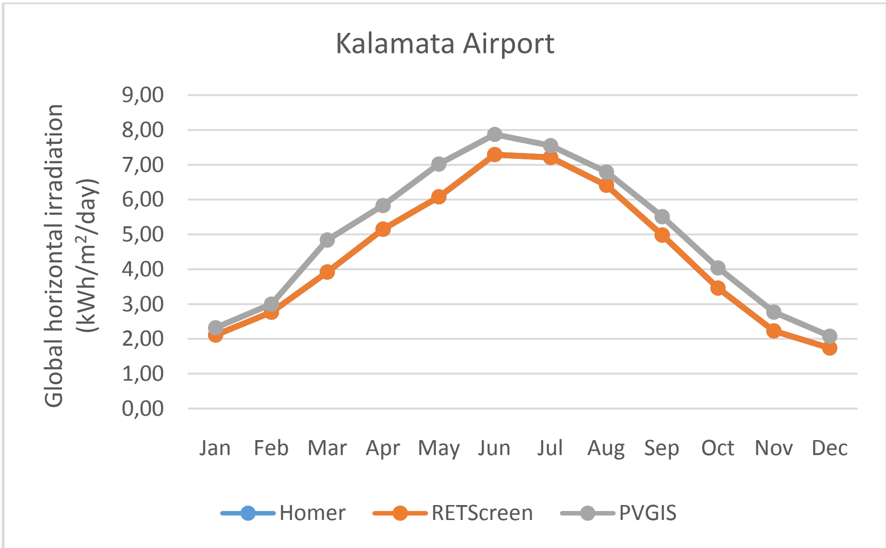



**Figure 3. 8: Original global horizontal irradiation data for Kalamata from various sources**

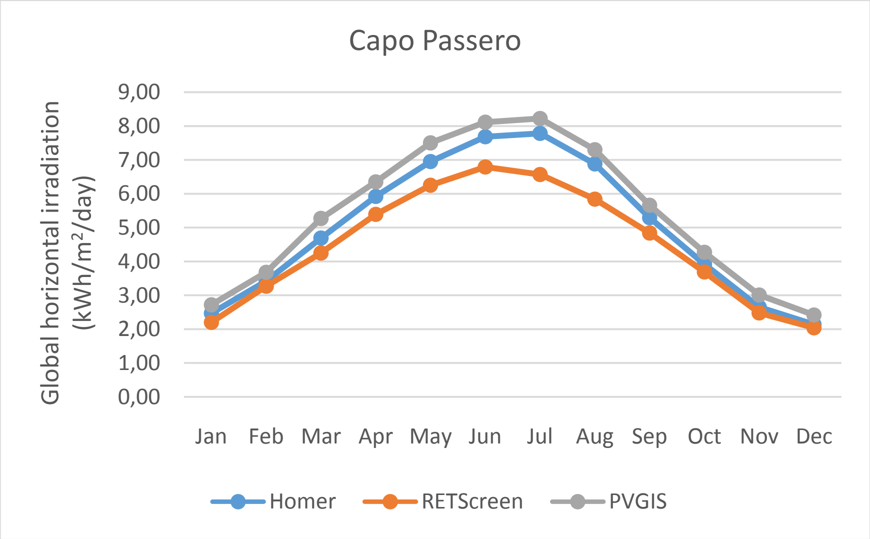



**Figure 3. 9: Original global horizontal irradiation data for Capo Passero from various sources**

Below are presented the weather data for the two locations that have been used in the simulation software packages in order to obtain the annual energy prediction of the RET systems. Moreover, Tables3.9 and 3.10, apart from the available wind speed data, also show the calculated data in the different hub heights of the small and large-scale wind turbines models chosen for the two locations (presented in chapter 4). Apart from those data, the HOMER's wind speed data, which have been already presented in Table 3.4, are used as well.

### Solar irradiation data

**Table 3. 7: Solar data for the area of Kalamata (PVSyst input data)**

| **Kalamata Airport (Latitude: 37.1° N, Longitude: 22.0° E, Elevation: 13 m) PVGIS CM-SAF** | | | |
|---|---|---|---|
| Month | Horizontal global irradiation GH (kW/m$^2$/d) | Diffuse global irradiation D (kW/m$^2$/d) | Ambient temperature (°C) |
| January | 2.32 | 0.97 | 13.7 |
| February | 3.00 | 1.29 | 14 |
| March | 4.84 | 1.94 | 15.2 |
| April | 5.83 | 1.98 | 17.5 |
| May | 7.02 | 2.11 | 20.8 |
| June | 7.87 | 1.81 | 24.8 |
| July | 7.55 | 1.51 | 27.8 |
| August | 6.79 | 1.49 | 28.7 |
| September | 5.51 | 1.49 | 26.3 |
| October | 4.04 | 1.45 | 22.2 |
| November | 2.77 | 1.02 | 19.2 |
| December | 2.08 | 0.92 | 15.6 |
| Annual | 4.97 | 1.49 | 20.48 |

Table 3. 8: Solar data for the area of Capo Passero (PVSyst input data)

| **Capo Passero (Latitude: 36.7° N, Longitude: 15.08° E, Elevation: 5 m) PVGIS CM-SAF** | | | |
|---|---|---|---|
| Month | Horizontal global irradiation GH (kW/m$^2$/d) | Diffuse global irradiation D (kW/m$^2$/d) | Ambient temperature (°C) |
| January | 2.72 | 1.03 | 13.60 |
| February | 3.68 | 1.25 | 12.90 |
| March | 5.27 | 1.90 | 13.80 |
| April | 6.35 | 1.84 | 15.80 |
| May | 7.50 | 2.03 | 18.30 |
| June | 8.11 | 1.87 | 21.90 |
| July | 8.22 | 1.56 | 25.30 |
| August | 7.30 | 1.53 | 26.20 |
| September | 5.66 | 1.58 | 24.50 |
| October | 4.27 | 1.49 | 21.70 |
| November | 3.01 | 1.05 | 18.60 |
| December | 2.42 | 0.92 | 15.00 |
| Annual | 5.38 | 1.51 | 18.97 |

## Wind speed data

Table 3. 9: Monthly averaged wind speed data for Kalamata region (SAM input data)

| **Kalamata Airport (Latitude: 37.1° N, Longitude: 22.0° E, Elevation: 13 m) Weather station and calculated data** | | | | | |
|---|---|---|---|---|---|
| Month | Wind speed (m/s) @ 6m above the ground | Wind speed (m/s) @ 15m above the ground | | Wind speed (m/s) @ 98m above the ground | |
| | Original data | a=0.16 | a=0.24 | a=0.16 | a=0.24 |
| January | 2.37 | 2.75 | 2.96 | 3.71 | 4.64 |
| February | 2.53 | 2.93 | 3.15 | 3.95 | 4.94 |
| March | 2.54 | 2.94 | 3.16 | 3.97 | 4.96 |
| April | 2.33 | 2.70 | 2.90 | 3.64 | 4.56 |
| May | 2.27 | 2.63 | 2.83 | 3.55 | 4.44 |
| June | 2.65 | 3.07 | 3.30 | 4.15 | 5.18 |
| July | 2.82 | 3.27 | 3.52 | 4.42 | 5.52 |
| August | 2.69 | 3.12 | 3.35 | 4.21 | 5.26 |
| September | 2.41 | 2.79 | 3.00 | 3.77 | 4.71 |
| October | 2.09 | 2.42 | 2.60 | 3.27 | 4.08 |
| November | 2.12 | 2.45 | 2.64 | 3.31 | 4.14 |
| December | 2.36 | 2.73 | 2.94 | 3.69 | 4.61 |
| Annual | 2.43 | 2.82 | 3.03 | 3.80 | 4.75 |

Table 3. 10: Monthly averaged wind speed data for Capo Passero region (SAM input data)

| **Capo Passero (Latitude: 36.7° N, Longitude: 15.08° E, Elevation: 5 m) RETScreen and calculated data** | | | |
|---|---|---|---|
| Month | Wind speed (m/s) | Wind speed (m/s) | Wind speed (m/s) |

| | @ 10m above the ground | @ 15m above the ground | | @ 69m above the ground | |
|---|---|---|---|---|---|
| | Original data | a=0.16 | a=0.24 | a=0.16 | a=0.24 |
| January | 4.00 | 4.27 | 4.41 | 5.45 | 6.36 |
| February | 3.90 | 4.16 | 4.30 | 5.31 | 6.20 |
| March | 3.80 | 4.05 | 4.19 | 5.18 | 6.04 |
| April | 3.80 | 4.05 | 4.19 | 5.18 | 6.04 |
| May | 3.40 | 3.63 | 3.75 | 4.63 | 5.41 |
| June | 3.20 | 3.41 | 3.53 | 4.36 | 5.09 |
| July | 2.90 | 3.09 | 3.20 | 3.95 | 4.61 |
| August | 3.00 | 3.20 | 3.31 | 4.09 | 4.77 |
| September | 3.00 | 3.20 | 3.31 | 4.09 | 4.77 |
| October | 3.00 | 3.20 | 3.31 | 4.09 | 4.77 |
| November | 3.50 | 3.73 | 3.86 | 4.77 | 5.56 |
| December | 3.70 | 3.95 | 4.08 | 5.04 | 5.88 |
| Annual | 3.43 | 3.66 | 3.78 | 4.67 | 5.45 |

It is observed that in both locations the annual average wind speed is from low to medium even for the calculated data at the HAWT's hub height. The range of the wind speed values, which depend on the shear coefficient, becomes wider as the turbine hub height increases. Figures 9 and 10 demonstrate the monthly average wind speed values for Kalamata and Capo Passero respectively. The original measured data are depicted with the light blue line while the orange and grey line show the calculated wind speed values at the hub height of Aeolos VAWT using a shear coefficient of 0.16 and 0.24 respectively. Similarly, the yellow and blue line present the calculated wind speed values at the hub height of Enercon HAWT.

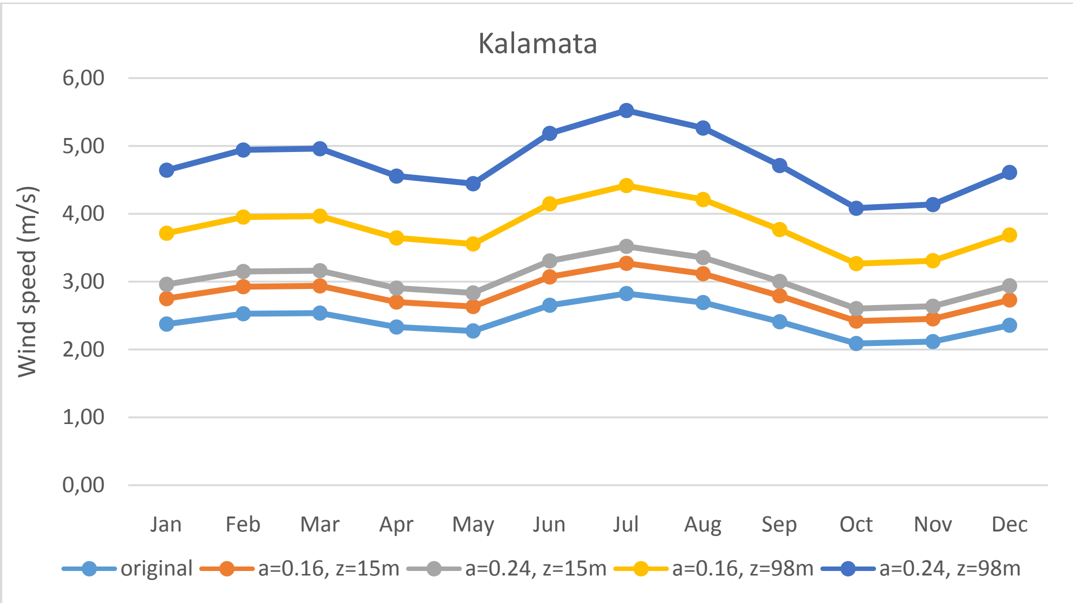



**Figure 3. 10: Monthly averaged wind speed values at turbines' hub height (Kalamata, Weather station)**

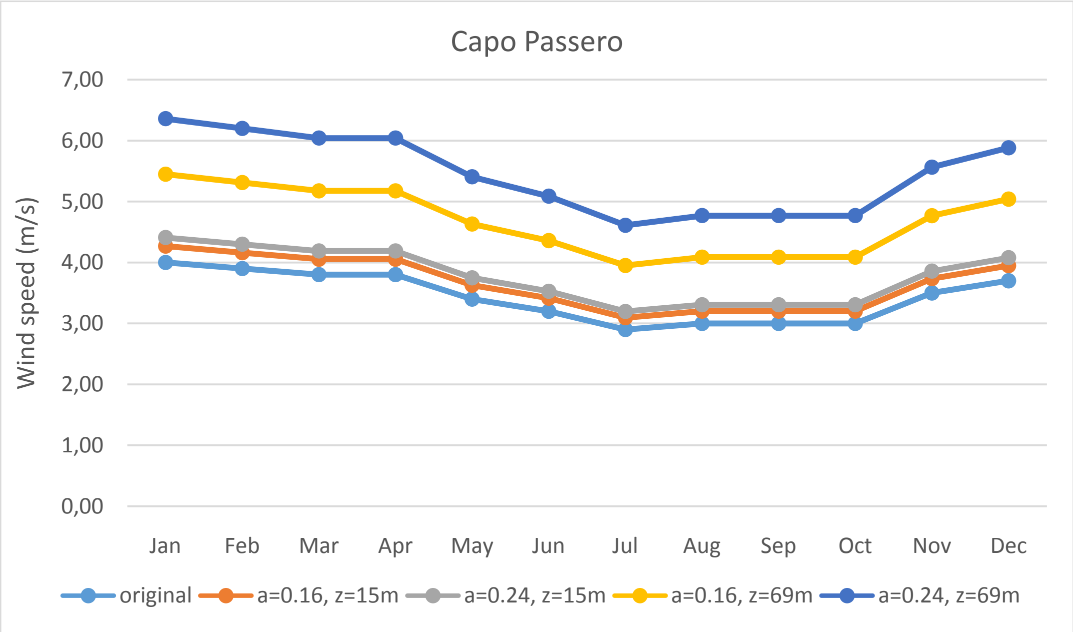



**Figure 3. 11: Monthly averaged wind speed values at turbines' hub height (Capo Passero, RETScreen database)**

Having finalised this analysis, a robust base for the climatic characteristics of each location has been formed containing also the uncertainties included in the data (measurement and/or computational uncertainties). The differences among the databases might be attributed either to the time period that the data were measured, or to the computational methods that the databases use to provide these data. In case of different time periods, the explanation may be fairly simple as the climatic characteristics of a location change over time (especially for parameters such as the irradiation and temperature).On the other hand, if the data among the databases have been acquired in similar time periods and there are still major discrepancies, then the computational methods, used by the databases, might be not straightforward to analyse, as in most cases limited information is provided on this subject. Hence, it is difficult to know how the various weather databases validate, compute and/or combine their sources. In order to avoid these factors, which can bring a great uncertainty on the energy prediction of the RET systems, the weather parameters have been presented individually for each database and a combination of weather databases is used in the simulation of the systems. Regarding the wind speed, a sensitivity analysis is made (chapter 5) in order to demonstrate the differences in the annual energy prediction of the wind turbines according to the various wind speeds. This is accomplished by using the "Wind speed Weibull distribution" option in SAM software in order to get a probabilistic approach. In addition, the temperature data influence the annual energy prediction of the PV systems but their influence is minor compared to the solar irradiation data. The approach is to use PVGIS data in order to retain a uniformity in the PV simulations by having both irradiation and temperature data form the same source. Further discussion takes place on Chapter 5 in the relevant sections.

To conclude, the PVGIS solar data are used for both locations for the PV system simulations. On the other hand, regarding wind turbines simulations for Capo Passero, RETScreen and HOMER software databases are used while for Kalamata the wind speed data from the local weather station and HOMER software are used.

# Chapter 4: RET market, technical characteristics and systems' design

## 4.1 RET market

The different PV and wind technologies have been presented in the first deliverable of WP10. This section presents the main manufacturers of horizontal and vertical axis wind turbines as well as of PV modules. According to PV tech, the top 10 module suppliers in 2017 are shown in the table below [37]:

Table 4. 1: The top 10 PV module suppliers in 2017

| Supplier | Headquarters | PV module technology |
|---|---|---|
| JinkoSolar [38] | China | mono and polycrystalline |
| Trina Solar [39] | China | mono and polycrystalline |
| Canadian Solar [40] | Canada | mono and polycrystalline |
| JA Solar [41] | China | mono and polycrystalline |
| Hanwha Q-cells [42] | South Korea | mono and polycrystalline |
| GCL-SI [43] | China | mono and polycrystalline |
| LONGi Solar [44] | China | monocrystalline |
| Risen Energy [45] | China | mono and polycrystalline |
| Shunfeng [46] | China | mono and polycrystalline |
| Yingli Green [47] | China | mono and polycrystalline |

As it is shown at the table, the PV module market is dominated by Chinese companies and mono and polycrystalline modules, as they are more technologically advanced regarding their efficiency. However, companies like Metsolar (European company) [48], Solaronix (Switzerland) [49] and Kameleon Solar (Netherlands) [50] produce coloured customised solar panels. Some pictures of their products and their applications are presented below.

Figure 4. 1: Kameleon Solar, LOF cells and PV façade [50]

Figure 4. 2: Solaronix, PV façade [49]

According to WindPower, the top 10 wind turbine manufacturers in 2017 are presented in Table 4.2 [51].

Table 4. 2: The top 10 wind turbine manufacturers in 2017 [51]

| Manufacturer | Headquarters | Wind turbine type |
|---|---|---|
| Vestas | Denmark | large-scale HAWT |
| Siemens Gamesa | Germany and Spain | large-scale HAWT |
| GE | US | large-scale HAWT |
| Goldwind | China | large-scale HAWT |
| Enercon | Germany | large-scale HAWT |
| Nordex group | Germany | large-scale HAWT |
| Senvion | Germany | large-scale HAWT |
| United Power | China | large-scale HAWT |
| Envision Energy | China | large-scale HAWT |

| | | |
|---|---|---|
| Suzlon | India | large-scale HAWT |

It can be noticed from Table 4.2 that HAWT market is mainly based in Europe in contrast to the PV module market. Similarly, with the PV module technologies, the large-scale onshore and offshore HAWTs dominate the market due to their better efficiency. Further, there are manufacturers of roof mounted VAWT such as Platek Services (Canada), Quietrevolution (UK) and V-air [52], [53]. In addition, manufacturers of small/medium-scale VAWT are GualIndustrie (France), OyWindside Production (Finland), Ropatec (Italy), Aeolos Wind Energy (UK), E-Novasolar (Italy)[52], HomeEnergy [54]etc. Some pictures of various types of VAWT are presented below.

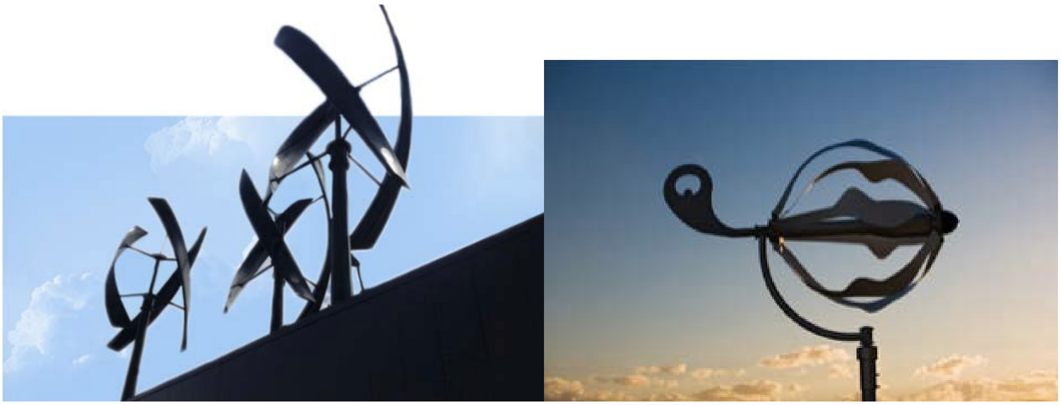


Figure 4. 3: Vision AIR and Energy ball wind turbines [53], [54]


Figure 4. 4: qr6, WS-30 and Aeolos V3kW wind turbines [55-57]

A communication plan was made and several companies have been contacted in order to ask for a quotation for specific models and/or technical queries about their products. Regarding the solar PV systems, Jinko Solar [38], Trina Solar [39] and JA solar [41], which are in the top 10 module manufacturers, have been contacted in order to obtain the costs of monocrystalline PV modules. Similarly, Metsolar [48], Solaronix [49] and Kameleon solar [50], which are manufacturers of coloured PV modules, have been contacted in order to check the costs for PV façades. Of course, the PV systems have three main parts; the PV module, PV inverter, and mounting structure. Hence, a market research was also made for PV inverter manufactures and their products. Some of the top inverter manufacturers are SMA [58], Solar Edge [59], ABB [60] and Fronius [61]. Specific manufacturers and/or distributors of PV mounting structures was not identified and contacted as the mounting structures will be provided along with the PV modules and inverters from the respective companies in Italy and Greece. Moreover, after contacting these companies, it was concluded that the chosen mounting structures will be fixed and not dual axis tracking mounted structures, as they will be much costlier in the initial investment and during the system lifetime because of their maintenance requirements. Table 4.3 summarises all the companies and their specific products regarding the PV systems. Similarly, Table 4.4 summarises all the models of the wind energy conversion systems considered in this study.

**Table 4. 3: Specific products for solar PV systems**

| SOLAR PV SYSTEMS | | |
|---|---|---|
| **Company** | **Product** | **Type** |
| Jinko Solar [38] | Eagle PERC 72<br>JKM350M-72 monocrystalline 350 W | PV module |
| Trina Solar [39] | Tallmax Plus<br>1. TSM-DD14A (II) (350 W)<br>2. TSM-DE14A (II) (350 W)<br>Splitmax<br>3. TSM-DE14H (II) (350 W) | PV module |
| JA Solar [41] | 72-Cell Mono PERC Module<br>JAM72S01/PR (375 W) | PV module |
| Metsolar [48] | Coloured customised | PV module |
| Solaronix [49] | Coloured customised | PV module |
| Kameleon solar [50] | Coloured customised | PV module |
| SMA [58] | 1. Sunny Tripower8000TL/ 8kW<br>2. Sunny Tripower 10000TL/ 10 kW<br>3. SUNNY TRIPOWER CORE1/ 50 kW | PV inverter |
| Solar Edge [59] | 1. SE100K/ 100 kW<br>2. SE50K/ 50 kW | PV inverter |
| ABB [60] | 1. PVI-10.0 /10 kW<br>2. TRIO-TM-50.0-400/ 50 kW | PV inverter |
| Fronius [61] | 1. Symo 8.2-3-M/ 8.2 kW<br>2. Symo 10.0-3-M/ 10 kW | PV inverter |

Regarding the large-scale wind turbines, Enercon [62], Senvion [63], Nordex [64] and Vestas [65], which are in the top 10 wind turbine manufacturers, were considered while regarding

VAWT and small-scale wind turbines models from Quietrevolution [55], V-air [53], HomeEnergy [54] and Aeolos Wind Energy [57] were contacted in order to have various options in the design.

Table 4. 4: Specific products for wind energy conversion systems

| WIND ENRGY CONVERSION SYSTEMS | | |
|---|---|---|
| Company | Product | Type |
| Enercon [62] | 1. E-103 EP2 / 2.35 MW<br>2. E-82 E4 / 2.35 / 3 MW<br>3. E-82 E2 / 2.0 MW<br>4. E-92/2.3 MW<br>5. E-126 EP3 / 3 / 3.5 MW | HAWT |
| Senvion [63] | 1. 3.4M122 NES<br>2. 2.3M130<br>3. MM100 (2 MW) | HAWT |
| Nordex [64] | 1. N100/2500 kW<br>2. AW140/3000<br>3. AW132/3000<br>4. AW125/3000<br>5. N117 / 2400 /3000 | HAWT |
| Vestas [65] | 1. V110-2.0 MW® IEC IIIA<br>2. V116-2.1 MW™ IEC IIB<br>3. V120-2.2 MW™ IEC IIB/IEC S<br>4. V126-3.45 MW. – IEC IIB/IEC IIA<br>5. V136-3.45 MW. – IEC IIB/IEC IIIA | HAWT |
| V-Air [53] | Vision Air 5 (130 RPM) | VAWT |
| HomeEnergy [54] | Energy Ball V200 / 2.5 kW | small-scale HAWT |
| Quietrevolution [55] | Qr6 / 100 – 260 RPM | VAWT |
| Aeolos [57] | 1. Aeolos-V 10kW<br>2. Aeolos-V 5kW | VAWT |

For all the products the installation costs have been asked for both locations along with the operation and maintenance (O&M) cost and the shipping costs. The companies have also been asked for local retailers/distributors. For the case of HWAT, technical questions have been asked as well (i.e. If these turbine models are suitable for the locations or not according to their wind generator class and wind zone specifications). Apart from the communication with these companies, PV and Wind installers in Greece and Italy were contacted in order to acquire a quotation for the various project costs. Not all of the companies replayed and not all the proposed products were suitable and/or economic for the two locations. For example, for the VAWT, Aeolos wind turbine is the most suitable choice because of its cut in wind speed. Appendix A includes all the quotations as they have been acquired for all the proposed RET projects in Italy and Greece and Appendix B includes all the technical datasheets of the main components of the RET systems. Further, Section 4.2 below analyses the choices of all products for the RET systems and presents their designs and technical characteristics.

## 4.2 Systems' designs and technical characteristics

This section presents all the systems' designs and their technical characteristics that are used in this techno-economic study for both locations. Enercon large-scale HAWT have been chosen of 2.35 MW and 3 MW installed capacity for the cities of Kalamata and Capo Passero respectively [62]. Regarding small-scale VAWT, Aeolos wind turbines have been chosen for installation inside the cities having an installed capacity of 10 kW each [66]. Table 4.5, shows the rated capacity, the respective models and the total number of the chosen wind turbines for both locations. Further, Figure 4.5 depicts the three wind turbine models.

**Table 4. 5: Chosen wind turbines**

| Wind Turbines | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Rated capacity (kW) | | Model | | Total No | |
| | | Kalamata | Capo Passero | Kalamata | Capo Passero | Kalamata | Capo Passero |
| Large-scale | HAWT | 2,350 | 3,000 | E-103 EP2 | E-82 E4 | 1 | 1 |
| Small-scale | VAWT | 10 | 10 | Aeolos-V | Aeolos-V | 6 | 6 |

**Figure 4. 5: Aeolos V 10 kW, Enercon E-103 EP2 2.35 MW, and Enercon E-82 E4 3 MW [67-69]**

Similarly, Tables 4.6 and 4.7 and Figures 4.6 to 4.9 present the chosen PV modules and inverters for large- and small-scale PV systems, which have been chosen for the two sites.

**Table 4. 6: Chosen PV modules and inverters for large-scale PV systems**

| Large-scale PV systems | | |
|---|---|---|
| | Kalamata | Capo Passero |

| | | |
|---|---|---|
| Module type | polycrystalline | monocrystalline |
| Module model | Suntech STP270-20/Wem | Jinko Eagle PERC 60 |
| No of modules | 1491 | 330 |
| Module rated power (W) | 270 | 305 |
| Inverter model | ABB PVS-100-TL | SolarEdge Synergy Technology |
| Inverter No | 4 | 1 |
| Inverter rated power (kW) | 100 | 82.8 |

**Table 4. 7: Chosen PV modules and inverters for small-scale PV systems**

| Small-scale PV systems (Kalamata and Capo Passero) | | | | |
|---|---|---|---|---|
| Customised module | 1 (Emerald Green) | 2 (Diamond Blue) | 3 (blue-green glass) | 4 (bronze glass) |
| Module type | polycrystalline | polycrystalline | monocrystalline | monocrystalline |
| Module colour | emerald green | diamond blue | standard | standard |
| Module glass colour | standard | standard | blue-green | bronze |
| Module rated power (W) | 240 | 235 | 251 | 254 |
| No of modules | 39 | 39 | 39 | 39 |
| Inverter model | Fronius Symo 8.2-3-M | Fronius Symo 8.2-3-M | Fronius Symo 8.2-3-M | Fronius Symo 8.2-3-M |
| Inverter No | 1 | 1 | 1 | 1 |
| Inverter rated power (kW) | 8.2 | 8.2 | 8.2 | 8.2 |

**Figure 4. 6: Customised 1 and 2; emerald green and diamond blue polycrystalline PV cells [70]**

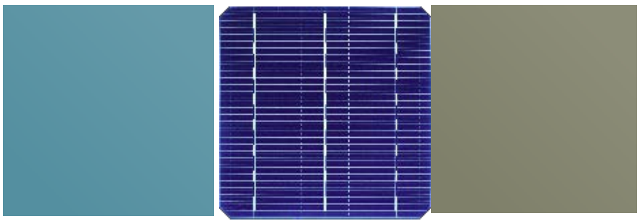


**Figure 4. 7: Customised 3 and 4; blue-green and bronze coloured glass with monocrystalline PV cells [70]**

Figure 4. 8: Polycrystalline Suntech STP270-20/Wem and monocrystalline Eagle PERC 60 modules [71, 38]


Figure 4. 9: Solar Edge Synergy technology SE 82.8K fixed voltage inverter, ABB PVS-100-TL string inverter and Fronius Symo 8.2-3-M [72-74]

All the choices of the systems have been based on their technical characteristics in combination with their utilisation purposes and the local weather conditions. For instance, for the customised modules the specific colours of the coloured cells and the coloured glasses have been chosen in order to provide a better efficiency than the rest available coloured options. Since these modules are going to be installed as façades, their tilt angle will be 90 degrees. This means that the systems would suffer a great loss in respect to their optimum designed tilt angle as they would not be able to utilise all the available irradiation. In both locations, the annual optimum tilt angle is around 29 to 30 degrees. On the other hand, these systems promote the RET technologies, the environmental awareness, and have an aesthetic value that may compromise their lower performance. The same stands for the vertical axis wind turbines. Further, as mentioned, the specific VAWT model was chosen because it has a low cut in wind speed (2.5 m/s). Since they are going to be installed in an urban environment with low wind speeds, most time of the year, the target is to produce as much energy as possible under the certain conditions. Moreover, the installed capacity of all RET systems is based on their economic characteristics as well in order to reduce the cost of the generated kWh where it is possible. For instance, in both locations it is more beneficial to installed a fixed mounted PV plant as the O&M cost would be disproportional to the advantage offered by the extra energy that a tracking mounted system can produce. The same reason stands for the choice of polycrystalline PV modules instead of monocrystalline for the case of Kalamata, even if it is widely known that the later have a greater efficiency. For the PV plant in Capo Passero, monocrystalline modules have been chosen with a fixed mounting structure based on the same logic. Finally, regarding the large-scale wind turbines, the two models have been chosen accordingly to the average wind speed of the two areas. Capo Passero has a low to medium annual average wind speed while Kalamata has a low annual average wind speed. Hence, for Kalamata a HAWT model of IIIA class was chosen while for Capo Passero a IIA class model was chosen. The wind turbine classes are divided according to the average wind speed and turbulence. The A stands for higher turbulence while the B stands for lower turbulence sites. The I, II, and III stand for high, medium, and low wind speed sites respectively.

Finally, Tables 4.8, 4.9, and 4.10, present the main technical characteristics of all the proposed RET systems.

**Table 4. 8: Wind turbines main technical characteristics [62, 75]**

| **Wind turbine** | E-103 EP2 | E-82 E4 | Aeolos-V |
|---|---|---|---|
| Rated power | 2.35 MW | 3.0 MW | 10 kW |
| Rotor diameter | 103.0 m | 82.0 m | – |
| Rotor width | – | – | 5.5 m |
| Hub height | 98 m | 69 m | 15 m |
| Wind class (IEC) | III A | II A | – |
| Cut-in wind speed | 2.5 m/s | 2.5 m/s | 2.5 m/s |
| Cut-out wind speed | 34 m/s | 34 m/s | 52.5 m/s |
| Rated wind speed | 12 m/s | 16 m/s | 11 m/s |
| Design lifetime | 25 yrs | 25 yrs | 20 yrs |
| Generator type | direct drive | direct drive | permanent magnet |

**Table 4. 9: PV inverters main technical parameters [73, 74, 76]**

| **PV inverter** | ABB PVS-100-TL | SolarEdge SE 82.8K | Fronius Symo 8.2-3-M |
|---|---|---|---|

| For the DC side | | | |
|---|---|---|---|
| Maximum DC power | 102 kW | 111.75 kW | – |
| Operating MPPT input voltage range | 480 – 850 V | Fixed voltage | 267 – 800 V |
| DC nominal voltage | 620 V | 750 V | 595 V |
| Maximum input voltage | 1000 V | 1000 V | 1000 V |
| No. of independent MPP trackers/ units | 6 / – | – / 3 units | 2/ – |
| Maximum DC current/ at each MPPT | – / 36 A | 120/ – A | – / 16 A |
| **For the AC side** | | | |
| AC Nominal Power | 100 kW | 82.8 kW | 8.2 kW |
| Maximum AC Voltage range | 320 – 480 V | 320 – 460 V | 150 –280 V |
| Nominal AC frequency range | 45 – 55 Hz | 50/60 ± 5 Hz | 50 / 60 Hz |
| Efficiency: Maximum/Euro-eta | 98.4% / 98.2% | 98.3% / 98.0% | 98.0% / 97.7% |

Table 4. 10: PV modules main technical parameters [38, 77, 78]

| **PV module** | STP270-20/Wem | Jinko Eagle PERC 60 | Customised 1 (Emerald Green) | Customised 2 (Diamond Blue) | Customised 3 (blue-green glass) | Customised 4 (bronze glass) |
|---|---|---|---|---|---|---|
| Number of cells | 60 | 60 | 60 | 60 | 54 | 54 |
| Maximum power rating ($P_{max}$) | 270 W | 305 W | 240 W | 235 W | 251 W | 254 W |
| Open circuit voltage ($V_{OC}$) | 37.9 V | 39.2 V | 37.74 V | 37.50 V | 36.12 V | 36.12 V |
| Maximum power voltage ($V_{MPP}$) | 31.1 V | 32.8 V | 31.38 V | 31.14 V | 30.61 V | 30.61 V |
| Short circuit current ($I_{SC}$) | 9.15 A | 10.12 A | 8.21 A | 8.12 A | 8.72 A | 8.81 A |
| Maximum power current ($I_{MPP}$) | 8.69 A | 9.31 A | 7.66 A | 7.54 A | 8.22 A | 8.32 A |
| Module efficiency (η) | 16.6 % | 18.63 % | 15.1 % | 14.7 % | 17.5 % | 17.7 % |

The main electrical components and their connections of the RET systems are depicted in the figures below.

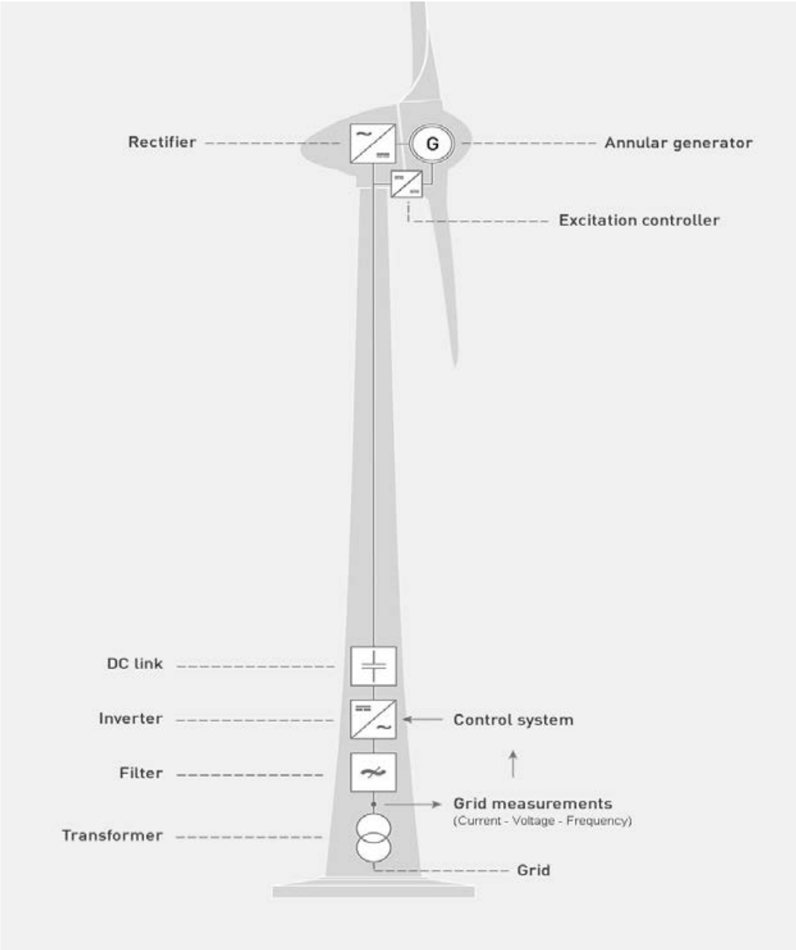



Figure 4. 10: Enercon wind turbines main electrical components [62]

Figure 4.10 presents the main electrical components of an Enercon HAWT. "The annular generator - comprising rotor and stator - forms the key component of the ENERCON wind energy converter design. Combined with the hub, it provides optimal energy flow. The sophisticated wind energy converter technology means minimal vibration during operation, low sound emissions and a long service life" [62]. Moreover, the "excitation systems can be defined as the system that provides field current to the rotor winding of a generator. Well-designed excitation systems provide reliability of operation, stability and fast transient response" [79].

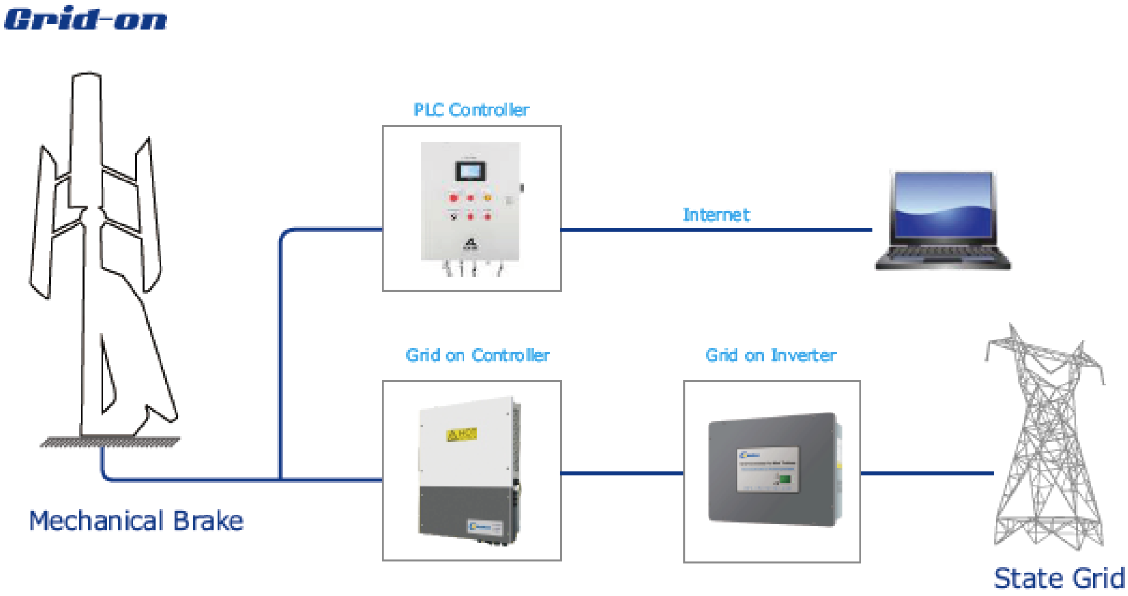



Figure 4. 11: Aeolos wind turbines wiring diagram [75]

Figure 4.11 presents the wiring diagram of Aeolos VAWT. The grid-connected Aeolos VAWTs are connected to the grid through a grid on controller and inverter. Moreover, they can use a PLC (Programmable Logic Controller) to monitor the inputs and the outputs of the turbine. Generally, a PLC "is an industrial computer control system that continuously monitors the state of input devices and makes decisions based upon a custom program to control the state of output devices" [80].

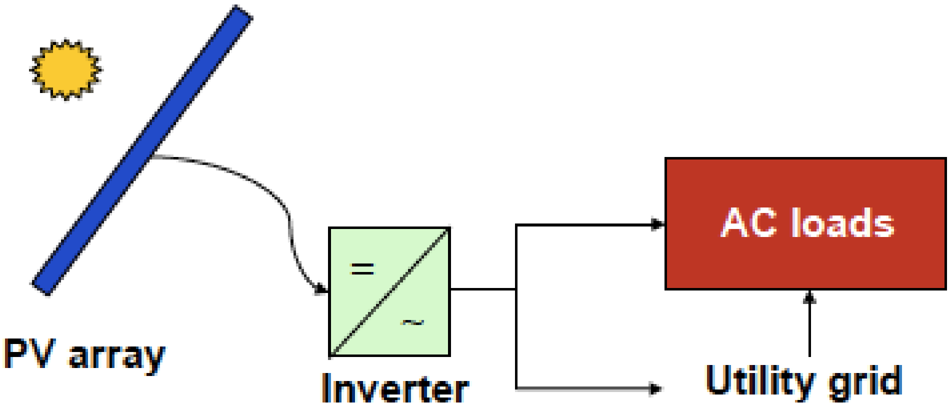



Figure 4. 12: Grid-connected PV systems [81]

Figure 4.12 presents the electrical configuration of any grid-connected PV system. The grid-connected PV systems are comprised by the PV modules that constitute the PV array. In addition, the PV array is connected to the grid through the inverter. The inverters that have been chosen for the two PV plants in Italy and Greece are the three phase SolarEdge Synergy Technology and ABB PVS respectively. The SolarEdge inverter is a fixed voltage inverter that uses the power optimiser technology. "The power optimizers are DC-DC converters connected to PV modules in order to maximize power harvesting by performing independent Maximum Power Point Tracking (MPPT) at the module level. The power optimizers regulate the string voltage at a constant level, regardless of string length and environmental conditions. The inverter is comprised of one Primary Unit with an integrated Connection Unit with a DC Safety Switch for disconnecting the DC power of a SolarEdge system, and of one or two Secondary Units, depending on the inverter's capacity. The Secondary Unit(s) are connected to the primary unit with AC, DC and communication cables. Each unit operates independently and continues to work in case the others are not operating" [72]. For the PV plant in Italy, SolarEdge technology seems to be a good solution on both technical and financial characteristics. From the point of the technical view, it is good that this inverter has three independent units since only one inverter will be used in this PV plant. Moreover, its DC maximum power input reaches the 111.75 kW even if its nominal AC power is 82.8 kW. This means that the losses over the inverter power input will be minimised. On the financial point of view is a good solution, since one inverter is better than two or more with smaller capacity.

Further, the ABB PVS inverter is a three-phase high power string inverter. The string inverters convert the power from the module strings that are connected. For the PV plant in Kalamata, four of them are going to be used and each of them has 6 maximum power point trackers [73]. This means that in case of a failure of one inverter the systems will still produce the 75% of each energy. Moreover, the 6 MPPTs in one inverter enable to harvest the maximum energy available from the strings of modules that are connected to each MPPT. Generally, the string inverters can be more convenient than the central type inverters regarding operation and maintenance aspects even if a central inverter may be a cheaper option in the initial investment [82].

# Chapter 5: Energy prediction

This chapter analyses the energy output of the proposed RET systems in accordance with the energy requirements of the KM3Net project in each site. As it was stated in the first deliverable of WP10, the averaged power requirement for each site of the project is assumed as 615 kW. Hence, every site will require 615 kW*365 days*24 hours= 5,387.4 MWh of energy for every year to be covered by RET. This amount of energy will cover a 24/7 operation. By taking into account the periods of maintenance, dead time etc., it has been concluded that in this initial study the systems will be designed in order to cover the 80% of this amount; hence, 5,387.4 MWh*0.8≈4310MWh/year. Note that this amount of required energy is based on an average assumption; thus, it might change in the future in order to cover the specific energy needs of each location. Moreover, by degrading the initial energy requirement 20%, it makes the overall RET investment more economic than the 100% amount of energy as it will not be needed for the experiment all of the time.

## 5.1 RET proposed scenarios

According to the climatic factors of the two locations, two scenarios are proposed in this deliverable; one for Kalamata and one for Capo Passero. These scenarios are based on the chosen systems presented in Chapter 4. Note that these suggestions might change during the realisation stage as the ultimate target is to propose scenarios both technically and economically viable for all the sites. However, at this stage various options are examined since the specific locations for the installation of the systems are not known yet.

In summary, the proposed scenarios are:

Kalamata: 1) one large-scale horizontal axis wind turbine of2.35 MW installed capacity, 2) PV systems of around 440 kW installed capacity (around 40 kW are infrastructures of high aesthetic value (PV façades), hence they will produce less energy and they will be costlier), 3)small-scale vertical axis wind turbines of 60 kW total installed capacity. These are considered to cover urban electricity needs and used for promotion purposes as their performance will be much lower compared to horizontal axis wind turbines.

Capo Passero: 1) one large-scale wind turbine 3 MW of installed capacity (it can produce fairly large amounts of energy if it is installed in the right location and at the same time it can be cost-effective), 2)PV systems of 140 kW of total installed capacity, and 3) 60 kW capacity of small-scale vertical axis wind turbines.

The total installed capacity is 2.85 MW for Kalamata while it is 3.2 MW for Capo Passero. The reason why the total installed capacity in Capo Passero is greater than in Kalamata is in accordance to the first deliverable where it is stated that the project facilities in Italy require around680 kW*365 days*24 hours= 5,956.8 MWh per year. By degrading the initial energy 20%, the required energy would be5,956.8*0.8≈4,766 MWh/year. Hence, for Italy the required energy is between 400 to 600 MWh/year above average depending on degrading or not the energy requirement.

The systems of high aesthetic value have very small total capacity compared to the common commercial systems. This is because they are mainly used for promotion purposes while the biggest amount of the required energy will be supplied by the commercial systems. Since the two locations have similar solar resource but they differentiate in their wind resource, the proposed HAWT in Italy has a greater capacity than the one in Greece. The small-scale PV and wind systems are the same for both sites while the commercial PV system in Kalamata is four times larger than the one in Capo Passero. These scenarios were chosen in order to examine the outcomes of installing different proportions between wind and PV technologies, as well as, to demonstrate the different types of RET that can be utilised in these locations. Finally, an example is also given for Kalamata region by replacing the HAWT with commercial PV plants only. This example covers the case of not actually finding an available location with the right wind resource to install the HAWT.

### 5.1.2 Methodology

As it was mentioned in Chapter 3, SAM and HOMER software packages are used for the wind turbines' simulation while PVsyst is used for the PV systems' simulation. Nine simulations in total were produced in SAM; five for the region of Kalamata and four for the region of Capo Passero. Respectively, in HOMER 12 simulations were conducted, six for each location. Of the 21 simulations in the two packages the 15 concern the HAWT, while the 6 the VAWT.

The purpose was to produce a range of annual energy values according to the various annual average wind speeds, which were either calculated, acquired from the meteorological database or assumed based on the calculated ones. These values present actually a sensitivity analysis relating different heights above the ground, shear coefficients and Weibull k parameters. Moreover, the option to investigate the outputs of the two simulation packages for the HAWT is provided by inserting similar inputs to some of the simulations. The VAWT is only simulated in HOMER software and a comparison of the simulated annual energy production is made with the annual energy provided in the manufacturer specifications. Each simulation case, with the respective parameters, is explained analytically in Section 5.2.1, where the inputs and the results of the 21 simulations are presented. Finally, about the PV systems, eleven simulations were conducted in total in PVsyst software. The ten simulations considered the 5 different PV systems proposed for each location. Hence, four simulations were made for the four PV façades and one for the PV plant in each site. The eleventh simulation was made as an example, only for Capo Passero, to demonstrate theenergy difference between a fixed mounted and a tracking mounted PV plant. Since in both countries the PV companies have suggested a fixed mounted structure the results of this extra simulation are included only in Section 5.2.2 and not in the overall analysis. Similarly, the input and the output parameters for each PV simulation are shown in Section 5.3.

The lifetime energy prediction, it is calculated according to the Equation 5.1 and assumes a linear average degradation rate of 0.5%/year. For the PV systems, which have crystalline module technology, and for the two specific locations, which have a Mediterranean climate, this assumption is very close to reality according to field studies. On the other hand, for the HWAT and VAWT systems there is no sufficient number of degradation studies in order to conclude in a degradation percentage and/or a pattern in accordance to the climate. In a study of Staffell and Green regarding the UK's wind farms and how their performance declines through time, it was found that the average degradation rate is 0.6%/year [83]. However, Olauson et al, by replaying in the aforementioned study regarding the WT performance decline in Sweden, stated that they found an overall degradation of 6% over a 20-year period (0.3%/year) [84]. Hence, in this study, a degradation rate of 0.5%/year is used for all RET systems, mainly for uniformity reasons.

$$Lifetime\ Energy = \sum_{i=0}^{N} E_n \times (1 - n \times D) \tag{5.1}$$

Where, $E_n$ is the generated energy by the RET system in year n and D is the annual degradation rate. Finally, the lifetime energy has been calculated for both 15 and 25 years for all the RET systems. The 15 years represent the period of the experiment operation while the 25 years represent the RET systems' lifetime.

### 5.1.3 Performance parameters

The most common performance parameter for the PV systems is the performance ratio while for the wind turbines is the capacity factor and for both is the specific production parameter.

The specific production is the generated energy by the system in one year and divided by its rated power. Otherwise, it is called specific yield and defines the number of hours that the system needs to operate at its maximum power in order to provide the same amount of energy and is often expressed as the annual energy output per kW (kWh/kW/year). Since the specific production normalises the produced energy with respect to the system size, this parameter is used to compare the produced energy of systems with different sizes, designs, or technologies. Regarding PV systems, the specific yield is dependent on the solar resource and varies in accordance with the irradiation. Hence, if the comparison is made for different locations or time periods, it will not be accurate because solar irradiation is varying [85, 86]. The same stands for the wind resource and consequently the Wind energy conversion systems.

The performance ratio (PR) is used in PV systems and is the final PV system yield ($Y_f$) divided by the reference yield ($Y_r$) (equation 5), where $Y_r$ is the system output for an ideal system and its numerical value is equal to the PV total in-plane irradiance divided by the reference irradiance. PR does not indicate the solar resource variations because of its definition and it is a dimensionless value. It describes the overall effect of system losses on the rated output due to the inverter inefficiency, wiring mismatch and general losses included in the system conversion efficiency. It also includes the losses from the PV module temperature, the partial use of irradiance due to the reflection from the module front surface, the soiling or the snow on the modules, the system downtime, and component failures [85].

$$PR = \frac{Y_f}{Y_r} \text{ (dimensionless)} \tag{5.2}$$

The capacity factor constitutes the ratio of the system's predicted electrical output during the first year of operation to the nameplate output that is equal to the quantity of energy the system would produce if it functioned at its nameplate capacity for each hour of the year [21] (equation 6).

Capacity Factor = Annual Energy (kWh/yr) / System Capacity (kW) / 8760 (h/yr) (5.3)

## 5.2PV monthly specific production and WT annual energy

In this section, thePV monthly and WT annual energy prediction of the RET systems in the two locations is presented as well as the simulation cases with their inputs and outputs. The input and output parameters of SAM, HOMER and PVsyst have already been discussed in Section 2.2.1 together with their calculations and losses treatment. Hence, their inputs and outputs presented here concern the specific simulation cases and the sensitivity analysis, which was made for the wind turbines.

### 5.2.1 Wind turbines' annual energy

The input parameters for the simulations in SAM were: the annual average wind speed (m/s), the k parameter of the Weibull distribution, the shear coefficient, the reference height for wind speed (m), the wind turbine loss factor (%) and the relevant wind turbine characteristics. The output parameters were: the annual energy (kWh), the specific production (kWh/kW/year) and the capacity factor (%) of the simulated HAWT. For HOMER the input parameters were: the geographical location (i.e. latitude, longitude, elevation), the monthly averaged wind speed data (m/s), anemometer height (m), wind speed profile (i.e. choice between power law and logarithmic), Weibull k parameter (default value 2), diurnal pattern strength (default value 0.25), 1 hr. autocorrelation factor (default value 0.85), hour of peed windspeed (default value 15), wind turbine losses (%) and the relevant wind turbine characteristics. From the various output parameters that HOMER provides, the annual energy and the capacity factor were chosen and the specific production was calculated for uniformity reasons between the two software packages.

Further, as mentioned, SAM's monthly energy values for the HAWT varying according to the days of each month as its input is the annual average wind speed for each location. Respectively, in HOMER, the monthly power output of the simulated wind turbines varies according to the average monthly wind speed values. Since the monthly wind speed values and their patterns have been analysed in Section 3.2, there is no need to present 12 graphs depicting the monthly power output for every wind turbine simulation conducted in HOMER. However, four graphs depicting the HWAT monthly power output are presented as an example at the end of this section. These graphs are provided by the HOMER software and they actually confirm the pattern of the wind speed values for each weather database and location.

The tables below show analytically the input values for all the simulation cases, which were created for the sensitivity analysis and the comparison between the two software packages. Except for those values, a constant loss factor of 6% is used in all the simulations to contemplate for the annual turbine losses. S1 to S4 or S5 are the simulations conducted in SAM, while H1 to H6 are the simulations conducted in HOMER for the two locations. For Kalamata and for the cases S1-S3 the shear coefficient value, is the value that was used to calculate the wind speed at the turbine's hub height (98 m).This also stands for S1 and S2 cases for Capo Passero (hub height 69 m). Further, because the S4 case for Kalamata and

S3for Capo Passero take an imaginary wind speed value (1m/s higher than the highest calculated value), they do not include a shear coefficient. Finally, the S5 case for Kalamata and S4 for Capo Passero use the same input data as in HOMER software. Hence, in this case the 0.14 shear coefficient is used by the software to adjust the wind speed from the 50 m at the anemometer height to the turbine's hub height. Regarding the Weibull k parameter, the values, which were chosen for the simulation cases, were the default value and the values that have been obtained for the specific locations through the literature. The observed k Weibull parameter for the region of Kalamata is 1.12 [87] while for the region of Pachino is 1.652 for an average annual wind speed [88]. In general, k parameter defines the shape of the Weibull wind speed distribution. As the value becomes smaller the shape leans towards smaller wind speed values. This is favourable for sites with low wind speeds, as it matches with the wind speed profile of the location and results to estimate higher energy output for the WT.

**Table 5. 1: Wind turbine simulation cases for Greece, Kalamata**

| Simulation case abbreviation | reference height for wind speed (m) | annual average wind speed (m/s) | Weibull k parameter | shear coefficient a | Weather database |
|---|---|---|---|---|---|
| SAM (Greece, Kalamata) | | | | | |
| **S1.WS** | 98 | 3.8 | 1.12 | 0.16 | weather station |
| **S2.WS** | 98 | 4.75 | 1.12 | 0.24 | weather station |
| **S3.WS** | 98 | 4.75 | 2 | 0.24 | weather station |
| **S4.Assumption** | 98 | 5.75 | 2 | - | Assumption |
| **S5.NASA** | 50 | 5.01 | 2 | 0.14 | NASA SSE |
| HOMER (Greece, Kalamata) | | | | | |
| **H1.NASA** | 50 | 5.01 | 2 | 0.14 | NASA SSE |
| **H2.WS** | 50 | 3.41 | 2 | 0.16/0.14 | weather station |
| **H3.WS** | 98 | 4.75 | 2 | 0.24 | weather station |
| **H4.VAWT** | 50 | 5.01 | 2 | 0.14 | NASA SSE |
| **H5.VAWT** | 50 | 4.05 | 1.12 | 0.24/0.14 | weather station |
| **H6.VAWT** | 50 | 4.05 | 2 | 0.24/0.14 | weather station |

Regarding HOMER, H1 and H4 cases use HOMER wind speed data (NASA SSE) and its default values for both locations. H1 case concerns the HAWT while H4 the VAWT simulations. Moreover, H2 case calculates the wind speed at 50 m above ground from the weather station or RETScreen data with a shear coefficient of 0.16 (red coloured values) while the software adjusts the wind speed at hub height with a shear coefficient of 0.14. Similar method is followed for the simulation of the VAWT in the cases H5 and H6 for both locations. The reason why a shear coefficient of 0.14 was chosen in order to adjust the wind speed at the WT's hub height (apart from the fact that it is the default value in both software), is to obtain a more realistic energy prediction. As it was mentioned, in the power low, the higher the exponent value, the higher the estimated wind speed value. Therefore, the higher the wind speed value, the higher the energy prediction. However, the option of a higher wind speed value than the ones obtained, it is covered by the assumption cases (S4 for Kalamata and S3 for Capo Passero). Finally, S5 case with H1 case (light green rows) and S3 with H3 (light orange rows) have the same inputs for Kalamata in order to compare the outputs of the two software. Similarly, for Capo Passero the inputs are the same in the cases S4 and H1 (light green rows).

**Table 5. 2: Wind turbine simulation cases for Italy, Capo Passero**

| Simulation case abbreviation | reference height for wind speed (m) | annual average wind speed (m/s) | Weibull k parameter | shear coefficient a | Weather database |
|---|---|---|---|---|---|
| SAM (Italy, Capo Passero) | | | | | |
| **S1.RETScreen** | 69 | 4.67 | 1.652 | 0.16 | RETScreen |
| **S2.RETScreen** | 69 | 5.45 | 1.652 | 0.24 | RETScreen |
| **S3.Assumption** | 69 | 6.45 | 2 | - | Assumption |
| **S4.NASA** | 50 | 5.84 | 2 | 0.14 | NASA SSE |
| HOMER (Italy, Capo Passero) | | | | | |
| **H1.NASA** | 50 | 5.84 | 2 | 0.14 | NASA SSE |
| **H2.RETScreen** | 50 | 4.44 | 2 | 0.16/0.14 | RETScreen |
| **H3.RETScreen** | 69 | 5.45 | 2 | 0.24 | RETScreen |
| **H4.VAWT** | 50 | 5.84 | 2 | 0.14 | NASA SSE |
| **H5.VAWT** | 50 | 4.44 | 2 | 0.16/0.14 | RETScreen |
| **H6.VAWT** | 50 | 4.44 | 1.652 | 0.16/0.14 | RETScreen |

Having analysed the inputs for the sensitivity analysis and the comparison between the two software, the results from all the simulations are presented below. In both locations, the best-case scenario is the assumption case for the HAWT where the highest wind speed value is encountered. On the other hand, the worst-case scenario is H2 case as apart from the lowest wind speed, it also uses a 0.14 shear coefficient for the adjustment of the wind speed to the hub's height and the default k parameter. By comparing the cases H2 with S1 for Kalamata, it is observed that even both cases have low wind speed, S1 has a capacity factor around 15% while H2 has 9.4%. This is attributed on the k parameter, which is smaller for S1 case and consequently more favourable than H2 case. Another reason is that by comparing the outputs of the two software packages when having the same inputs, it is shown that SAM software gives an estimation of the annual specific production about 9.73% higher than HOMER (average value). Specifically, the specific production percentage differences based on SAM software for the cases S3/H3, S5/H1 (Kalamata) and S4/H1 (Capo Passero) are 8.16%, 9.7% and 11.35% respectively. Finally, it is noticed that the capacity factor for the HAWT is higher in Kalamata than Capo Passero for all the simulation cases. The main difference is the turbine's hub height between the two locations as the wind speed in Capo Passero is higher than the wind speed in Kalamata. Moreover, this might be an indication that the wind speed values in Capo Passero are not high enough for the specific hub height (69 m) of the WT.

**Table 5. 3: Simulation results for Kalamata, Greece**

**Kalamata, Greece**

| **Simulation case abbreviation** | Annual Energy (kWh) | Specific Production (kWh/kW) | Capacity Factor (%) |
|---|---|---|---|
| **S1.WS** | 3017585.00 | 1311.99 | 14.98 |
| **S2.WS** | 4354678.00 | 1893.34 | 21.60 |
| **S3.WS** | 3821068.00 | 1661.33 | 19.00 |
| **S4.Assumption** | 5834823.00 | 2536.88 | 29.00 |
| **S5.NASA** | 5342338.00 | 2322.76 | 26.50 |
| **H1.NASA** | 4929048.00 | 2097.47 | 23.90 |
| **H2.WS** | 1931280.00 | 821.82 | 9.38 |
| **H3.WS** | 3585715.00 | 1525.84 | 17.40 |
| **H4.VAWT** | 7597.00 | 759.70 | 8.67 |
| **H5.VAWT** | 7484.00 | 748.40 | 8.54 |
| **H6.VAWT** | 3976.00 | 397.6 | 4.54 |

Regarding the VAWT (cases H4-H6), it is observed that by using NASA SSE wind speed at 50 m above ground, they provide quite descent results for their annual energy generation especially for Capo Passero (capacity factor 13.6%, case H4).However, when the wind speed is calculated for 50 m above ground (cases H5 and H6) the annual energy is reduced to around the half of its value in both locations. The only exception is the case H5 for Kalamata and it is attributed to the use of a low k parameter. According to the manufacturer's specifications, Aeolos 10 kW VAWT is expected to produce 8158 kWh/year at an annual average wind speed of 4 m/s and 15026 kWh/year at 5 m/s. The percentage difference form those values to the simulated ones based on the manufacturer's specifications are 6.88% and 20.83% for Kalamata and Capo Passero respectively (case H4). Accounting for the turbine losses of 6% that are included in the simulations and that the wind speeds at the turbine's hub height are 4.24 m/s for Kalamata and 4.93 m/s for Capo Passero (i.e. using the power low, a=0.14) the percentage difference between the two values could be reduced. Moreover, the values from the manufacturer's specification concern the standard conditions of temperature and pressure while HOMER makes a correction from the standard air density to the actual.

Table 5. 4: Simulation results for Capo Passero, Italy

**Italy, Capo Passero**

| Simulation case abbreviation | Annual Energy (kWh) | Specific Production (kWh/kW) | Capacity Factor (%) |
|---|---|---|---|
| **S1.RETScreen** | 3148869.00 | 1042.67 | 11.90 |
| **S2.RETScreen** | 4489736.00 | 1486.67 | 17.00 |
| **S3.Assumption** | 6040304.00 | 2000.10 | 22.80 |
| **S4.NASA** | 5373432.00 | 1779.28 | 20.30 |
| **H1.NASA** | 4732127.00 | 1577.38 | 18.00 |
| **H2.RETScreen** | 2268897.00 | 756.30 | 8.63 |
| **H3.RETScreen** | 3539734.00 | 1179.91 | 13.50 |
| **H4.VAWT** | 11896.00 | 1189.60 | 13.60 |
| **H5.VAWT** | 5135.00 | 513.50 | 5.86 |
| **H6.VAWT** | 6636.00 | 663.60 | 7.58 |

In both locations the difference between the max and the min annual energy predictions among the cases is around 3,800,000 kWh for the HAWT. This value demonstrates a great uncertainty considering that the average and median energy values are around 4,100,000 kWh/year and 4,360,000 kWh/year for Kalamata and Capo Passero respectively. Hence, in the technical (section 5.3) and economic evaluation of all the RET systems, the S2 case is used for the HAWT in Italy and S2 and S3 for Kalamata as they are the closest to the median and average of all the cases. Moreover, there is no point to install a system with low capacity factor and specific energy production as it will not be economically viable. For the VAWT, the best and the worst cases are presented in both locations in order to gain a better view in their technical and economic viability.

Table 5. 5: Average, median, max and min values for the HAWT

| | Kalamata | | Capo Passero | |
|---|---|---|---|---|
| HAWT | Annual Energy (kWh) | Specific Production (kWh/kW) | Annual Energy (kWh) | Specific Production (kWh/kW) |
| **Average** | 4102066.88 | 1771.43 | 4227585.57 | 1403.19 |
| **Median** | 4087873.00 | 1777.34 | 4489736.00 | 1486.67 |
| **Max** | 5834823.00 | 2536.88 | 6040304.00 | 2000.10 |
| **Min** | 1931280.00 | 821.82 | 2268897.00 | 756.30 |

The graphical representation of the HAWT is shown in the Figures5.1-5.4. The first two depict the specific production with the average annual wind speed and the annual energy with the capacity factor for all the cases for Kalamata. Similarly, the other two depict the cases for the HAWT in Capo Passero. Finally, the last four figures of this section have been acquired in picture format by HOMER software. They demonstrate that the pattern of the monthly WT power output follows the pattern of the monthly average wind speed values of each database that have been inserted in the software. Hence, the pattern of the Figure 5.5 matches with NASA SSE and Kalamata's weather station monthly wind speed pattern. Similarly, Figure 5.6 matches with the wind speed patterns of NASA SSE and RETScreen for Capo Passero(see section 3.2, figures3.4 and 3.5).

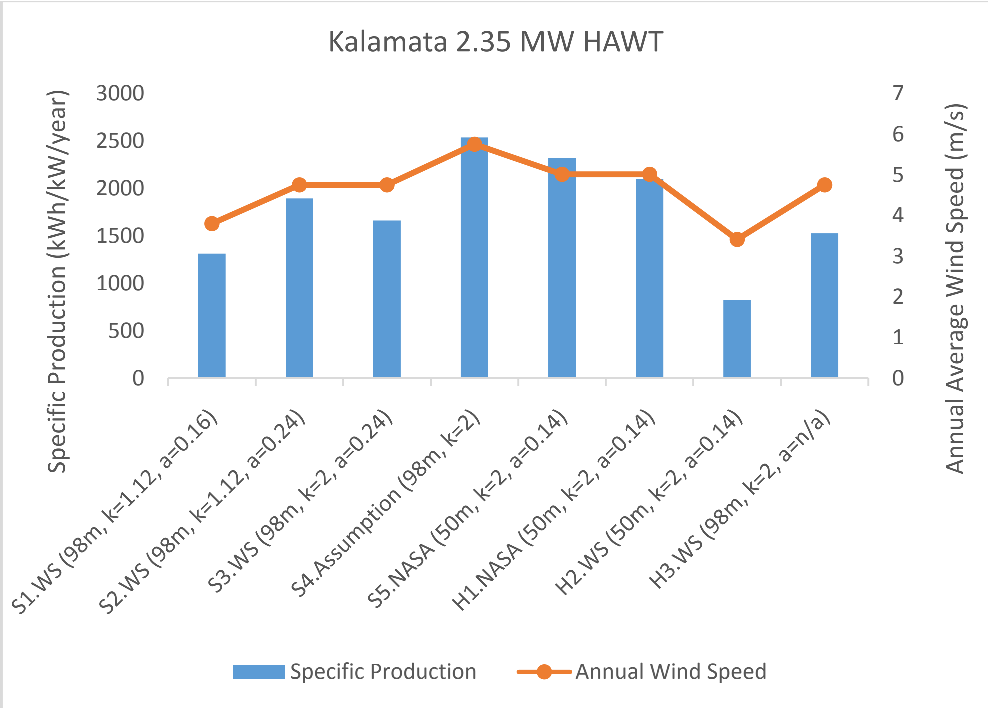



**Figure 5. 1: Specific production and annual wind speed for the HAWT cases in Kalamata**

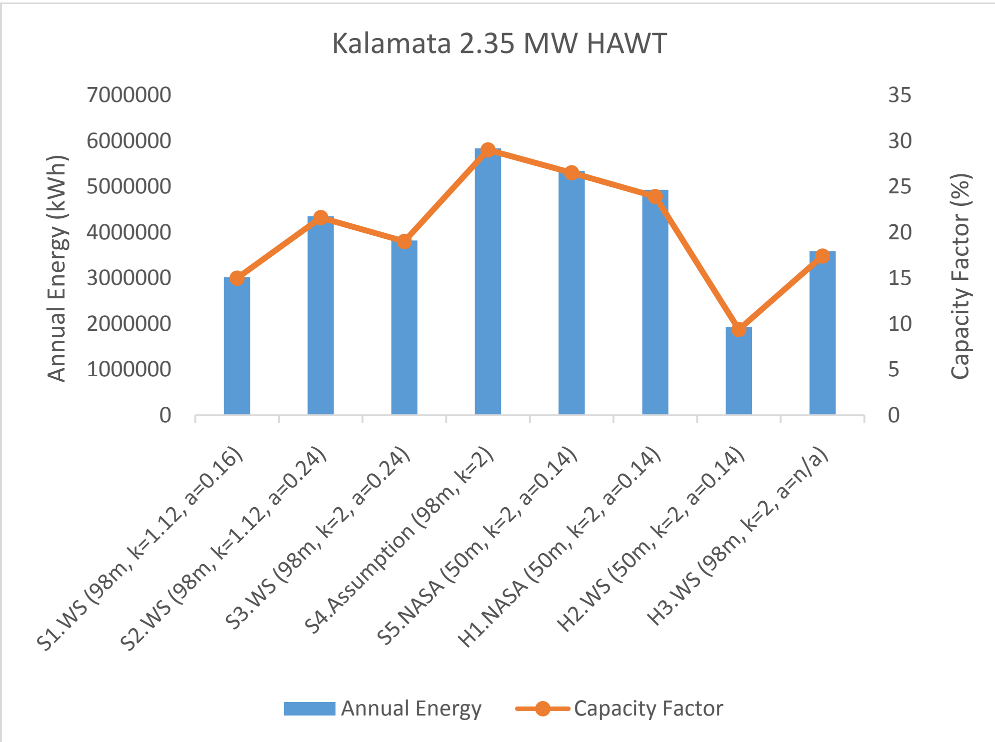



**Figure 5. 2: Annual energy and capacity factor for the HAWT cases in Kalamata**

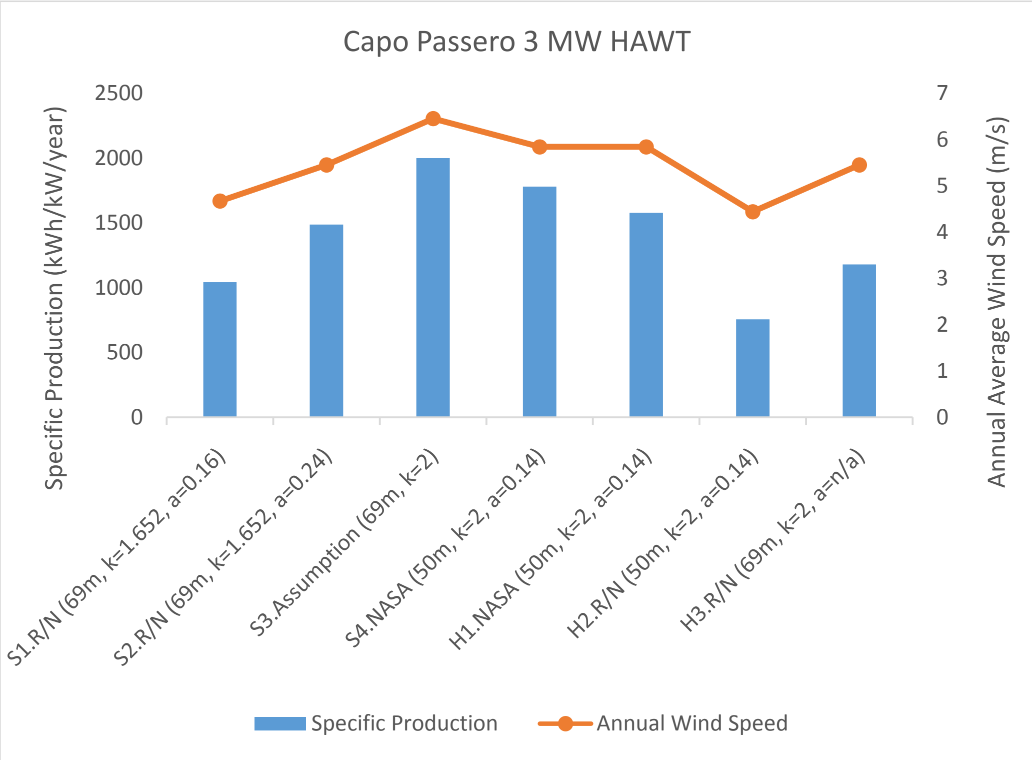



**Figure 5. 3: Specific production and annual wind speed for the HAWT cases in Capo Passero**

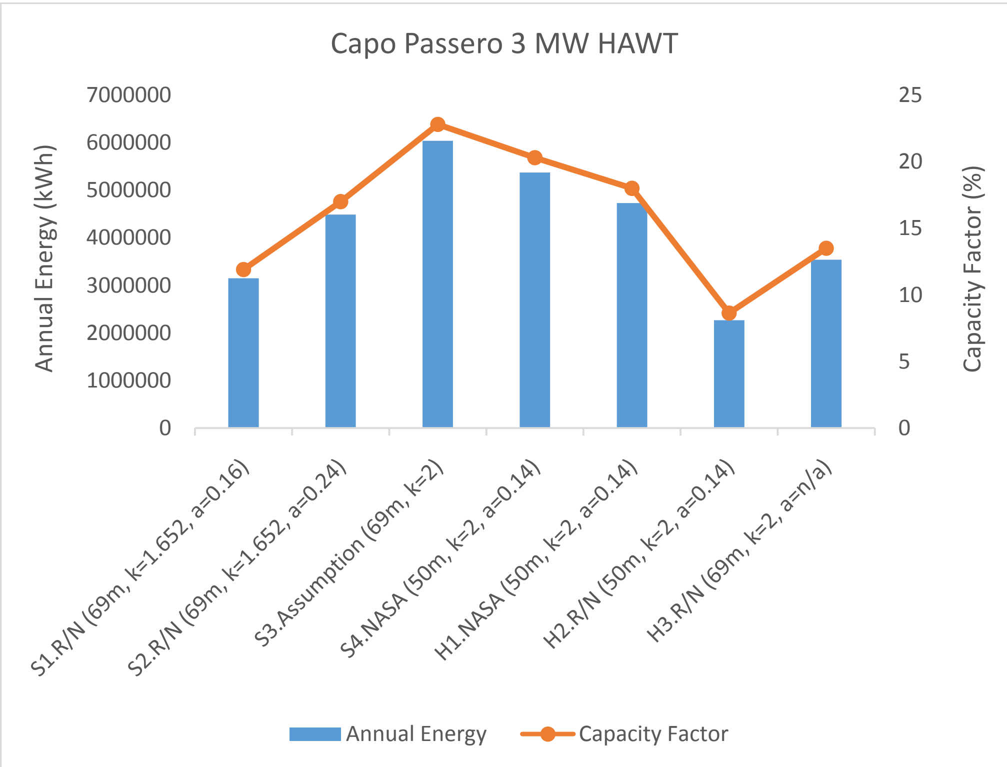



**Figure 5. 4: Annual energy and capacity factor for the HAWT cases in Capo Passero**

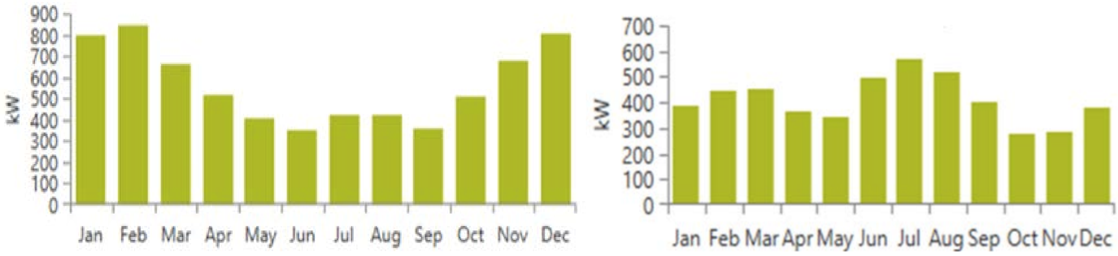



Figure 5. 5:Kalamata NASA SSE and weather station (H1 &H3 cases) [19]

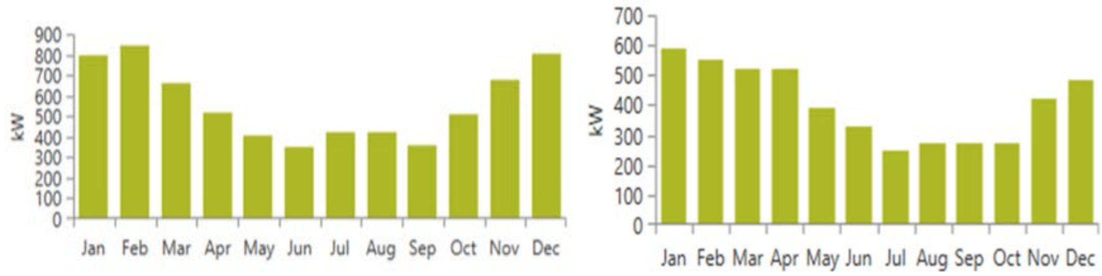



Figure 5. 6: Capo Passero NASA SSE and RETScreen (H1 & H3 cases) [19]

### 5.2.2 PV systems' monthly specific production

This section presents the monthly specific production for all the PV systems in both locations and the input parameters for the simulations. The same annual output parameters with the WT have been chosen for comparison purposes and are presented in the following section. However, the annual PV systems' performance ratio is presented in the end of this section as the performance ratio is a metric that concerns only PV systems.

The main inputs for the PV systems simulations were: the geographical location and PVGIS meteo data, tilt angle (optimum for the PV plants and 90° for the PV façades), orientation (due to south), field type of the array (i.e. fixed or tracking mounted), albedo value (default value 0.2 for an urban environment and grass) and the array loss factors, which have been explained in Section 2.2.1 and are summarised in the table below.

Table 5. 6: PV array loss factors

| PV array loss factors | | | | | | |
|---|---|---|---|---|---|---|
| Thermal loss factor | Wiring ohmic loss at STC | Module quality loss | Power loss at MPP | Loss at fixed voltage | Soiling loss | IAM loss ASHRAE model $b_0$ |
| 20 $(W/m^2)$*K | 1.5% | 1.5% | 2% | 4% | 3% | 0.05 |

From Figures 5.7 and 5.8, it can be observed that the Customised 3 and 4 systems produce steadily more energy per kW for both locations. This is mainly due to the efficiency of the solar modules since the systems' designs are identical. Customised 3 and 4 systems are comprised by mono-crystalline solar modules, which have a better efficiency than the polycrystalline modules (customised 1 and 2 systems). Moreover, it is noticed that the systems produce less energy/kW during the summer months even if the available irradiation is higher (green colour line) because the irradiation that falls into the panels and can be absorbed is actually lower (blue colour line).

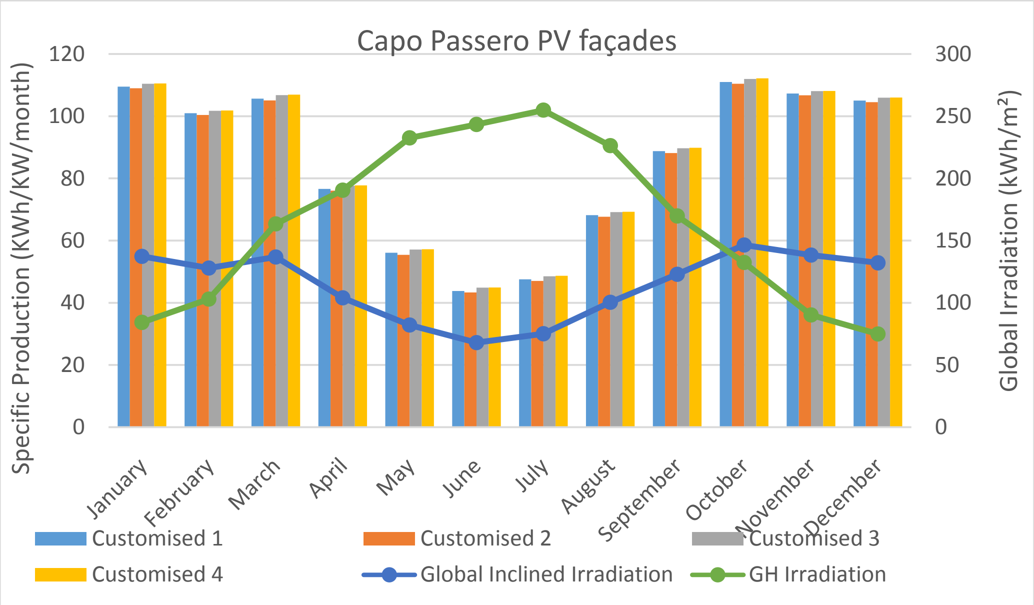



**Figure 5. 7: Monthly specific production for the PV façades in Capo Passero**

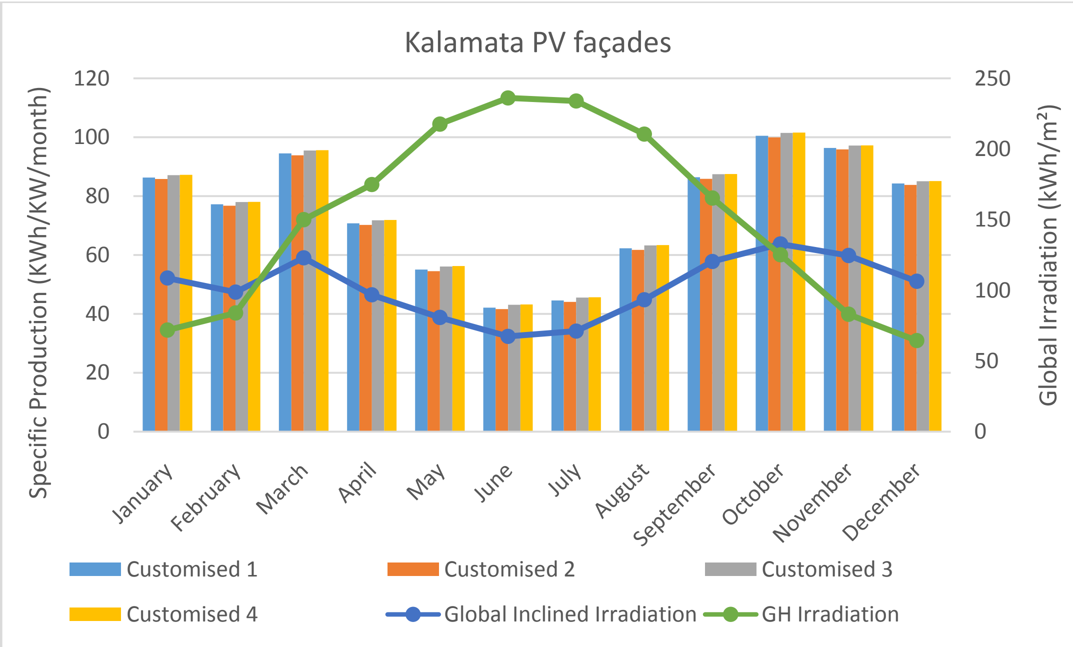



**Figure 5. 8: Monthly specific production for the PV façades in Kalamata**

Figure 5.9 presents the PV plants' options that have been discussed for Capo Passero. It shows the monthly specific production and the respective global inclined irradiation for both fixed and tracking mounted PV system. As it was expected, the dual axis tracking mounted systems produces around 30% more energy annually than the fixed mounted. However, as mentioned, the decision on which option is used has been made in accordance with the PV companies and the costs of the systems. Hence, it is actually demonstrated that even with an increase of 30% in the annual energy production, it is not beneficial in these two locations to install a tracking mounted PV plant because of its high capital and operation and maintenance costs.

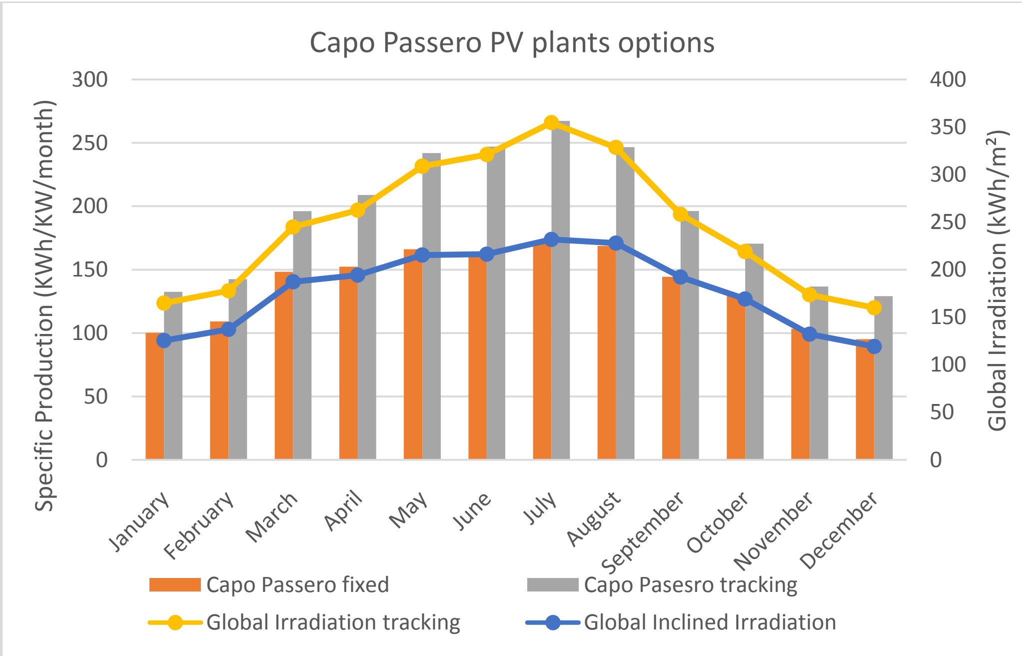



Figure 5. 9: Monthly specific production for the PV plants' options in Capo Passero

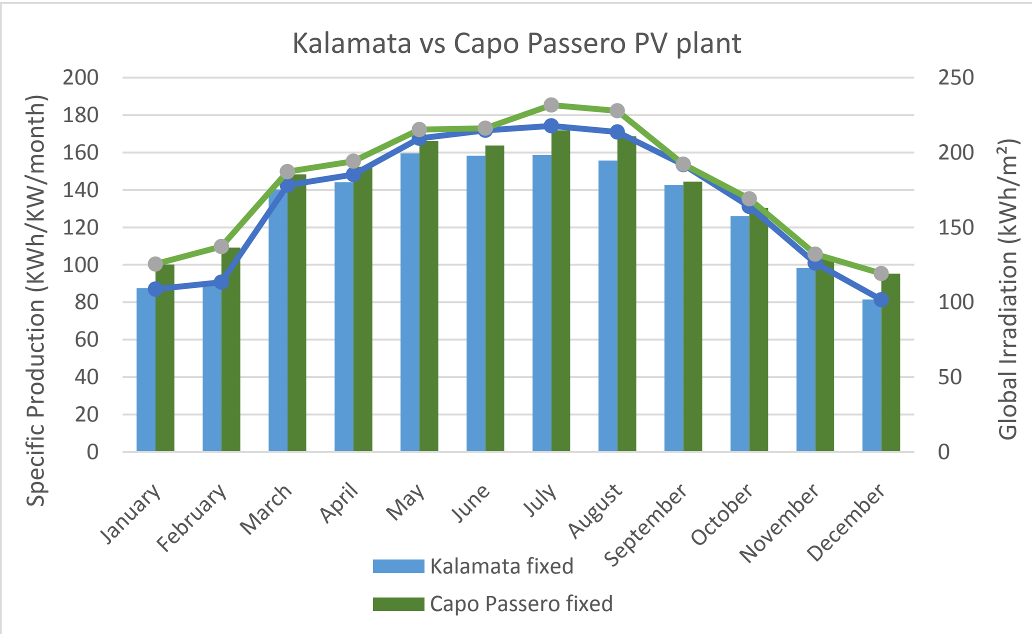



Figure 5. 10: Monthly specific production comparison between Kalamata and Capo Passero

Figure 5.10 depicts a comparison between the monthly specific production of fixed mounted PV plants in Kalamata and Capo Passero. It is shown that the PV plant in Capo Passero produces more energy/kW mainly due to the slightly higher global irradiation.

Finally, Table 5.7 presents the annual performance ratio for all the simulated PV systems. As it was mentioned, the performance ratio describes the overall effect of system losses. Even if the customised PV systems are identical in respect to their design for the two locations, it is observed a difference of 0.7-0.9% in their PR between Greece and Italy. This is attributed to the losses from the PV module temperature and the partial use of irradiance due to the reflection from the module front surface since the temperature and irradiance are the only different input parameters for the two sites. For the PV plants, the difference in their PR is mainly attributed to PV loss due to temperature. PVGIS gives higher average temperature data in Kalamata than Capo Passero and the temperature coefficient of the PV modules used in Kalamata is also higher than Capo Passero (Kalamata: -0.41%/°C, Capo Passero: -0.39%/°C) resulting in higher losses.

Table 5. 7: PV systems' Performance Ratio

| Simulations | Performance Ratio (%) | Performance Ratio (%) |
|---|---|---|
| | Greece | Italy |
| **Customised 1** | 73.6 | 74.4 |
| **Customised 2** | 73.0 | 73.9 |
| **Customised 3** | 74.5 | 75.2 |
| **Customised 4** | 74.6 | 75.3 |
| **PV plant fixed** | 76.2 | 77.0 |
| **PV plant tracking** | - | 77.9 |

## 5.3 Annual and lifetime energy

This section analyses the annual and the lifetime energy prediction in both locations. All the RET systems have been calculated for a lifetime of 15 and 25 years. The annual and lifetime energy generation for the HAWT is S2 case (Kalamata includes S3 case as well) and for the VAWT are the best- and worst-case scenarios (H4 and H6 for Kalamata and H4 and H5 for Capo Passero). Tables 5.8 and 5.9, apart from the annual and lifetime energy, also present two metrics regarding the systems' performance; the specific production and the capacity factor, which are used to compare systems with different sizes, designs or technologies. However, both metrics are dependent on the weather resource. Hence, it is suggested that the compared systems to be in the same location. This is also demonstrated in Figure 5.11, which depicts the specific production for all the RET systems in Greece and Italy. It is observed that the PV systems in Capo Passero produce slightly more energy per KW compared to Kalamata. The same stands for the VAWT. This is attributed to the difference in their solar and wind recourse respectively. The only case that makes an exemption on this is about the HAWT, which as have been discussed in Section 5.2.1 its lower specific production might attributed in the turbine's hub height.

Table 5. 8: RET systems' energy production and capacity factor-Greece

| Greece RET systems | Specific Production (kWh/kW/year) | Capacity Factor (%) | Annual Energy (kWh) | Lifetime Energy (kWh) | Lifetime Energy (kWh) |
|---|---|---|---|---|---|
| | | | | N=15 years | N=25 years |
| **Customised 1** | 900.40 | 10.28 | 8427.70 | 121358.88 | 196997.49 |
| **Customised 2** | 894.00 | 10.21 | 8193.50 | 117986.40 | 191523.06 |
| **Customised 3** | 911.41 | 10.40 | 8921.80 | 128473.92 | 208547.08 |
| **Customised 4** | 912.68 | 10.42 | 9041.00 | 130190.40 | 211333.38 |
| **PV plant** | 1542.95 | 17.61 | 621145.00 | 8944488.00 | 14519264.38 |
| | | | | | |
| **HAWT (S2)** | 1893.34 | 21.6 | 4354678.00 | 62707363.20 | 101790598.25 |
| **HAWT (S3)** | 1661.33 | 19 | 3821068.00 | 55023379.20 | 89317464.50 |
| **VAWT (H4)** | 759.70 | 8.67 | 7597.00 | 109396.80 | 177579.88 |
| **VAWT (H6)** | 397.60 | 4.54 | 3976.00 | 57254.40 | 92939.00 |

Table 5. 9: RET systems' energy production and capacity factor-Italy

| Italy RET systems | Specific Production (kWh/kW/year) | Capacity Factor (%) | Annual Energy (kWh) | Lifetime Energy (kWh) | Lifetime Energy (kWh) |
|---|---|---|---|---|---|
| | | | | N=15 years | N=25 years |
| **Customised 1** | 1020.30 | 11.65 | 9550.00 | 137520.00 | 223231.25 |
| **Customised 2** | 1013.53 | 11.57 | 9289.00 | 133761.60 | 217130.38 |
| **Customised 3** | 1031.77 | 11.78 | 10100.00 | 145440.00 | 236087.50 |
| **Customised 4** | 1033.01 | 11.79 | 10233.00 | 147355.20 | 239196.38 |
| **PV plant** | 1653.88 | 18.88 | 166463.00 | 2397067.20 | 3891072.63 |
| | | | | | |
| **HAWT (S2)** | 1486.67 | 17 | 4489736.00 | 64652198.40 | 104947579.00 |
| **VAWT (H4)** | 1189.60 | 13.58 | 11896.00 | 171302.40 | 278069.00 |
| **VAWT (H5)** | 513.50 | 5.86 | 5135.00 | 73944.00 | 120030.63 |

In addition, from the capacity factor it is shown that the small-scale RET systems do not perform as well as they could. The main reason for the PV façades is that they cannot absorb all the available solar irradiation in the two locations due to their tilt angle. Similarly, for the VAWT the reason is the low annual average wind speed of the two sites. However, the performance of the wind turbines is related with the specific spot of the installation. Hence, according to the site that they will be installed, their capacity factor might increase while this is not the case for the PV systems. Moreover, it is observed that the PV plant performs quite well in both locations. Hence, if, for example, the HAWT is excluded from the scenario of Kalamata, in order to cover the required amount of energy, a PV plant of 2.6-2.8 MW capacity would have to be installed depending on its PR. This is not big difference between the installed capacity of the two systems (HAWT of 2.35 MW to PV plant of 2.6- 2.8 MW). Note that the replacement of the HAWT generated energy concerns S2 case, which has a quite descent capacity factor (21.6%). In the following chapter, which has the economic analysis, is shown that especially for Greece, the large-scale HAWT has almost the double life cycle cost/kW of installed capacity than the large-scale PV plants. This is expected for 25 years period of system lifetime and it is not the same for the Italian HAWTLCC. Therefore, for Kalamata an altered scenario might be to include only PV plants for the large-scale systems' category. Although, this suggestion is valid only if the HAWT performs lower or up to the case S2. If it performs better, then this will change as more PV installed capacity will be required to cover the HWAT generated energy.

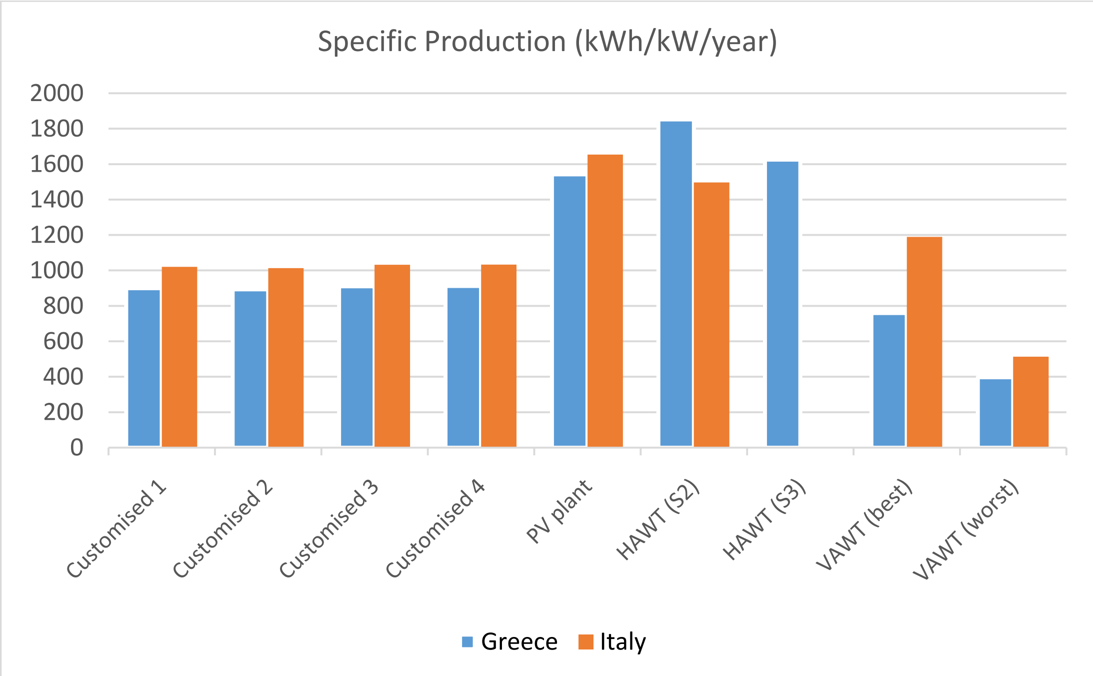



**Figure 5. 11: Specific production for all the systems in Greece and Italy with WT variations**

Table 5.10 shows the ranges of the annual required and predicted energy by the RET systems in both locations. For Capo Passero, the range of the predicted energy is too narrow as the only difference in the summation of systems' annual energy is between the best and the worst case of the VAWT (6.76 MWh/year). For Kalamata, this range is wider as apart from the different VAWT cases, two cases for HAWT (S2 & S3) are also included (537.23

MWh/year). It is observed that the predicted annual energy for Kalamata covers the required energy even if the whole amount (max: 100%) is required or not (min: 80%). However, in the 100% case, there is a deficit of 360 kWh/year, which is considered small (6.86%) as it can be inside the limits of the simulation uncertainty prediction. On the other hand, the energy shortage in the 100% case for Capo Passero is rather big (20.98%). This is attributed to the low performance of the 3 MW HAWT. Finally, it has to be considered that the amount of the required energy might remain constant during the years while the annual predicted energy will degrade through the RET systems' degradation mechanisms.

**Table 5. 10: Total energy**

| Scenarios | Required Energy | Predicted energy |
|---|---|---|
| | MWh/year | MWh/year |
| **Capo Passero max** | 5,956.80 | 4,707.27 |
| **Capo Passero min** | 4,766.00 | 4,700.51 |
| **Kalamata max** | 5,387.40 | 5,018.00 |
| **Kalamata min** | 4,310.00 | 4,480.77 |

# Chapter 6: Costs and LCOE

## 6.1 Economic assessment background

The enhancement of the RET penetration in the global market requires the periodical assessment of the cost-effectiveness of RET projects. The levelised cost of energy (LCOE) is the common parameter that is used to assess the economic feasibility of RET systems. Moreover, LCOE is commonly utilised for the comparison of several different energy sources, so allowing RET to be compared to other electricity generation technologies [89]. Usually, the comparison of the RET LCOE occurs, depending on the size and connection details of the system, either with the retail electricity cost or the wholesale cost of the conventional energy technology. For residential systems, it is more preferable to compare the LCOE value to the retail electricity cost while for large-scale systems this comparison could occur to the wholesale cost of fossil fuels generators [90]. It should be noted that conventional sources of energy such as pollution and impacts on climate change include hidden costs that are seldom incorporated in the comparison [89, 91].

### 6.1.1 LCOE formulae analysis

LCOE is defined as the ratio of the lifetime cost of a project to the lifetime energy production.

$$LCOE = \frac{Total\ Life\ Cycle\ Cost}{Total\ Lifetime\ \ Energy\ \ Production} \tag{6.1}$$

Based on the parameters incorporated in the calculations, there are numerous types of formulae. According to the Imperial College report "Investment in electricity generation: the role of costs, incentives and risks" made on behalf of the UK Energy Research Centre, there are two major methods used for the LCOE calculation: the "discounting" and the "annuity''. In the "discounting" method, all the lifetime costs and energy outputs are discounted back to the present value (eq. 6.2).

$$LCOE = \frac{\sum_{n=0}^{N} \frac{C_n}{(1+d)^n}}{\sum_{n=0}^{N} \frac{E_n}{(1+d)^n}} \tag{6.2}$$

Where $C_n$is the costs of the system in year $n$. When $n$=0 the cost is equivalent to the initial capital cost. $E_n$ is the energy produced by the system in year $n$. $N$ is the project lifetime, and $d$ is the discount rate. Concerning this method, the reduction of non-financial parameters is a controversial issue [92]. Nevertheless, in the literature the LCOE is defined: “The sum of the present value of LCOE multiplied by the energy generated should be equal to the present valued net costs” (eq.6) [93]. Thus, based on this view of the literature, it is argued that although the lifetime energy appears to be discounted, in reality this result is obtained by rearranging Equation 6.3 [93].

$$\sum_{n=0}^{N}\left[\frac{LCOE_n}{(1+d)^n} \times E_n\right] = \sum_{n=0}^{N} \frac{C_n}{(1+d)^n} \tag{6.3}$$

The Equation 6.3 is originated by a published NREL document of 1995 [94]. It shows the net present value of the LCOE while the methodology used in this study for the development of the RET LCOE equation is based on expressing the average cost of the generated energy throughout the system’s lifetime.

In the “annuity’’ method, the present values of the costs are calculated, and then they are converted to an equivalent annual cost with the use of an annuity formula. Moreover, the denominator of this equation is the average annual energy output over the lifetime of the project (eq. 6.4).

$$LCOE = \frac{\sum_{n=0}^{N} \frac{C_n}{(1+d)^n} \times \frac{d}{[1-(1+d)^{-N}]}}{\frac{\sum_{n=1}^{N} E_n}{N}} \tag{6.4}$$

Based on the Imperial College report, the two aforementioned methods should provide the same LCOE values when they utilise the same inputs. However, an examination of these two formulas showed that the LCOE would be the same only if the annual output of the energy source is constant over its lifetime. This does not apply for renewable energy sources and for the RET systems because their energy output varies constantly [91, 92].

Finally, except from the different formulas that can be formed for the calculation of the LCOE, there are simulation software packages such as the System Advisor Model (SAM), RETScreen, and HOMER. These software packages can compute the levelised cost of energy or offer RET system economic analysis based on the given inputs. Moreover, they can provide an economic assessment of renewable energy projects through the use of financial models. Therefore, the above discussion indicates that sufficient information cannot be obtained by acquiring an LCOE value for a system if the calculation method is unknown. Additionally, the LCOE for a RET system in a specific location can be calculated as a single number, a range of numbers or a statistical distribution [89, 90, 93]. The LCOE formula incorporates numerous variables that may be subject to uncertainties since these variables would be assumed for the lifetime of the project. Hence, it would be more suitable not to treat the LCOE values as a single number and to conduct a sensitivity analysis in order to account for these uncertainties [93].

Generally, a RET system can be deemed financially viable when it reaches grid parity. The term grid parity, for a RET system, refers to the point at which the RET LCOE is equal to the retail cost or to the wholesale cost of electricity. Despite the fact that the LCOE value constitutes an average cost over the lifetime of a project, it is frequently contrasted with the current electricity cost that is characterised by volatility [93]. Due to the fact that the electricity cost has increased while the RET system cost has decreased, grid parity has already been accomplished in some locations in Europe and the USA [91, 93].

Individuals may be interested in investing in RET system for various reasons based on the expected return on investment. However, in order to decide, they would have to weigh the climate benefits and the substantial cost of electricity generated by the system. Moreover, it should be noted that there is a level of inertia in all investments because even if all the economic indicators support this investment, the stability of the investment and transaction cost are important factors for investors. Transaction cost consists of all the processes needed for the completion of an investment.

From an economic perspective, individuals might not be sufficiently influenced to invest in a RET system by grid parity. As it occurs with investments, there is some level of risk. For example, based on an IEA report, PV plants have low risk characteristics based on their low operation and maintenance cost, short lead times and absence of fuel costs and emissions [95]. However, the decision to invest will be based on evaluations of economic factors other than grid parity. The two main parameters considered for the economic evaluation of a RET system investment are: the Net Present Value (NPV) and the Pay-Back Period of the investment. The NPV defines the suitability of the investment and demonstrates if the benefits would be greater than the costs. Therefore, NPV should be as large as possible and always positive in order to invest in a project. Furthermore, the Pay-Back Period is the length of time needed to recuperate the expenses of the project [96].

The LCOE parameters depend on the location and size of the RET system and current market policies and prices. The lifetime finance and the lifetime energy production constitute the two main categories. For lifetime finance, the parameters include the system installation cost, financial factors (inflation and discount rates), operation and maintenance costs, support mechanisms, insurance, taxes, loans (equity/debt ratio), credits, depreciation, carbon credits, etc. For lifetime energy production the parameters include the irradiation, wind speed and temperature values, PV and Wind system conversion efficiency (dependent on selected technology),system electrical and mechanical design, system degradation rate, reliability and operational issues (e.g. shading) etc. These parameters may not all be integrated in the LCOE formula, but those included should be clearly stated [93].

In this study, LCOE is the average cost paid to produce 1 kWh of electricity during a certain period under the financial parameters valid for the system operation in that period. Particularly, the average cost per kWh is the required amount to be paid for the reimbursement of all the expenses within the project lifetime.

The LCOE formula that is used in this study is the following:

$$LCOE = \frac{\sum_{n=0}^{N}[C_n \times (\frac{1+i}{1+d})^n]}{\sum_{n=0}^{N}[E_n \times (1-n \times D)]} \tag{6.5}$$

where $C_n$is the cost of the system (expressed in euros) (installation, system components, electrical equipment, finance, operation and maintenance (*O&M*) etc.) in year *n*. When *n*=0 the cost is equivalent to the investment cost ($C_0$). $E_n$ is the energy produced by the system (expressed in kWh or MWh) in year *n* and $E_0$ is energy production in the first year when no degradation is applied .*N* is the system lifetime (expressed in years)*, i* and *d* are the inflation and discount rate of the investment (expressed as fractions representing percentage change per annum) and *D* is the annual degradation rate of the system energy output (expressed as a fraction representing percentage change per annum).

This formula takes into account all the cost for the system lifetime and it also considered the energy degradation of the system through time. Moreover, it can be modified accordingly to the RET policies of the two countries in order to express also the benefits for the proposed systems and can be correlated with the NPV and Payback period of the systems [97]. However, in this study, the correlation with the NPV and Payback period is not demonstrated as the RET policies and electricity prices change over time. Hence, it is better to examine the net LCOE value for the proposed systems and account for any benefits close to the realisation stage of the projects.

### 6.1.2 RET Policies

Although it was stated above that the RET policies are not included in the LCOE analysis of this study, this section presents the RET policies of Greece and Italy as well as indicative costs, LCOE and capacity factor values to provide a reference to the reader.

There are various support schemes in Italy and in Greece for the different renewable energy technologies. Namely, for Italy are [98]:

- Feed-in tariff I (tariff onnicomprensiva)
- Feed-in tariff II (Ritirodedicato)
- Net-Metering (scambio sulposto)
- Premium tariff I
- Premium tariff II (Conto energia per ilsolare termodinamico)
- Tax regulation mechanisms I (Reduction in value-added tax)
- Tax regulation mechanisms II (Reduction in real estate tax)
- Tenders (Auction Process)

while for Greece are [99]:

- Feed-in tariff I
- Feed-in tariff II (rooftop PV)
- Feed-in tariff III (Feed-In premium exemptions)
- Net-Metering (Law No.3468/2006 amended by Law No.4203/2013)
- Premium tariff (Feed-in Premium)
- Subsidies (Development Law)
- Tax regulation mechanism (Development Law)
- Tenders (Feed-in Premium - Pilot Tender).

All of the schemes are not eligible for all RET, hence only the ones concerning the RET types of this study are analysed below.

**Greece**

1. Feed-in tariff II (rooftop PV): The scheme promotes electricity generation by rooftop PV installations of up to 10 kW through a guaranteed feed-in tariff. The electricity exported to the grid is measured by the national energy supplier that sends electricity bills to the operators of PV installations. The supplier will be responsible for the difference of electricity charges if the feed-in tariff for the generated electricity surpasses installation operator's charges. The scheme concerns private individuals, small enterprises and public entities.

In this scheme the 10 kW PV façades may be included. The tariff will be € 80/MWh from August 2019 and is paid for 25 years from the moment of connection (art. 3 par. 3 FEK 1079/2009).

The electricity generated by an installation or plant is offset with self-consumed energy. Any additional electricity is supplied to the grid without any responsibility for compensation. Except from this, PV installed on public buildings as a result of EU funded programmes can obtain up to 20% of the value of the total annual electricity generation (art.14A par.4 Law No.3468/2006).

**2. Feed-in tariff III (feed-in premium exemptions):** From 2016, RES and CHP plants that are going to be connected to the transmission system take part in the electricity market and are granted a sliding feed-in premium (called “Operating support based on a differential compensation price”). From 2017, feed-in premium is granted through tenders. However, smaller installations are exempted, i.e. wind energy plants ≤3MW and other RES installations ≤500kW, as they are qualified for a feed-in tariff.

For Greece if a HAWT is installed less than 3 MW then it will be included in this scheme. The tariff will be€ 98/MWh (art.4 par.1b Law No. 4414/2016) and the duration of Operating Support Contracts is 20 years. This support mechanism is not eligible for solar PV plants.

Every first trimester of each year, Reference Prices are changed (art.4 par.5 Law No.4414/2016). Except from this, the level of the feed-in tariff is also altered i.e. decreased if the plant operator obtains support from any type of investment (except EU support). In this case, the support is decreased based on the Capital Depreciation Coefficient (art.3 par.7 Law No. 4414/2016).

**3.Net-Metering:** In Greece, a net metering system was launched for autonomous producers in 2014. FEK B’ 3583/2014 illustrates the net metering process. Moreover, “virtual net metering” was pioneered in 2016 (art. 2 par. Law No. 3428/2006). Particularly, the development of PV and Wind power projects of up to 500 kW will be allowed to city/regional councils, schools, universities, farmers and farming associations if installations are placed at a significant distance from the location of the actual power consumption (art.14A par.4 Law No.3468/2006). A new but similar virtual net metering scheme has been established in 2017.

PV plants connected to the grid are eligible (art.14A Law No.3468/2006). For the interconnected system: PV plants <20kW or 50% of the agreed capacity consumption (PV Capacity ≤0.5 x Sum of the agreed power consumption (kVA). For non-profit legal person this could reach up to 100%.

Wind power plants up to 50 kW connected to the mainland grid is eligible (art.14A Law No.3468/2006).

An annual cycle is followed by Net metering process. The electricity supplied to grid and the used electricity need to be measured in order for the electricity retailer to issue each electricity bill. If there is a positive difference, namely more electricity is generated and supplied to the grid than used, this surplus is credited to the following electricity bill. After the end of the year, the electricity retailer will not disburse any surpluses to the self-producing electricity consumer but they will be cancelled. If there is a negative difference, for example, more electricity was used than generated, the plant/ installation operator is responsible for the payment of the difference (art.2. FEK B’ 3583/2014).

**Italy**

**Feed-in tariff I (tariff onnicomprensiva):** Except for PV plants with an installed capacity from 1 kW to 0.5 MW, all plants have the right to choose the feed-in tariff instead of the premium tariff I (Art.3, c.1 and c.4 & 7, c.4 and c.6 DM 23/06/16). Based on their size, plants may enter this scheme directly or through a registry listing with capacity limits adjusted each year.

PV systems are not eligible for this scheme. On the other hand, wind energy is eligible for capacities between 1 kW and 0.5 MW (Art. 3 and 7, c.4, DM 23/06/16) and plants with a capacity up to 60 kW can access incentives directly (Art. 4, c. 3 DM 23/06/16). Hence, the small-scale wind turbines are eligible for this scheme in Italy. The tariff for onshore wind plant with installed capacity between 20-60 kW is € 190/MWh for 20 years of operation.

**Feed-in tariff II (Ritirodedicato):** The sale of electricity in Italy is regulated by the "RitiroDedicato" rather than a "classical" feed-in tariff. The producers do not have to sell their energy on the free market personally because GSE (i.e. Manager of Energy Services) handles the sale on their behalf. Hence, GSE acts as a mediator between the producers and the market. Due to this system, renewable energy can access the market in an indirect and easier manner. Producers up to certain capacities (100kW for PV and 500kW for hydro if they make use of other support schemes, 1 MW for all sources if they do not make use of support schemes) may choose between the minimum tariff (prezzominimogarantito) determined by the energy authority and the market prices (Art. 7 AEEG 280/07 in connection with Art. 4 AEEG 34/05).”

Regarding solar energy, the formulas for calculating the exact minimal tariff are available in Art. 7, par. 6, of the adapted Annex A, AEEG 280/07. This tariff is re-assessed every year and

is based on the ISTAT's (office for statistics) calculation on the consumption prices of families of workers and employees (Art. 7 par. 5 AEEG 280/07).
Eligible period: The guaranteed minimum tariffs are applicable for one year (Art. 7 par. 2 AEEG 280/07).

Hence, this scheme can be utilised from the 100 kW PV plant and the PV façades.

Net metering is similar to Greece. All plants generating up to 500 kW are eligible, regardless of the technology used.

Premium tariff I is for all types of plants except for PV. For onshore wind turbine plant with installed capacity between 1-5 MW the incentive is € 135/MWh for 20 years' time period.

Finally, apart from these schemes, Italy support both solar and wind investments by a reduction in value-added tax and/or reduction in real estate tax.

**Indicative costs**

According to an IRENA report, the global weighted average total installed cost for solar PV is 1388 USD/kW in 2017 (€ 1243.14/kW) while the capacity factor and the LCOE are 0.18 and 0.10 USD/kWh(€ 0.09/kWh) respectively. For onshore wind, the weighted average total installed cost is 1535 USD/kW (€ 1374.80/kW) while the capacity factor and the LCOE are 0.48 and 0.05 USD/kWh(€ 0.045/kWh) respectively. The exchange rate from USD dollars to Euros was 1 USD= 0.895636 EUR as per 17/05/2019. "For the LCOE data, the real WACC (weighted average cost of capital/ or discount rate) is 7.5% for OECD countries and China, and 10% for the rest of the world" [100]. These indicative values show that even if onshore wind is more expensive than solar PV, as a capital cost, its LCOE is half compared to solar PV. This is attributed to the capacity factor, which is more than double for the onshore wind compared to the solar PV. However, this might not be the case for sites with low wind resource as the capacity factor might fall to values similar or even lower than the solar PV values. Hence, these aspects have to be taken into account before the final suggestions of the RET scenarios.

## 6.2 Cost

This section discusses the quotations that have been acquired for the RET systems and the methodology that have been used for the life cycle cost (LCC) calculations. Finally, it presents the LCC for all the RET systems.

For the PV systems in Italy the quotation for the components has been acquired by a different company from the one that gave the quotation from installation and O&M costs. On the other hand, in Greece the same company provided the quotation for both the PV products and work required for the PV systems. Regarding the HAWT the branch of Enercon in Greece provided the quotations for both countries. Aeolos company gave a quotation for the required products to assembly the VAWT and their transport to Greece and Italy ports but different companies gave quotations for their transport from the ports of the two countries to the locations of Kalamata and Capo Passero as well as their installation and O&M costs. The same stands for the coloured PV modules, which will be shipped to Capo Passero and Kalamata but the respective companies that have undertaken the PV plants have also undertaken to provide the rest of the materials needed for the PV façades as well as their installation and maintenance. However, the costs of the RET systems, in this study, are divided in two categories; initial investment and operation and maintenance cost. The initial investment cost includes the materials of the system, the transportation of the materials to the specific locations and all the works required for their installation. The O&M cost incudes their annual maintenance plus any part that has to be replaced during their lifetime. Hence, the life cycle costs of the systems include both categories and have been calculated for two financial scenarios and two project lifetimes. The project lifetimes are in accordance with the calculations of the lifetime energy hence the LCCs have been calculated for N=15 years and N=25 years of the systems' operation. The financial scenarios concern the long-term inflation and discount rates of the two countries.

The mean inflation rate in Greece in the last 25 years is 3.3% while the discount rate during the same period is 1.8%. Italy mean inflation rate is 2.1% while discount rate is 1.8 % from 1994 to 2019. Moreover, it was decided to double the inflation rate in both countries in order to examine the changes in the life cycle costs of the systems. The first scenario uses the mean inflation and discount rates while the second uses a double inflation rate while having the same discount rate. Below are presented the life cycle costs for all the systems for the two countries. In this way, a range of LCC values is obtained for both 15 and 25 years of the systems' operation. In both countries, Scenario 2 gives higher life cycle cost as the inflation is double than Scenario 1 and all the other input parameters remain the same. The less costly case for all the systems is for Scenario 1 and N=25 years. Based on the prices provided for Greece, it is noted that the PV façades in Italy cost around 11% more than Greece for 25 years of lifetime (Scenario 1). Similarly, the VAWT cost around 40% more in Italy than Greece. On the other hand, the PV plant in Greece is slightly more expensive than Italy (4.3%) while the HAWT has a considerable higher cost in Greece (40% more than Italy).

All the aforementioned percentage differences are based on the prices per kW for each system and concern the most favourable financial case (Scenario 1 for N= 25 years).

**Table 6. 1: Life cycle costs (Scenarios 1 and 2), Greece**

| Greece RET systems | Life Cycle Costs (€) | Life Cycle Costs (€) | Life Cycle Costs (€) | Life Cycle Costs (€) |
|---|---|---|---|---|
| | Scenario 1 | | Scenario 2 | |
| | N=15 years | N=25 years | N=15 years | N=25 years |
| **Customised 1** | 26196.69 | 30854.32 | 26867.37 | 34587.80 |
| **Customised 2** | 26053.95 | 30711.58 | 26724.63 | 34445.06 |
| **Customised 3** | 27947.79 | 32605.42 | 28618.47 | 36338.90 |
| **Customised 4** | 27947.79 | 32605.42 | 28618.47 | 36338.90 |
| **PV plant** | 369300.90 | 434627.76 | 378243.27 | 486036.28 |
| **HAWT** | 3742279.24 | 4607588.16 | 4032906.26 | 5643156.06 |
| **VAWT** | 36241.17 | 44017.54 | 36688.29 | 48865.58 |

**Table 6. 2: Life cycle costs (Scenarios 1 and 2), Italy**

| Italy RET systems | Life Cycle Costs (€) | Life Cycle Costs (€) | Life Cycle Costs (€) | Life Cycle Costs (€) |
|---|---|---|---|---|
| | Scenario 1 | | Scenario 2 | |
| | N=15 years | N=25 years | N=15 years | N=25 years |
| **Customised 1** | 28167.55 | 34768.12 | 29335.76 | 38890.26 |
| **Customised 2** | 28024.81 | 34625.38 | 29193.02 | 38747.52 |
| **Customised 3** | 29918.65 | 36519.22 | 31086.86 | 40641.36 |
| **Customised 4** | 29918.65 | 36519.22 | 31086.86 | 40641.36 |
| **PV plant** | 85852.30 | 103977.30 | 89381.27 | 115879.86 |
| **HAWT** | 2980984.26 | 3521123.82 | 3105106.57 | 3910264.95 |
| **VAWT** | 52146.28 | 73569.58 | 55796.94 | 86692.59 |

## 6.3 LCOE

Tables 6.3 and 6.4 show the LCOE values for the systems' lifetimes, scenarios and countries. The range of the LCOE value is related to the systems' finance and it can be observed between Scenarios 1 and 2 in the respective systems' lifetime. For instance, for N=15 years in the most of the systems in Greece the difference between Scenario 1 and 2 is around half cent to 0.8 cent per kWh. This difference becomes around 1 to 2.7 cent/kWh for N=25 yrs. This is reasonable as the inflation rate in Scenario 2 is higher than Scenario 1. Hence, by calculating a longer time period the gap between Scenario 1 and Scenario 2 values becomes bigger. On the other hand, by comparing the different lifetimes in the same scenario, it is clearly depicted that the cost per generated kWh drops significantly as the system's lifetime is prolonged. Further, the tables show the LCOE values for the wind turbines by using the same cases, which have been used in the lifetime energy calculations. It is clearly demonstrated that the LCOE value can change considerably by changing the wind speed of the site even for the same scenario and system lifetime (VAWT cases).

**Table 6. 3: LCOE (Scenarios 1 and 2), Greece**

| Greece RET systems | LCOE (€/kWh) | LCOE (€/kWh) | LCOE (€/kWh) | LCOE (€/kWh) |
|---|---|---|---|---|
| | Scenario 1 | | Scenario 2 | |
| | N=15 years | N=25 years | N=15 years | N=25 years |
| Customised 1 | 0.216 | 0.157 | 0.221 | 0.176 |
| Customised 2 | 0.221 | 0.160 | 0.227 | 0.180 |
| Customised 3 | 0.218 | 0.156 | 0.223 | 0.174 |
| Customised 4 | 0.215 | 0.154 | 0.220 | 0.172 |
| PV plant | 0.041 | 0.030 | 0.042 | 0.033 |
| | | | | |
| HAWT (S2) | 0.060 | 0.045 | 0.064 | 0.055 |
| HAWT (S3) | 0.068 | 0.052 | 0.073 | 0.063 |
| VAWT (H4) | 0.331 | 0.248 | 0.335 | 0.275 |
| VAWT (H6) | 0.633 | 0.474 | 0.641 | 0.526 |

**Table 6. 4: LCOE (Scenarios 1 and 2), Italy**

| Italy RET systems | LCOE (€/kWh) | LCOE (€/kWh) | LCOE (€/kWh) | LCOE (€/kWh) |
|---|---|---|---|---|
| | Scenario 1 | | Scenario 2 | |
| | N=15 years | N=25 years | N=15 years | N=25 years |
| Customised 1 | 0.205 | 0.156 | 0.213 | 0.174 |
| Customised 2 | 0.210 | 0.159 | 0.218 | 0.178 |
| Customised 3 | 0.206 | 0.155 | 0.214 | 0.172 |
| Customised 4 | 0.203 | 0.153 | 0.211 | 0.170 |
| PV plant | 0.036 | 0.027 | 0.037 | 0.030 |
| | | | | |
| HAWT (S2) | 0.046 | 0.034 | 0.048 | 0.037 |
| VAWT (H4) | 0.304 | 0.265 | 0.330 | 0.310 |
| VAWT (H5) | 0.705 | 0.613 | 0.750 | 0.720 |

Figures 6.1 to 6.4 depict the respective LCOE values from Tables 6.3 and 6.4 by divide them to small and large-scale RET systems for comparison purposes. For every large-scale RET systems an extra LCOE value is depicted in the figures. These extra values have an 8% difference to the original LCOE values and include an uncertainty of 8% in the lifetime energy yield prediction (systems with the (U) symbol in the figures).According to Thevenard and Pelland, “the combined uncertainty over a PV system’s lifetime could be up to 7.9% for an average modelled energy yield” [101, 102]. In this study, an 8% of combined uncertainty have been applied in the lifetime energy yield of all systems for uniformity purposes. Moreover, this uncertainty concerns the 25 years of the system’s lifetime though in the graphs, it is depicted for all the scenarios.

The RET systems in Capo Passero have lower LCOE values from the respective systems in Kalamata. Even for the VAWT where the life cycle cost of the system is 40% higher in Italy than Greece, it still has a lower LCOE value in H4 case and for N=15 yrs because of the better performance of the VAWT. However, this performance cannot compensate the LCC in the long-term (25 yrs). In addition, the worst case of the VAWT is the only case where Greece has lower LCOE values than Italy. Further, the HAWTs have the greatest LCOE difference between the two countries as the better performance of the HAWT in Greece cannot compensate the price difference between the countries. Regarding the PV systems, the PV façades have slightly lower LCOE value in Italy even if they are more expensive. This is because they are not that much costlier than the ones in Greece (11%) and the solar resource in Capo Passero is slightly higher than in Kalamata. The PV plant has an LCOE difference of 0.3 to 0.5 cent/kWh (higher values in Kalamata) between Greece and Italy, which is expected as it is a combination of slightly lower LCC and slightly higher solar recourse for Capo Passero.

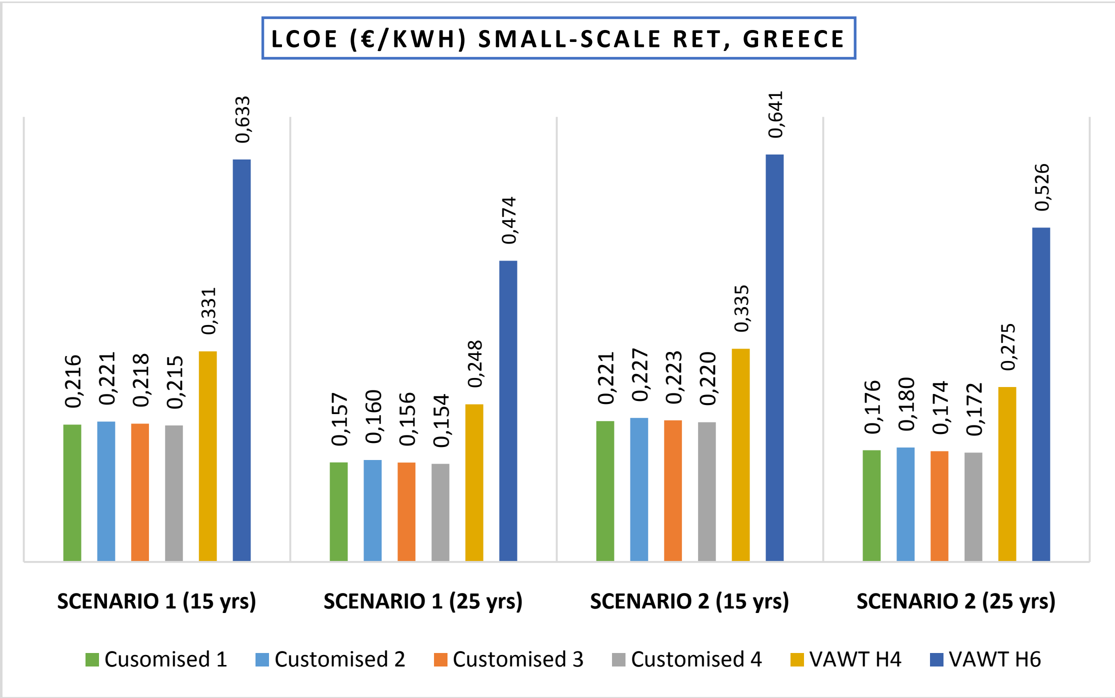



Figure 6. 1: LCOE small-scale systems (Scenarios 1 and 2), Greece

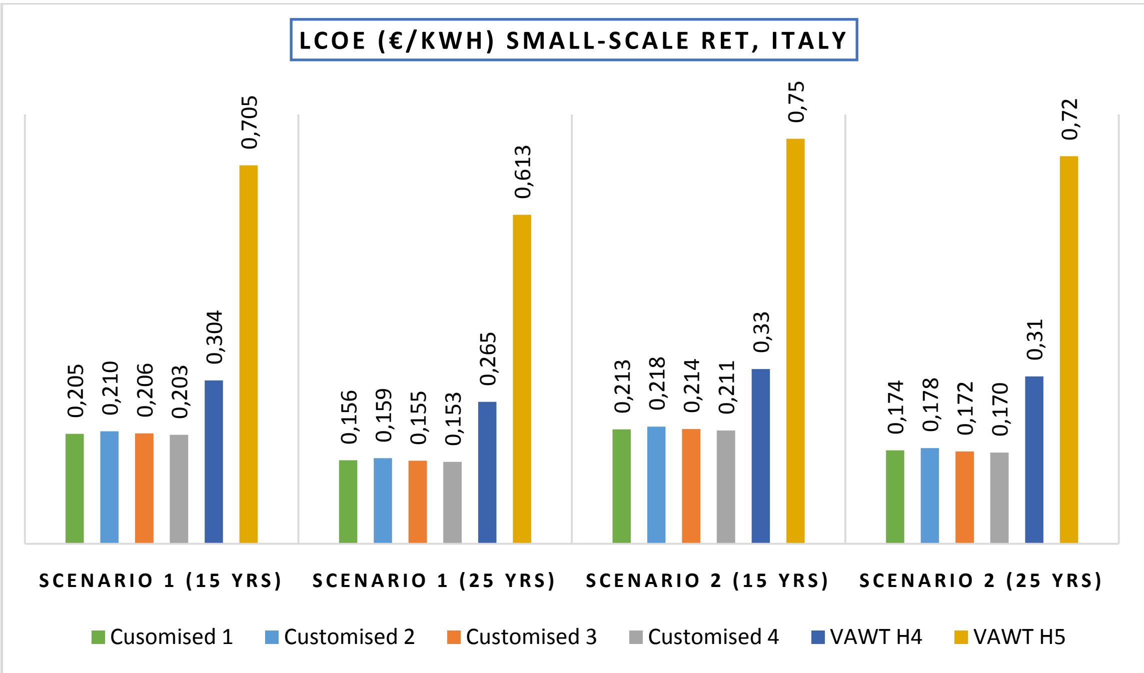



Figure 6. 2: LCOE small-scale systems (Scenarios 1 and 2), Italy

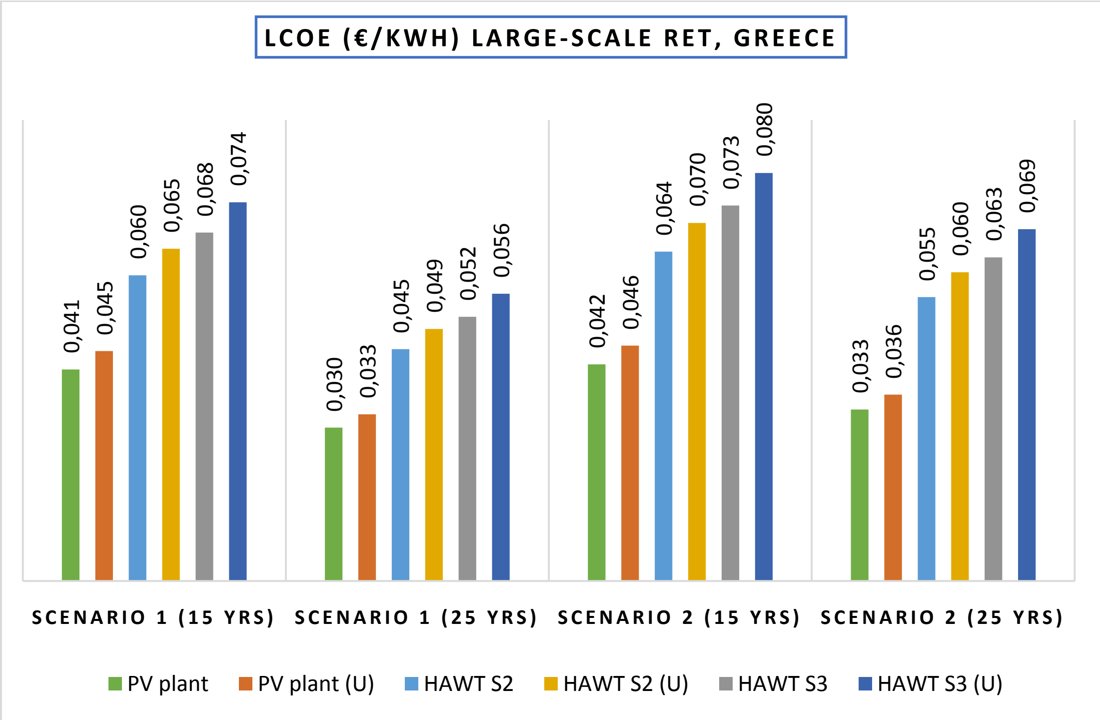



Figure 6. 3: LCOE large-scale systems (Scenarios 1 and 2), Greece

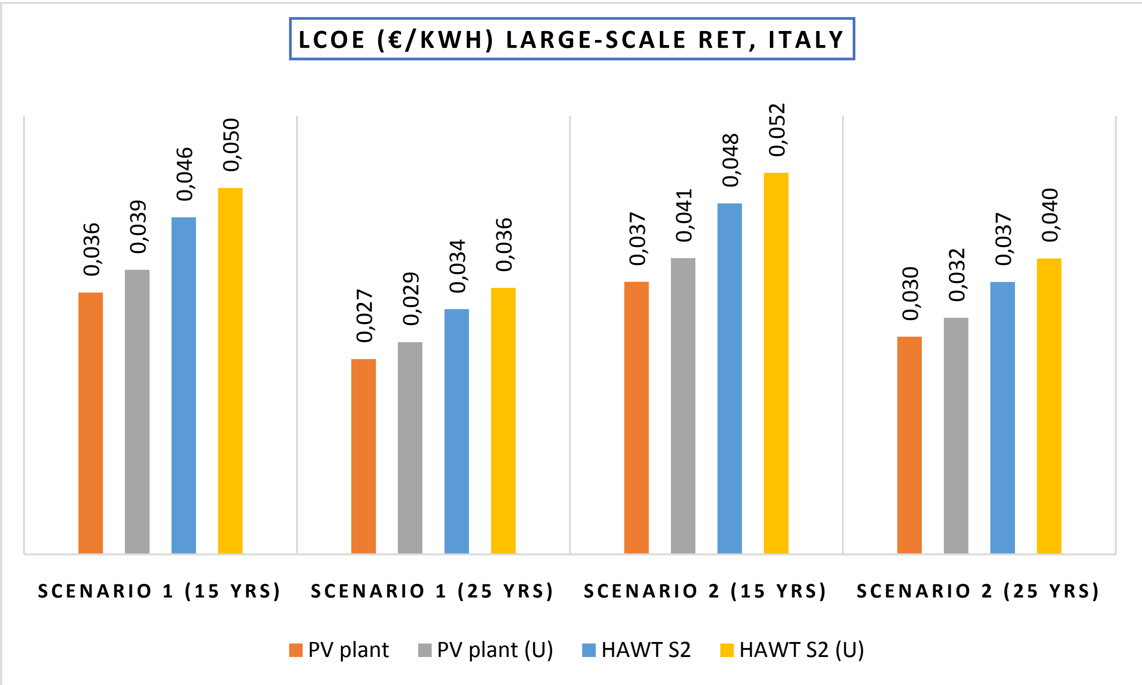



Figure 6. 4: LCOE large-scale systems (Scenarios 1 and 2), Italy

The range of the LCOE for the PV plants for all the scenarios, including the uncertainty, is € 0.030-0.046/kWh in Kalamata and € 0.027-0.041/kWh in Capo Passero. Respectively, for the HAWT the LCOE range is € 0.045-0.070/kWh for Kalamata and € 0.034-0.052/kWh for Capo

Passero (S2 case). For the KM3Net site in France at Toulon, which was stated that green energy will be bought to cover the experiment needs, it was acknowledged that the green energy costs around € 0.15/kWh for retail prices (domestic) [103]. Thus, the € 0.15/kWh is considered as the upper limit since for large amounts of energy a low-price deal may be achieved. Finally, it is noticed that the LCOE value for the large-scale RETsystems is well below the retail price of the green energy in Toulon. However, it has to be stated that compare to the small-scale RET systems is slightly lower than the PV façades (0.3-1 cent/kWh) while it is around the half price for the VAWT (best case).

# Chapter 7: Conclusions and recommendations

Chapter 7 presents the main conclusions of this study. It also makes some suggestions for the steps forward after having evaluated the results in relation to different target groups (i.e. investors, governments/ local authorities, general public, scientists).

## Main conclusions

This study has as a base the concluding points of the first deliverable and investigates various types of PV and Wind energy conversion systems for the locations of Kalamata and Capo Passero. It analyses and uses the available tools (weather data and simulation software programs) in order to have an approach, at this stage of the project, regarding the prediction of the annual and lifetime energy yield of the RET systems in these two locations. Further, it describes generally the systems' design and provides their indicative LCCs. Finally, the technoeconomic evaluation of the systems is presented using the LCOE as a metric.

Chapter-wise the main concluding points are:

In Chapter 2, after the analysis of various meteorological databases and simulation software programs, it was concluded that three software programs for the RET systems simulation will be used in this study. Specifically, PVsyst software was used for all the PV systems simulations while HOMER and SAM were used for the WT simulations. 32 simulations in total were made by using these software programs for both locations in order to predict the first year's annual energy of the RET systems. Moreover, Chapter 2 built the base for the comparison of the meteorological databases that was conducted in Chapter 3.

Chapter 3 demonstrated the discrepancies that can be caused in the data for the same location just by the choice of database. The annual percentage differences between RETScreen and PVGIS CM-SAF for Capo Passero are 1.67%, 16.9%, and 33.62% for the temperature, the GHI, and the wind speed respectively. Similarly, for Kalamata the annual percentage differences between the two databases are 17.41%, 10.52%, and 8.58% for the temperature, the GHI, and the wind speed respectively. In general, four weather databases were examined for three weather parameters that were used in the software programs. These databases were the PVGIS CM-SAF, RETScreen, NASA SSE, and wind speed data from Kalamata's weather station while the weather parameters were the temperature, the GHI, and the wind speed. Capo Passero receives slightly more solar irradiation and has higher wind speed annually than Kalamata according to all databases. Regarding the irradiation and temperature, PVGIS CM-SAF database was used for the PV systems' simulations. It is a valid solar database that provides recent solar irradiation data and has a small uncertainty in its data for Europe. Moreover, the highest annual GHI values for both locations were provided by PVGIS CM-SAF database; 5.38 kWh/m$^2$day and 4.97 kWh/m$^2$day for Capo Passero and Kalamata respectively. Regarding the wind speed data, which are more trivial and not straight forward to interpret, various values are considered for the two locations. For Kalamata, the used wind speed values in this study are from the local weather station and HOMER are used while for Capo Passero are from HOMER and RETScreen databases. HOMER database gives the highest wind speed values for both locations, namely 5.84 m/s and 5.01 m/s at 50 m above ground for Capo Passero and Kalamata respectively. Additionally, it was observed that even if the wind speed values from the weather station and RETScreen databases were extrapolated to 50 m height, their values were sufficiently lower than the one provided by HOMER(Kalamata weather station and RETScreen annual averaged wind speed at 50 m and a=0.16 equals 3.41 and 3.48 m/s respectively while for Capo Passero, RETScreen annual average wind speed at 50 m and a=0.16 is 4.44 m/s). Finally, by taking different values of shear coefficient in order to extrapolate the wind speed values in various heights, it was observed that in both locations the annual average wind speed is from low to medium even for the calculated data at the HAWT's hub height.

Chapter 4 presented the PV and WT market in respect of the most popular manufacturers. It demonstrated various models of RET systems and analysed the technical characteristics and the designs of the chosen systems. It showed that the initial choice of the systems' components, for a certain location, is dependent on three key parameters; their technical characteristics compared to the weather resource (i.e. if they are suitable for a certain location), the balance between the cost and performance compared to their design, and the availability of these products in the specific locations. Chapter 3 and 4 built the base for the annual energy prediction of the RET systems by the simulation software packages.

Chapter 5 described analytically all the input parameters of all the simulations. A sensitivity analysis was made for various wind speed, k Weibull parameter, and shear coefficient values and quantified the uncertainty of WT's annual energy prediction. It was shown that the difference between the maximum and the minimum annual energy was around 3,800,000 kWh for the HAWT among the sensitivity cases for each location. Moreover, from the simulations it was revealed that the HAWT in Capo Passero might not perform as it was expected because its capacity factor for the best-case scenario is 22.8% while the respective value for Kalamata's HAWT is 29%. This might be an indication that the wind speed values in Capo Passero are not sufficiently high for the specific hub height (69 m) of the WT. Regarding the VAWT, the sensitivity analysis showed that their annual energy production is reduced approximately to the half between the best and worst case. Further, an analysis was made for the monthly specific production of the PV systems. PV systems simulation results were as expected for both PV façades and PV plants. It was shown that the PV façades perform worse during the summer months because of their tilt angle while the PV plants perform vice versa during the year in both locations. Similarly, for the comparison between the tracking mounted versus the fixed mounted system in Italy, it was shown that the tracking mounted systems produces around 30% more energy annually because it captures a larger spectrum of the solar irradiance. Further the PV systems in Italy perform slightly better than Greece(PR difference of 0.7-0.9%). This is mainly attributed to the losses from the PV module temperature and the partial use of irradiance due to the reflection from the module front surface since the temperature and irradiance are the only different input parameters for the two sites. Finally, Chapter 5 summarises the performance parameters for all the systems and presents their lifetime energy production for both 15 and 25 years of the systems operation. It was shown that it might be more profitable for Kalamata to replace the HAWT with a PV plant of similar installed capacity. More specifically, the comparison referred to S2 case, which has a HAWT capacity factor of 21.6% even if the proposed PV plant's capacity factor is 17.61%. Chapter 6, which focuses on the economic analysis, showed that especially for Greece, the large-scale HAWT has almost the double life cycle cost/kW of installed capacity than the large-scale PV plants. This is expected for a 25-year period of system lifetime and it is not the same for the Italian HAWTLCC. Hence, although it seems that the HAWT performs better than the PV plant for a certain wind resource, it might not be a profitable investment.

Chapter 6 presents the background of the systems' economic analysis and the RET policies in the two countries. It has to be noted that the RET policies are not included in the techno-economic calculations as they change periodically and their results might be misleading for prospect investors at this stage of the project. However, at the realization stage, it is suggested that they are included in order for the investor to have the whole picture of the costs and the profits of the investment. At this point, the study provides a general view for all the RET systems' LCCs and a range for the average cost per generated kWh by the systems during 15 and 25 years of operation under valid financial parameters (i.e. inflation and discount rates). Regarding the LCC of the systems, in both countries, Scenario 2 provides higher life cycle cost as the inflation is double than Scenario 1 while all the other input parameters remain the same. Based on the less costly scenario (Scenario 1, 25 years), the PV façades in Italy cost around 11% more than Greece and the VAWT cost around 40% more in Italy than Greece per kW of installed capacity. On the other hand, the PV plant in Greece is slightly more expensive than Italy (4.3%) while the HAWT has a considerable higher cost in Greece (40% more than Italy).

Generally, for the LCOE values, it is clearly depicted that the cost per generated kWh drops significantly as the system's lifetime is prolonged and that the LCOE value can change considerably for a WT by changing the wind speed of the site even for the same scenario and system lifetime. The RET systems in Capo Passero have lower LCOE values from the respective systems in Kalamata even for the cases where the life cycle cost is higher in Italy than Greece. The only exemptions are for the worst case of the VAWT and for the 25 years of the VAWT lifetime where its performance is not high enough to compensate the high LCC in the long-term. Further, the biggest discrepancy of the LCOE values between the two countries concerns the HAWT, as the better performance of the HAWT in Greece cannot compensate the price difference between the countries. The HAWT LCOE range is € 0.045-0.070/kWh for Kalamata and € 0.034-0.052/kWh for Capo Passero (S2 case). Regarding the PV systems, the PV façades have slightly lower LCOE value in Italy while the PV plants have an LCOE difference of 0.3 to 0.5 cent/kWh (higher values in Kalamata). The range of the LCOE for the PV plants is € 0.030-0.046/kWh in Kalamata and € 0.027-0.041/kWh in Capo Passero. Finally, by comparing the retail price of the green energy in Toulon (0.15/kWh) with the LCOE values, it is shown that the large-scale RET systems are well below this price while the small-scale have slightly higher pricefor the PV façades (0.3-1 cent/kWh) or double the price for the VAWT (best case).It has to be stated that for large amounts of energy a low-price deal may be achieved in Toulon. Hence, when the wholesale price of the green energy is acquired, it will be compared with the LCOE values of the large-scale RET systems.

## 7.2 Recommendations

This study investigates the possible RET systems that can be installed in the two out of three sites of the KM3Net project. It presents a holistic review regarding the technical and economic feasibility of the systems in these two locations.

For prospect investors, the study provides the average net cost per generated kWh during the experiment and the systems' lifetime in both locations (LCOE values). The LCOE methodology, which is used, offers a robust base as it can be easily modified, when more specific information is available. The modifications can incorporate the RET incentive policies and the grid electricity prices of the two countries and correlate the LCOE values with the NPV and the payback period of the systems. The required info for this further analysis is the exact location of the RET installations. This will be agreed in cooperation with the local authorities of the two locations and it will offer the following advantages:1) to investigate further the wind resource in order to have a clearer view on the HAWT and the VAWT performances (especially for HWAT it has been demonstrated that the wind speed is a decision-making point for the choice of the model or for its replacement with a PV plant), 2)to know the exact buildings for the PV façades installation and the available space for the PV plant installationwill contribute to the knowledge of the systems' specific design, cost and energy yield. The above will shorten the LCOE ranges for each RET and express, apart from the costs, the economic benefits to the investors. In addition, this study is a techno-economic analysis, which reports analytically on the various systems' performances compared to their costs. Hence, the investor is in a position to judge the provided information and decide the minimum performance that is required by the system in order to have a profit.

For governments/local authorities and general public, this study promotes the RET and enhances people's awareness by presenting realistic values on their performances and costs. Moreover, it reveals that the experiment's energy needs willnot burden the local environment and that the surplus of the generated energy will contribute to the local energy demand of each location by suppling green energy. This environmental friendly approach can be promoted in cooperation with the local authorities by the installation of the small-scale RET systems inside the cities.

Regarding the scientific community, a research paper that discusses the results of this study can be written and published. The methodologies, which are used in this study, are not novel. However, the results that have arisen from the combination of these methodologies and the comparison among the various RET types and between the two countries constitute a subject of scientific interest. More specifically, the study provides the different techno-economic status of various RET between two locations with similar RES in two different countries. Hence, this information contributes to the better understanding of the technical potential and the transformation of this potential into economic terms and values for these two locations. Moreover, the scientific community is especially interested in field studies of various RET types and locations. Hence, if this project is implemented, the monitored data can be analysed and evaluated in order to contribute to the scientific knowledge of the field systems' performance.

Concluding, the work forward is to agree with the governments/local authorities for the places of installation in order to finalise the scenarios on the RET systems' models, capacities, designs, and costs. Of course, any decision on the steps forward will be in accordance with the renewable energy laws of each country [104].Finally, an optional parameter can be presented regarding the $CO_2$ emission savings. This is considered as an adding value in a RET investment, as the systems' generated energy during their lifetime is clean from greenhouse gas emissions.

# IX. References

[1] Markou, C. Beurthey, S. Papaleo, R. &Georgitsioti, T. (2017)'Report on contacts/discussions with power companies/local authorities/potential partners', *National Centre of Scientific Research Demokritos*, KMNeT3 IFRADEV-H2020-739560
Members of the KM3NeT Collaboration
KM3NeT INFRADEV GA DELIVERABLE: D10.01

[2] European Commission (2001-2017) *Photovoltaic Geographical Information System (PVGIS)*, (Version PVGIS-5) [computer program]. Available at: http://re.jrc.ec.europa.eu/pvgis.html (Accessed: 10 July 2019).

[3] Natural Recourses Canada (2018) *RETScreen*, (Version RETScreen Expert) [computer program]. Available at: https://www.nrcan.gc.ca/energy/software-tools/7465(Accessed: 10 July 2019).

[4] Meteotest (2018) *Meteonorm,* (Version Meteonorm7.2.4) [computer program]. Available at: https://www.meteonorm.com(Accessed: 10 July 2019).

[5] NASA-Power (2018) *How to access data*, Available at: https://power.larc.nasa.gov(Accessed: 10 July 2019).

[6] World Radiation Data Centre, Available at: http://wrdc.mgo.rssi.ru(Accessed: 10 July 2019).

[7] Solargis (2018) *Historical time series and TMY data*, Available at: https://solargis.com/products/time-series-and-tmy-data/overview/(Accessed: 10 July 2019).

[8] White Box Technologies (2008) *Weather data for energy calculations,* Available at: http://weather.whiteboxtechnologies.com(Accessed: 10 July 2019).

[9] Remund, J. (2015) 'Accuracy of Meteonorm (7.1.6.14035)', *Meteotest*, Available at: https://meteonorm.com/assets/publications/Accuracy_of_Meteonorm_7.pdf(Accessed: 10 July 2019).

[10] Meteotest (2018) *Meteonorm Features*, Available at: http://www.meteonorm.com/en/features/features(Accessed: 10 July 2019).

[11] PVsyst (2012) *Meteo data sources*, Available at:https://www.pvsyst.com/meteo-data-source/(Accessed: 10 July 2019).

[12] NASA-Atmospheric science data centre (2018) *Power*, Available at: https://eosweb.larc.nasa.gov/https%3A//power.larc.nasa.gov (Accessed: 10 September 2018)

[13] ASHRAE (2012) *Frequently Asked Questions - About the Data*, Available at: http://ashrae.whiteboxtechnologies.com/faq(Accessed: 10 July 2019).

[14] Energy Plus (2018) *Weather Data for Simulation*, Available at: https://energyplus.net/weather/simulation(Accessed: 10 July 2019).

[15] Huld, T. Pascua, I. &Amillo, A. (2017) 'PVGIS 5: New algorithms and features', *JRC Technical Reports*, 33rd EU PVSEC conference proceedings pp. 2069-2074.

[16] European Commission (2001-2017) *PVGIS users manual*, Available at: http://re.jrc.ec.europa.eu/pvg_static/en/manual.html#database(Accessed: 10 July 2019).

[17] European Commission (2001-2017) *Overview of PVGIS data sources and calculation methods*, Available at: http://re.jrc.ec.europa.eu/pvg_static/methods.html(Accessed: 10 July 2019).

[18] Huld, T. (2017) 'PVMAPS: Software tools and data for the estimation of solar radiation and photovoltaic module performance over large geographical areas' *Solar Energy*, 142, pp.171-181, *Science Direct* [Online]. Available at: https://www.sciencedirect.com(Accessed: 10 July 2019).

[19] Homer Energy (2018) *Homer Pro*, (Version 3.12.1) [computer program]. Available at: https://www.homerenergy.com/products/pro/index.html(Accessed: 10 July 2019).

[20] Natural Recourses Canada (2018) *Data Analysis Software and Modelling Tools*, Available at: https://www.nrcan.gc.ca/energy/software-tools/7417(Accessed: 10 July 2019).

[21] National Renewable Energy Laboratory (NREL) (2017) *System Advisor Model (SAM)*, (Version SAM 2017.9.5.) [computer program]. Available at: https://sam.nrel.gov(Accessed: 10 July 2019).

[22] PVsyst (2012) *A powerful software for your photovoltaic systems*, Available at: http://www.pvsyst.com/en/(Accessed: 10 July 2019).

[23] CRES (2012) *WindRose*, (Version v4.32-6.32) [computer program]. Available at: http://www.windrose.gr(Accessed: 10 July 2019).

[24] ReSoft Ltd (2016) *WindFarm*,(Version 5) [computer program]. Available at: http://resoft.co.uk/English/index.htm(Accessed: 10 July 2019).

[25] UL LLC (2018) *Windographer*, (Version 4.1) [computer program]. Available at: https://www.windographer.com(Accessed: 10 July 2019).

[26] DTU Wind Energy (2016) *WAsP*[computer program]. Available at: http://www.wasp.dk/wasp ((Accessed: 10 July 2019).

[27] Technical University Berlin (2018) *Qblade*[computer program]. Available at: http://fd.tu-berlin.de/en/research/projects/wind-energy/qblade/(Accessed: 10 July 2019).

[28] Bagiorgas, H. Assimakopoulos, M. Theoharopoulos, D. Matthopoulos, D. &Mihalakakou, G. (2007) 'Electricity generation using wind energy conversion systems in the area of Western Greece' *Energy Conversion and Management*, 48, pp. 1640-1655,*ScienceDirect* [Online]. Available at: http://www.sciencedirect.com(Accessed: 10 July 2019).

[29] University of Geneva (2010) *PVsyst*(Version 5.3.1) [computer program].

[30] Hellenic National Meteorological Service (HNMS) (2018) E-mailto TatianiGeorgitsioti, 4 December.

[31] Ministry of New and Renewable Energy (MNRE) (2006) 'Chapter 2: Climate and Buildings'

[32] GraciaAmillo, A. Huld, T. &Müller, R. (2014) 'A New Database of Global and Direct Solar Radiation Using the Eastern Meteosat Satellite, Models and Validation' *remote sensing*, 6, pp. 8165-8189.

[33] Ineichen, P. (2013) 'Long term satellite hourly, daily and monthly global, beam and diffuse irradiance validation. Interannual variability analysis. (Adapted to CM-SAF product from the IEA 2013 report)' *University of Geneva*. Available at: https://archive-ouverte.unige.ch/unige:29606(Accessed: 10 July 2019).

[34] Networked Energy Services (2019) *Wind speed extrapolation*, Available at: https://websites.pmc.ucsc.edu/~jnoble/wind/extrap/(Accessed: 10 May 2019).

[35] Danish Wind Industry Association (1997-2003) *Roughness and Wind Shear*, Available at:http://drømstørre.dk/wp-content/wind/miller/windpower%20web/en/tour/wres/shear.htm(Accessed: 10 May 2019).

[36] Bechrakis, D. &Sparis, P. (2000) 'Simulation of the wind speeds at different heights using artificial neural networks' *Wind Engineering*, 24 (2), pp. 127-136, *Sage Journals* [Online]. Available at: https://journals.sagepub.com(Accessed: 10 May 2019).

[37] PVTech (2018) *Top 10 module suppliers in 2017*, Available at: https://www.pv-tech.org/editors-blog/top-10-module-suppliers-in-2017(Accessed: 10 July 2019).

[38] Jinko Solar (2013) *Solar module*, Available at: https://www.jinkosolar.com/product_256.html?lan=en(Accessed: 10 July 2019).

[39] Trina Solar (2018) *Reliable and smart solar*, Available at: https://www.trinasolar.com/us/product(Accessed: 10 July 2019).

[40] Canadian Solar (2018) *Solar modules*, Available at: https://www.canadiansolar.com/solar-panels/dymond.html (Accessed: 10 September 2018).

[41] JA Solar (2018) *PV modules*, Available at: http://www.jasolar.com/index.php?m=content&c=index&a=lists&catid=83(Accessed: 10 July 2019).

[42] Q Cells (2017)*Solar panels*, Available at: https://www.q-cells.com/en/main/products/solar_panels~solar_panels~.html(Accessed: 10 July 2019).

[43] GCL-SI (2018) *Modules*, Available at: http://en.gclsi.com/modules/(Accessed: 10 July 2019).

[44] LONGi Solar (2016) *About LONGi Solar*, Available at: http://en.longi-solar.com(Accessed: 10 July 2019).

[45] Risen Energy (2018) *High Performance PV Modules*, Available at: http://en.risenenergy.com/index.php?c=category&id=18 (Accessed: 10 September 2018).

[46] Shunfeng International (2018) *Solar modules*, Available at: http://sfcegroup.com/en/?page_id=1039 (Accessed: 10 September 2018).

[47] Yingli Solar (2018) Available at: http://www.yinglisolar.com/en/(Accessed: 10 July 2019).

[48] MetSolar (2018) Available at: https://metsolar.eu(Accessed: 10 July 2019).

[49] Solaronix SA (2018) Available at: https://www.solaronix.com(Accessed: 10 July 2019).

[50] Kameleon Solar (2018) Available at: https://kameleonsolar.com(Accessed: 10 July 2019).

[51] Haymarket Media Group (2017) *WindPower monthly*, Available at: https://www.windpowermonthly.com/article/1445638/top-ten-turbine-makers-2017(Accessed: 10 July 2019).

[52]EcoBusinessLinks (1998-2018) *Vertical Axis Wind Turbine Manufacturers*, Available at: http://www.ecobusinesslinks.com/clean-energy-water/wind_energy/Micro___Small_Wind/vertical_axis_wind_turbine_manufacturers/(Accessed: 10 July 2019).

[53] V-Air Wind Technologies (2018) *VisionAIR*, Available at: http://visionairwind.com(Accessed: 10 July 2019).

[54] Home Energy (2018) *Energy Ball*, Available at: https://www.homeenergy.nl/en-gb/about(Accessed: 10 July 2019).

[55] QuietRevolution (2018) *The qr6 Vertical Axis Wind Turbine*, Available at: https://www.quietrevolution.com(Accessed: 10 July 2019).

[56] OyWindside Production (2018) *WS-30*, Available at: http://www.windside.com/products/ws-30(Accessed: 10 July 2019).

[57] Aeolos Wind Energy (2018) *Installation case*, Available at: http://www.windturbinestar.com/france-3kw-vertical-wind-turbine.html(Accessed: 10 July 2019).

[58] SMA Solar Technology AG (2018) Available at: https://www.sma.de/en/products/solarinverters.html(Accessed: 10 July 2019).

[59] SolarEdge Technologies Inc. (2018) Available at: https://www.solaredge.com(Accessed: 10 July 2019).

[60] ABB (2018) Available at: https://new.abb.com/power-converters-inverters/solar(Accessed: 10 July 2019).

[61] Fronius International GmbH (2017 – 2018) Available at: https://www.fronius.com/en/photovoltaics/products(Accessed: 10 July 2019).

[62] ENERCON GmbH (2016) Available at: https://www.enercon.de/en/products/(Accessed: 10 July 2019).

[63] Senvion S.A. (2018) Available at: https://www.senvion.com/global/en/products-services/wind-turbines/(Accessed: 10 July 2019).

[64] Nordex SE (2013) Available at: http://www.nordex-online.com/en/products-services/wind-turbines.html(Accessed: 10 July 2019).

[65] Vestas (2018) Available at: https://www.vestas.com/en/products/turbines (Accessed: 10 December 2018).

[66] Aeolos Wind Energy (2018) Available at: http://www.windturbinestar.com/products.html(Accessed: 10 July 2019).

[67] wind-turbine-models.com (2011-2019) *AeolosAeolos-V 10kW*, Available at: https://en.wind-turbine-models.com/turbines/1854-aeolos-aeolos-v-10kw (Accessed: 10 July 2019).

[68] Smart grids info (2018) Available at: https://www.smartgridsinfo.es/2018/09/06/energia-verde-propiedad-compartida-primer-molino-eolico-comunitario-sur-europa(Accessed: 10 July 2019).

[69] Renewables First (2015)*Enercon E82 E4 3000 kW Wind Turbine*, Available at: https://www.renewablesfirst.co.uk/windpower/wind-turbines/enercon-e82-e4-3000-kw-wind-turbine/ (Accessed: 10 July 2019).

[70] Laima(2019) *Metsolar*, E-mail to TatianiGeorgitsioti, 7 February.

[71] Energy Club (2019) *Suntech STP270-20/Wem (Poly)*, Available at:http://www.energyclub.gr/index.php?route=product/product&product_id=572 (Accessed: 10 July 2019).

[72] SolarEdge Technologies Inc. (2019) 'Three Phase Inverter with Synergy Technology Installation MAN-01-00402-1.2', Available at: https://www.solaredge.com(Accessed: 10 July 2019).

[73] ABB (2019)*PVS-100/120-TL*, Available at: https://new.abb.com/power-converters-inverters/solar/string/three-phase/pvs-100-120-kw(Accessed: 10 July 2019).

[74] Fronius International GmbH (2019) *FRONIUS SYMO*, Available at: https://www.fronius.com/en/photovoltaics/products/all-products/inverters/fronius-symo/fronius-symo-8-2-3-m(Accessed: 10 July 2019).

[75] Jessica (2019) *Lotus Energy Technology Co., Ltd.*,E-mail to TatianiGeorgitsioti, 31 January.

[76]SolarEdge Technologies Inc. (2018) Available at: https://www.solaredge.com(Accessed: 10 July 2019).

[77] EmmanouilSorokos (2019) *PVeye*, E-mail to TatianiGeorgitsioti, 6 February.

[78] Laima (2019) *Metsolar*, E-mail to TatianiGeorgitsioti, 17 April.

[79]Diesel Service & Supply (1999-2019) *Generator Excitation Control Systems and Methods*, Available at: https://www.dieselserviceandsupply.com/Generator-Excitation-Methods.aspx (Accessed: 10 July 2019).

[80] Advanced Micro Controls, Inc. (2019) *What is a PLC?*, Available at: https://www.amci.com/industrial-automation-resources/plc-automation-tutorials/what-plc/(Accessed: 10 July 2019).

[81] Pearsall, N. (2010) 'PV Systems and Applications'. *EN550 Photovoltaic System Technology*. Northumbria University, UK

[82] Misbrener, K. (2018) *How to choose between string and central inverters in utility-scale installations*, Available at: https://www.solarpowerworldonline.com/2018/12/choose-between-string-and-central-inverters-utility-scale-solar/(Accessed: 10 July 2019).

[83]Staffell, I.& Green, R. (2014) 'How does wind farm performance decline with age?' *Renewable Energy*, 66, pp. 775-786,*ScienceDirect* [Online]. Available at: http://www.sciencedirect.com(Accessed: 10 July 2019).

[84]Olauson, J. Edström, P. &Rydén, J. (2017) 'Wind turbine performance decline in Sweden' *WILEY*, (short communication).

[85] Marion, B. Adelstein, J. Boyle, K. Hayden, H. Hammond, B. Fletcher, T. Canada, B. Narang, D. Shugar, D. Wenger, H. Kimber, A. Mitchell, L. Rich, G. & Townsend, T. (2005) 'Performance Parameters for Grid-Connected PV Systems', *31st IEEE Photovoltaics Specialists Conference and Exhibition,* Lake Buena Vista Florida, 3-7 January.

[86] Hamidah, I. Sathyajith, M. Aloka, S. Balakrishnan, N. Lim C. & Saiful, H. (2013) 'Comparative Performance of Grid Integrated Solar Photovoltaic Systems under the Tropical Environment' *IEEE ISGT Asia 2013*. Bangalore India, 10-13 November.

[87] Giannaros, T. Melas, D. &Ziomas, I. (2017) 'Performance evaluation of the Weather Research and Forecasting (WRF) model for assessing wind resource in Greece' *Renewable Energy*, 102, pp.190-198,*ScienceDirect* [Online]. Available at: http://www.sciencedirect.com (Accessed: 10 July 2019).

[88] Cellura, M. Cirrincione, G. Marvuglia, A. &Miraoui, A. (2008) 'Wind speed spatial estimation for energy planning in Sicily: Introduction and statistical analysis' *Renewable*

*Energy*, 33 (6), pp.1237-1250,*ScienceDirect* [Online]. Available at: http://www.sciencedirect.com(Accessed: 10 July 2019).

[89] Darling, S.You, F. Veselkad, T. &Velosae, A. (2011) 'Assumptions and the levelized cost of energy for photovoltaics' *Energy Environ.Sci.*, 4(9), pp. 3077–3704,*RSC Publishing* [Online]. Available at: http://pubs.rsc.org/en/journals/journalissues/ee (Accessed: 10 December 2018).

[90] Bazilian, M. Onyeji, I. Liebreich, M. MacGill, I. Chase, J. Shah, J. Gielen, D. Arent, D. Landfear, D. &Zhengrong, S. (2013) 'Re-considering the economics of photovoltaic power' *Renewable Energy*, 53, pp. 329-338,*ScienceDirect* [Online]. Available at: http://www.sciencedirect.com(Accessed: 10 July 2019).

[91] Allan, G. Gilmartin, M. McGregor, P. & Swales, K. (2011) 'Levelised costs of Wave and Tidal energy in the UK: Cost competitiveness and the importance of ''banded'' Renewables Obligation Certificates' *Energy Policy*, 39(1), pp. 23-39,*ScienceDirect* [Online]. Available at: http://www.sciencedirect.com(Accessed: 10 July 2019).

[92] Gross, R. Heptonstall, P. & Blyth, W. (2007) 'Investment in electricity generation: the role of costs, incentives and risks', *UK Energy Research Centre* [Online]. Available at: http://seg.fsu.edu/Library/Investment%20in%20Electricity%20Generation_%20The%20Role%20of%20Costs,%20Incentives,%20and%20Risks.pdf(Accessed: 10 July 2019).

[93] Brankera, K. Pathaka, M. &Pearcea, J. (2011) 'A review of solar photovoltaic levelized cost of electricity' *Renewable and Sustainable Energy Reviews*, 15(9), pp. 4470-4482,*ScienceDirect* [Online]. Available at: http://www.sciencedirect.com(Accessed: 10 July 2019).

[94] Short, W. Packey, D. & Holt, T. (1995) 'A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies', *National Renewable Energy Laboratory*

[95] NEA & IEA (2005) 'Projected costs of generating electricity', Paris: OECD/IEA [Online]. Available at: http://horabsurda.org/wp-content/plugins/downloads-manager/upload/costs_electricity.pdf (Accessed: 10 December 2018).

[96] Brealey, R. Myers, S. & Marcus, A. (2007) *Fundamental of Corporate Finance.*5th edn. New York: McGraw-Hill.

[97] Georgitsioti, T. Pearsall, N. & Forbes, I. (2014) 'Simplified levelised cost of the domestic photovoltaic energy in the UK: the importance of the feed-in tariff scheme' *IET Renewable Power Generation*, 8(5), pp.451-458,*IET Digital Library* [Online]. Available at: http://digital-library.theiet.org(Accessed: 10 July 2019).

[98] Legal Sources on Renewable Energy (2017) *Promotion in Italy*, Available at:http://www.res-legal.eu/search-by-country/italy/tools-list/c/italy/s/res-e/t/promotion/sum/152/lpid/151/(Accessed: 10 July 2019).

[99] Legal Sources on Renewable Energy (2017) *Promotion in Greece*, Available at:http://www.res-legal.eu/search-by-country/greece/tools-list/c/greece/s/res-e/t/promotion/sum/140/lpid/139/(Accessed: 10 July 2019).

[100] IRENA (2018), 'Renewable Power Generation Costs in 2017', International Renewable Energy Agency, Abu Dhabi.

[101] Georgitsioti, T. Pearsall, N. Forbes, I. & Pillai, G. (2019) 'A combined model for PV system lifetime energy prediction and annual energy assessment' *Solar Energy*, 183, pp. 738–744, *ScienceDirect* [Online]. Available at: http://www.sciencedirect.com(Accessed: 10 July 2019).

[102] Thevenard, D. &Pelland, S. (2013) 'Estimating the uncertainty in long-term photovoltaic yield predictions' *Solar Energy*, 91, pp. 432-445, *ScienceDirect* [Online]. Available at: http://www.sciencedirect.com(Accessed: 10 July 2019).

[103] Stephan Beurthey (2019) E-mail to Tatiani Georgitsioti, 4 June 2019.

[104] KM3NeT INFRADEV GA DELIVERABLE: D10.02

# X. Appendix A

# Appendix A

## PV Systems

*Italy*

1. Solar PV modules and PV inverter for the PV plant plus four PV inverters for the PV facades(acquired 30/04/2019)

greensun group

Spett.le
NATIONAL CENTER FOR SCIENTIFIC RESEARCH 'DEMOKRI
Patr.Gregoriou E & 27 Neapoleos St
15341 Agia Paraskevi

Destinazione corrispondenza
NATIONAL CENTER FOR SCIENTIFIC RESEARCH 'DEMOKRI
Patr.Gregoriou E & 27 Neapoleos St
15341 Agia Paraskevi

| Cod. Cli. | IVA | Valuta | Codice fiscale | Partita IVA | Numero doc. | Data doc. | Pag. |
|---|---|---|---|---|---|---|---|
| 3.506 | | EURO | 090085651 | EL 090085651 | 3052/00 | 29/04/2019 | 1 / 1 |

| Codice e descrizione pagamento | Banca d'appoggio |
|---|---|
| PAV PAGAMENTO AD AVVISO DI MERCE PRONTA | |

| Telefono | Agente | Tipo documento |
|---|---|---|
| 30 210 6503512 | 30 Carlo Ieva +39 344 0122914 | PREVENTIVO |

| Codice | Descrizione | Data Disponibilità | U.M. | Quantità | Prezzo Un. | Imp. Netto | IVA |
|---|---|---|---|---|---|---|---|
| JINJKM305M-60 | Mod. PV. Jinko JKM305M-60 305 Wp Mono Perc | 03/06/2019 | PZ | 330,00 | 93,1836 | 30.750,59 | 10 |
| SLESE82.8K-RW0P0BNU4 | SolarEdge 3 Ph. Inverter synergy technology, 82.8kW, DCD, MC4 | 30/06/2019 | PZ | 1,00 | 2.422,0000 | 2.422,00 | 10 |
| SLESE8K-RW0TEBNN4 | SolarEdge Inverter 3F 8.0Kw with SetApp Config. | 26/06/2019 | PZ | 4,00 | 1.070,6600 | 4.282,64 | 10 |

| Imponibile | Al.IVA | Importo IVA | Totale merce | % Sconto | Importo sconto | Netto merce |
|---|---|---|---|---|---|---|
| | | | 37.455,23 | 0,00 | | 37.455,23 |

| Bolli | Spese incasso | | Abbuono | Acconto |
|---|---|---|---|---|
| | | | | |

| Imponibile | Al.IVA | Importo IVA | TOTALE A PAGARE | TOTALE PREVENTIVO |
|---|---|---|---|---|
| 37.455,23 | Tot. | 3.745,52 | 41.200,75 | 41.200,75 |

| Firma (per uso interno) | Firma per accettazione merci |
|---|---|
| | |

VALIDITA 'OFFERTA 5GG

Informativa di sintesi: ai sensi dell'art. 13 D.Lgs. 196/2003, informiamo che i Vostri dati sono inseriti in banche dati sia elettroniche che cartacee e sono trattati dagli incaricati preposti, esclusivamente per finalità amministrative e contabili. I dati potranno essere comunicati a terzi per dar corso ai rapporti in essere o per obblighi di legge, ma non saranno diffusi. Ai sensi degli artt. 7-8-9 del medesimo D.Lgs. 196/2003 a cui si rimanda per completezza, informiamo inoltre che in qualsiasi momento potrà essere richiesto l'accesso ai dati e sarà possibile opporsi a taluni loro utilizzi, rivolgendosi allo scrivente Titolare od al Responsabile.
Nota: La presente informativa di sintesi, è integrata da ulteriore informativa articolata ed estesa, disponibile senza alcun onere presso la sede sociale e/o visionabile sul sito internet aziendale.

Greensun Srl – Via E. Mattioli 4 – 42011 Bagnolo in Piano RE Italy – info@greensun.it – www.greensun.it
Capitale Sociale € 192.000,00
Registro Imprese di RE 02314900354 – C.F. e P.IVA 02314900354
Tel. +39 0522 654640 – Fax. +39 0522 758406

2.

2. Transportation cost of the above materials from the Green Sun company to Capo Passero (acquired 30/04/2019)

**TRANSPORT COST - Project PV plants for Italy Sicily and Greece** 1 message

From: Carlo Ieva
To: Tania Georgitsioti
30 Apr

CLS-PREVEN00030... _DEMOKRITOS__.pdf (108.4 KB) Download | Briefcase | Remove

Good Morning Tania,

for integration to our offer, sent to you yesterday, please find following the TRANSPORT COSTS:
from REGGIO EMILIA to CAPO DEL PASSERO, Sicily the trasport cost is: € 1200,00.
This quotation do not include the Mounting system who will calculeted a part.

I remain at your disposal.

Best Regards

Carlo Ieva
Export Manager

GREENSUN GROUP
Via E. Mattioli, 4 Bagnolo in Piano 42011 RE
T +39 (0)522 654640
M +39 344 0122914
E export@greensun.it W www.greensun.it/eng

3. Fixed mounted structure including transportation cost (acquired 02/07/2019)

**Offer for Mounting System/Sicily** 1 message

From: Carlo Ieva 02 Jul

To: Tania Georgitsioti

GS2782.19-P - G…ra palificato).pdf (756.5 KB) Download | Briefcase | Remove

Hi Tania,

sorry for my late reply.

As already said, without any layout, geological study and other specific info. is impossibile for us to give you detailed price for the PV mounting system, referred to 100kW PV project.
But if you just need an indicative price, I will take in consideration another similar offer (developed on the ground in Albania), made for another customer.

So, for this project, take in consideration an indicative cost for the mounting system of **€ 27.000.**

**This offer doesn't not include:**

-Possible costruction operations
-Costruction and building materials
-excavations and backfills,
-foundation works,
-scaffolding
-project and calculation for site accessibility,
- final structural tests

If do you have any doubts, I am at your disposal.

Waiting for your reply.

Best Regards

4. Change of inverter model for the PV facades, net cost of each unit: € 1327.24, plus VAT: € 1459.98 (acquired 04/02/2019)

| Item Code | Fronius Symo Three Phase Inverter | Net Price |
|---|---|---|
| FRO4,210,036 | Fronius Symo 3.0-3-M WLAN/LAN/Webserver | 848,70 € |
| FRO4,210,038 | Fronius Symo 3.7-3-M WLAN/LAN/Webserver | 931,35 € |
| FRO4,210,033 | Fronius Symo 4.5-3-M WLAN/LAN/Webserver | 982,86 € |
| FRO4,210,034 | Fronius Symo 5.0-3-M WLAN/LAN/Webserver | 999,03 € |
| FRO4,210,040 | Fronius Symo 6.0-3-M WLAN/LAN/Webserver | 1.019,99 € |
| FRO4,210,041 | Fronius Symo 7.0-3-M WLAN/LAN/Webserver | 1.266,16 € |
| FRO4,210,039 | Fronius Symo 8.2-3-M WLAN/LAN/Webserver | 1.400,92 € |
| FRO4,210,050 | Fronius Symo 10.0-3-M WLAN/LAN/Webserver | 1.471,52 € |
| FRO4,210,051 | Fronius Symo 12.5-3-M WLAN/LAN/Webserver | 1.669,43 € |
| FRO4,210,052 | Fronius Symo 15.0-3-M WLAN/LAN/Webserver | 1.826,76 € |
| FRO4,210,053 | Fronius Symo 17.5-3-M WLAN/LAN/Webserver | 1.949,75 € |
| FRO4,210,054 | Fronius Symo 20.0-3-M WLAN/LAN/Webserver | 2.037,16 € |
| FRO4,210,036,001 | Fronius Symo 3.0-3-M Light | 775,03 € |
| FRO4,210,038,001 | Fronius Symo 3.7-3-M Light | 857,68 € |
| FRO4,210,033,001 | Fronius Symo 4.5-3-M Light | 909,19 € |
| FRO4,210,034,001 | Fronius Symo 5.0-3-M Light | 925,36 € |
| FRO4,210,040,001 | Fronius Symo 6.0-3-M Light | 946,32 € |
| FRO4,210,041,001 | Fronius Symo 7.0-3-M Light | 1.192,49 € |
| FRO4,210,039,001 | Fronius Symo 8.2-3-M Light | 1.327,25 € |
| FRO4,210,050,001 | Fronius Symo 10.0-3-M Light | 1.394,73 € |
| FRO4,210,051,001 | Fronius Symo 12.5-3-M Light | 1.592,64 € |
| FRO4,210,052,001 | Fronius Symo 15.0-3-M Light | 1.749,97 € |
| FRO4,210,053,001 | Fronius Symo 17.5-3-M Light | 1.872,95 € |
| FRO4,210,054,001 | Fronius Symo 20.0-3-M Light | 1.960,36 € |

5. PV installation for both PV plant and PV facades systems: price per KW plant € 350.00 * (Three hundred and fifty) * VAT excluded according to law, plus € 36.00 for the connection request and € 122.00 for connection to the system(acquired 04/06/2019)

| EDIL PROGRESSO Operation & Maintenance | MANUTENZIONE<br>&<br>COSTRUZIONE | **Mod. 05-03 Rev. 1 del 18.11.2016** |
|---|---|---|

**Sciacca, Li 05/06/2019**

**Spett.Le Tatiani Georgitsioti**

**E p.c. GREENSUN GROUP**

**Via E. Mattioli, 4 Bagnolo in Piano 42011 RE**

**<u>OGGETTO</u>:** *PREVENTIVO MANODOPERA PER COSTRUZIONE DI IMPIANTI FOTOVOLTAICI IN SICILIA*

Facendo seguito alla Vostra gradita richiesta, siamo lieti di presentarvi l'offerta economica per la installazione di cui in oggetto.Vi preghiamo di prendere visione dei dettagli relativi alla fornitura ed alle condizioni di vendita.

I dettagli di carattere tecnico-economico relativi verranno concordati in sede successiva e formalizzati in apposito contratto. Restiamo a disposizione per qualsiasi ulteriore informazione dovesse rendersi necessaria.

EDIL PROGRESSO O&M S.r.l.
C.da S.Maria, snc - Z.I. - 92019 Sciacca (AG)
Tel./Fax 0925 86045 - info.oem@edilprogresso.it
P.Iva 02830760845 - R.E.A. 209411 CCIAA - AG

## TIPOLOGIA DEL SERVIZIO:

- ✓ Posa in opera di modulo fotovoltaico in silicio policristallino, struttura in alluminio verniciato color rosso resistente alla torsione, telaio in vetro con carichi resistenti fino a 5,4 kN/m² . Scatola di connessione piatta IP 65, con 3 diodi di by-pass, completa di cavo e connettori multicontact MCType con segno + e -. Numero di celle per modulo61215. Resa della cella fotovoltaica: >14,2%. Decadimento sulla potenza di picco: = 20% in 25 anni= 12% in 10 anni o superiore : 250 Wp.

- ✓ Posa in opera di gruppo di conversione trifase (inverter). Range di tensione FV, MPPT (Umpp): 320 - 800V. Ripple di tensione CC (Upp):<10% . Dispositivo di separazione CC: sezionatore o dispositivo elettronico Electronic Solar Switch. Varistori controllati termicamente. Monitoraggio della dispersione di terra. Protezione contro l'inversione di polarità: diodo di cortocircuito. Tensione nominale CA (Uca, nom): 230V/ 400V – 160V/280V.

- ✓ Posa in opera di quadro dì campo per protezione CC, con interruttore isolante, scaricatore con 2 poli. Conduttori L+ ed L- protetti da un elemento per la sovratensione con indicatore di insufficienza. Tensione massima: 600 V / 1000 V. Categoria richiesta: C. Perdita

- ✓ Posa in opera di cavo solare composto da fili di rame zincato della classe speciale

- ✓ Posa in opera di connettori multicontact per sezionamento lato CC sezione 2-6 mm2 Tensione max di sistema 1000 V Grado di protezione IP. Temperatura di esercizio -40°/+90°. Resistenza all'estrazione magg 50 N Classe di protezione II tensione 6,6 kV. Connettore con segno +/-

- ✓ Posa in opera di sistema di acquisizione dati, per il monitoraggio dell'impianto da PC o da quadro sinottico attraverso interfaccia RS485/232 o tramite porta ethemet, con possibilità di utilizzo di modem GSM/ISDN.

  Posa in opera di interfaccia Rs 485/232 per comunicazioni tra gli inverter, comunicazione inverters/sistema di acquisizione dati, comunicazione sistema acquisiszione dati/ PC o sinottico

- ✓ Posa in opera di sistema di fissaggio per moduli su superfici piane o inclinate, completo di puntello triangolare regolabile a 30°, 35°, 40°, profilo trasversale, angolare di giunzione, morsetto medio, morsetto terminale, calotta terminale, viti e bulloneria. per tetti inclinati o piani

- ✓ Collegamento equipotenziale principale di massa estranea, di conduttore in rame con rivestimento termoplastico di colore giallo/verde del tipo N07V-K posato entro i tubi di materiale termoplastico autoestinquente del tipo pieghevole del diametro esterno non inferiore a mm 25. Inclusi i capicorda, i morsetti, i collari per le tubazioni ed ogni altro onere.

- ✓ Posa in opera di tubi di materiale plastico rigido o pieghevole, canala metallica o plastica, cassette di derivazione, conformi alle norme CEI, complete di coperchio ed eventuale separatore e ogni altro onere.

- ✓ Posa in opera di Quadro Elettrico da parete in materiale isolante, conforme alla norma CEI 23-51 drado di protezione IP55 completo di portello trasparente/fumè guide DIN pannelli ciechi e forati, copri foro, barra equipotenziale e morsetteria.
- ✓ **Oneri relativi alla sicurezza in cantiere e approntamento di ponteggio realizzato per interventi superiori a 3,50 mt;**
- ✓ **Nolo gru o piattaforma aerea per eventuali elevazioni di materiali;**
- ✓ **Progetto esecutivo e relazione tecnica (escluso);**
- ✓ **Richiesta installazione contatore ENEL (escluso);**
- ✓ **Inoltro richiesta "DETRAZIONE" al GSE compresi gli oneri per la gestione delle pratiche necessarie e SCAMBIO SUL POSTO (escluso);**
- ✓ **Posa in opera della struttura, dei pannelli, collegamento e collaudo;**
- ✓ **Predisposizione e presentazione di progetto per il rilascio del nulla-osta per vincolo soprintendenza (escluso);**
- ✓ **Redazione e Presentazione della documentazione DIA in Comune (escluso).**
- ✓ **Manutenzione per il 1° anno di vita dell'impianto (escluso);**
- ✓ **Smaltimento dei moduli fotovoltaici a fine ciclo naturale di vita dell'impianto (escluso) ;**

**Prezzo per impianto a KW € 350,00*** (Trecentocinquanta) *Iva esclusa secondo legge.

**ESCLUSIONI: Materiale, tutto quanto evidenziato in rosso e specificatamente riportato nella voce escluso, Versamento ENEL per l'ottenimento del preventivo, (€ 36,00 per la domanda di connessione e € 122,00 per allaccio impianto) e comunque tutto quanto non descritto nel presente preventivo.**

**DOVRA' NECESSARIAMENTE ESSERE CONSEGNATO IL PROGETTO DEFINITIVO PRIMA DELL'INIZIO DEI LAVORI.**

| | | |
|---|---|---|
| EDIL PROGRESSO Operation & Maintenance | MANUTENZIONE & COSTRUZIONE | **Mod. 05-03 Rev. 1 del 18.11.2016** |

**TEMPI DI CONSEGNA**: Entro 20 gg. Lavorativi dalla data di inizio lavori per l'Impianto da 100 kw
Entro 20 gg. Lavorativi dalla data di inizio lavori per 4 impianti da 10 kw

**MODALITA' DI PAGAMENTO:** 30% a firma contratto,
30% a inizio lavori,
40% a fine lavori (escluso allaccio enel)

**VALIDITA' DELL'OFFERTA:** 60 gg dalla data dell'offerta

**Il presente preventivo a carattere provvisorio acquisisce carattere definitivo una volta formalizzato il contratto di appalto.In attesa di un Vs. gradito riscontro e ringraziando anticipatamente della disponibilità mostrata porgiamo, Distinti Saluti**
**Per Accettazione**

EDIL PROGRESSO O&M S.r.l.
C.da S.Maria, snc - Z.I. - 92019 Sciacca (AG)
Tel./Fax. 0925 86045 - info.oem@edilprogresso.it
P.Iva 02830760845 - R.E.A. 209411 CCIAA - AG

**Per Accettazione**

_______________________

Si autorizza la Edil Progresso O&M S.r.l. ad espletare tutte le formalità, autorizzandola già sin d'ora al trattamento dei dati personali e divulgazione a terzi ai sensi del D. Lgs 196/2003.

6. PV operation and maintenance cost for both PV plant and PV facades systems: € 480/ year for the PV facades and € 1450/ year for the PV plant (acquired 05/06/2019)

| | | |
|---|---|---|
| EDIL PROGRESSO Operation & Maintenance | Costruzione<br>&<br>MANUTENZIONE | Mod. 05-03 Rev. 1 del 18.11.20146 |

# Listino prezzi per impianti di potenza richiesta

## 1. IMPIANTI FOTOVOLTAICI

| ART. | DESCRIZIONE | UNITA' | BASE | PLUS |
|---|---|---|---|---|
| 1 | IMPIANTO DA 6 KW A 15 KW | €/anno | 480,00 | 780,00 |
| 2 | IMPIANTO DA 80 KW A 120 KW | €/anno | 1050,00 | 1450,00 |
| 8 | IMPIANTO OLTRE I 200 | Personalizzato | | |
| 9 | HIGECO GWC + CONFIGURAZIONE (UNA TANTUM) | € | 500,00 | |
| 10 | MANTENIMENTO SERVER SU INTERNET | € | 70,00 | |
| 11 | DISPLAY LCD | € | 1500,00 | |
| 12 | MODULO GPRS PER DISPLAY | € | 500,00 | |
| | **SERVIZIO DI MONITORAGGIO** | | | |
| 13 | Canone Annuale | €/anno | 100,00 | |
| | **GESTIONE GSE E UTF (impianti >20 kW)** | | | |
| 15 | Canone Annuale | €/anno | 700,00 | |
| | **GESTIONE GSE E UTF (impianti >20 kW)** | | | |
| 16 | Canone Annuale | €/anno | 900,00 | |

## 2. SERVIZI ADDIZIONALI

### 2.1.- TARIFFE ORARIE PER SERVIZI AGGIUNTIVI

In questa sezione sono presenti un elenco delle tariffe orarie del personale per categoria. Le ore sono definiti come segue:

Al costo di manodopera è previsto un costo di chiamata pari ad € 25,00 ad intervento.

Art. 2.1.1: ORA NORMALE: Giorni Lavorativi 7:00 - 20:00

Art 2.1.2.: ORA NOTTURNA: Giorni Lavorativi 20:00 - 7:00

Art. 2.1.3.: ORA NORMALE FESTIVA: Fine settimana e giorni di festività Nazionale 8:00-16:00

Art. 2.1.4.: ORA NOTTURNA FESTIVA: Fine settimana e giorni di festività Nazionale

**Sede legale:**
**EDILPROGRESSO O&M SRL**
**C.da Santa Maria Z.I. snc**
92019 Sciacca (AG)

**Sede Operativa:**
**C.da Santa Maria Z.I. 92019 SCIACCA AG**
Iscrizione C.C.I.A.A./C.F./P.IVA: 02830760845
Cap. Soc. € 10.500,00 Interamente Versato

Tel. e Fax. +39 0925 86045
mail: info@edilprogresso.it
mail: edilprogresso@pec.it

| | | | |
|---|---|---|---|
| | 16:00-8:00 | | |
| INDICE ART. | DESCRIZIONE | UNITA' | VALORE |
| 101 | Ora Normale di Ingegnere | €/h | 40,00 |
| 102 | Ora Notturna di Ingegnere | €/h | 45,00 |
| 103 | Ora Normale Festiva di Ingegnere | €/h | 49,00 |
| 104 | Ora Notturna Festiva di Ingegnere | €/h | 69,00 |
| 105 | Ora Normale di Tecnico | €/h | 35,00 |
| 106 | Ora Notturna di Tecnico | €/h | 65,00 |
| 107 | Ora Normale Festiva di Tecnico | €/h | 70,00 |
| 108 | Ora Notturna Festiva di Tecnico | €/h | 120,00 |
| **2.2 - SERVIZI ADDIZIONALI** | | | |
| INDICE ART. | DESCRIZIONE | UNITA' | VALORE |
| 201 | Pulizia dei Moduli (sporcizia, escrementi, etc) | €/MWp | 3500,00 |
| 202 | Spostamento con macchina tipo van (renault kangoo o similare) | €/km | 0,300 |
| 203 | Spostamento con macchina tipo pick-up o 4x4 | €/km | 0,300 |
| 204 | Spostamento con macchina tipo small (fiat punto o simile) | €/km | 0,300 |
| 204 | Spostamento con macchina tipo normal car (fiat bravo o simile) | €/km | 0,300 |

Tutti i prezzi riportati sopra sono da considerarsi IVA esclusa secondo legge.

7. Customised PV modules plus transportation cost for the PV facades in Italy and Greece (acquired 17/04/2019)

metsolar

**Indicative Offer**
**No. 20190417-01**
17/4/2019

| From: | | To: | |
|---|---|---|---|
| **JSC Modern E-Technologies** | | **National Centre of Scientific Research Demokritos** | |
| VAT No.: | LT100003641116 | VAT No.: | |
| Ref. No.: | 300852013 | Ref. No.: | |
| Address: | Vismaliukai str. 34, LT-10243<br>Vilnius, Lithuania | Address: | |

| No. | Product category: | Product code/description | Meas. Unit | Quantity | Price, EUR/pc | Total Sum |
|---|---|---|---|---|---|---|
| 1. | *PV panel* | Glass/Glass PV panel:<br>**980x1630_6x10_PFC**<br><br>polycrystalline full cells (Emerald Green)<br>dimensions: 980mm x 1630mm<br>frame: no<br>junction box: yes<br>front glass: 3mm, lowiron float (tempered)<br>rear glass: 3mm, low iron float (tempered)<br><br>Electrical characteristics (±3%):<br>Pmax 240Wp<br>Isc 8,21A<br>Impp 7,66A<br>Voc 37,74V<br>Vmpp 31,38V<br><br>Cell qty: 60<br>Cell size: 156,75mm x 156,75mm | pcs. | 80 | €361,72 | €28 937,60 |
| 2. | *PV panel* | Glass/Glass PV panel:<br>**980x1630_6x10_PFC**<br><br>polycrystalline full cells (Diamond Blue)<br>dimensions: 980mm x 1630mm<br>frame: no<br>junction box: yes<br>front glass: 3mm, lowiron float (tempered)<br>rear glass: 3mm, low iron float (tempered)<br><br>Electrical characteristics (±3%):<br>Pmax 235Wp<br>Isc 8,12A<br>Impp 7,54A<br>Voc 37,50V<br>Vmpp 31,14V<br><br>Cell qty: 60<br>Cell size: 156,75mm x 156,75mm | pcs. | 80 | €358,06 | €28 644,80 |
| 3. | *PV panel* | Glass/Glass PV panel:<br>**980x1470_6x9_MFC**<br><br>monocrystalline full cells<br>dimensions: 980mm x 1470mm<br>frame: no<br>junction box: yes<br>front glass: 3mm, colored glass (blue-green)<br>rear glass: 3mm, low iron float (painted in black)<br><br>Electrical characteristics (±3%):<br>Pmax 251Wp<br>Isc 8,72A<br>Impp 8,22A<br>Voc 36,12V<br>Vmpp 30,61V<br><br>Cell qty: 54<br>Cell size: 156,75mm x 156,75mm | pcs. | 80 | €406,62 | €32 529,60 |
| 4. | *PV panel* | Glass/Glass PV panel:<br>**980x1470_6x9_MFC**<br><br>monocrystalline full cells<br>dimensions: 980mm x 1470mm<br>frame: no<br>junction box: yes<br>front glass: 3mm, colored glass (bronze)<br>rear glass: 3mm, low iron float (painted in black)<br><br>Electrical characteristics (±3%):<br>Pmax 254Wp<br>Isc 8,81A<br>Impp 8,32A<br>Voc 36,12V<br>Vmpp 30,61V<br><br>Cell qty: 54<br>Cell size: 156,75mm x 156,75mm | pcs. | 80 | €406,62 | €32 529,60 |
| 5. | ***Shipping*** | Packaging, shipping and Insurance DAP Passero/Kalamata | pcs. | 2 | €6 368,18 | €12 736,36 |
| | | | **Total EUR:** | | | **€135 377,96** |

* price valid for complete order

| | |
|---|---|
| Incoterms 2010: | DAP Passero/Kalamata |
| Payment terms: | TBD |
| Production lead time: | TBD |
| Offer valid until: | 2019-06-17 |

*Offer written by:* BDM, Adolis Jančiauskas
*(position, name, surname, signature)*

Greece

8. PV plant in Kalamata complete offer (acquired 06/02/2019)

ΑΘΗΝΑ 5/2/2019

**ΠΡΟΣ: ……………….**

**ΠΡΟΣΦΟΡΑ ΦΩΤΟΒΟΛΤΑΪΚΟΥ ΣΤΑΘΜΟΥ ΙΣΧΥΣ «400 kW»**

Αξιότιμε κύριε …………….,

Το γραφείο μας είναι στην ευχάριστη θέση να σας προτείνει την οικονομική προσφορά για την υλοποίηση φωτοβολταϊκής μονάδας **«400 kW»**, στην περιοχή της Καλαμάτας.

**ΣΥΝΟΠΤΙΚΟ ΣΗΜΕΙΩΜΑ**

Μία από τις βασικές ενασχολήσεις του γραφείου μας είναι η εγκατάσταση φωτοβολταϊκών συστημάτων. Προσαρμοζόμαστε στις ανάγκες των πελατών μας και αναπτύσσουμε όλες τις φάσεις ενός έργου ακόμη και σε περιπτώσεις που δεν έχουμε αναλάβει εξ ολοκλήρου την κατασκευή του. Με τον όρο εγκατάσταση εννοείται όλο το εύρος εργασιών, ξεκινώντας από την αδειοδότηση του έργου, τα έργα πολιτικού μηχανικού μέχρι και τη διασύνδεση με το δίκτυο. Με τον τρόπο αυτό ελέγχουμε την ποιότητα υλοποίησης του έργου, μέχρι την τελική παράδοση στον πελάτη.

Το γραφείο μας έχει την δυνατότητα να αναλάβει όλα τα αδειοδοτικά και μελετητικά στάδια όπως:

- αξιολόγηση του προτεινόμενου χώρου
- εκτίμηση ενεργειακού δυναμικού
- τοπογραφικό διάγραμμα του χώρου εγκατάστασης
- αίτηση εξαίρεσης ή άδεια παραγωγής ηλεκτρικής ενέργειας
- περιβαλλοντική αδειοδότηση
- έκδοση όρων σύνδεσης
- σύναψη συμβάσεων με ΔΕΗ/ΔΕΣΜΗΕ
- διαχείριση και υλοποίηση έργου

Ένα από τα σημαντικότερα ανταγωνιστικά πλεονεκτήματα μας είναι να προσφέρουμε υπηρεσίες ***«με το κλειδί στο χέρι»***. Η **το** γραφείο μας θέτει στη διάθεση των πελατών της τους μηχανικούς και συνεργάτες της προκειμένου να σχεδιάσουν και να διαστασιολογήσουν οποιαδήποτε εγκατάσταση, αναλαμβάνοντας επιπλέον από τα έργα μηχανικού της εγκατάστασης, μέχρι και τη σύνδεση με το δίκτυο καθώς και τη συντήρησή του. Το μόνο που απαιτείται από τον πελάτη είναι να διευκρινίσει τις ανάγκες του τα υπόλοιπα μπορεί να τα αφήσει σε μας, για να του παραδώσουμε έναν ολοκληρωμένο, τεχνικά άρτιο και λειτουργικά αξιόπιστο φωτοβολταϊκό σταθμό.

## ΠΡΟΤΕΙΝΟΜΕΝΟ ΣΥΣΤΗΜΑ

Το φωτοβολταϊκό σύστημα που σας προτείνουμε είναι σχεδιασμένο με την βοήθεια εξελιγμένων σχεδιαστικών και υπολογιστικών λογισμικών, τα οποία λαμβάνουν υπόψη όλες τις κλιματικές και περιβαλλοντικές ιδιαιτερότητες της περιοχής και του χώρου εγκατάστασης.

Κατά την επιλογή των υλικών και όλων των παρελκόμενων συνυπολογίστηκαν τα εξής:

- ✓ η διάρκεια ζωής.
- ✓ η αξιοπιστία.
- ✓ η μέγιστη δυνατή απόδοση.
- ✓ η ελαχιστοποίηση των απαιτήσεων συντήρησης.
- ✓ η λειτουργία σε ένα μεγάλο εύρος κλιματολογικών συνθηκών (υγρασία, θερμοκρασία).
- ✓ η ευελιξία του συστήματος.

## ΦΩΤΟΒΟΛΤΑΪΚΕΣ ΓΕΝΝΗΤΡΙΕΣ (PANELS)

Τα φωτοβολταϊκάπάνελς που θα χρησιμοποιηθούν είναι πολυκρυσταλλικά της **SUNTECH** Το μοντέλο φωτοβολταϊκού πάνελ που έχουμε επιλέξει είναι το **STP270P20** ισχύος 270W. Η ποσότητα που απαιτείται για την εγκατάσταση των 400kW είναι 1481 τεμάχια (1481 τεμάχια X270Wp = 399.87W).

Τα τεχνικά χαρακτηριστικά του προσφερόμενου πάνελ επισυνάπτονται στο τέλος της προσφοράς μας.

## ΑΝΤΙΣΤΡΟΦΕΙΣ (INVERTER)

Για την μετατροπή του συνεχούς ρεύματος σε εναλλασσόμενο ρεύμα επιλέχθηκαν να χρησιμοποιηθούν αντιστροφείς (inverter) του κατασκευαστικού οίκου **ABB**. Οι προσφερόμενοι αντιστροφείς έχουν μεγάλο συντελεστή απόδοσης **(98,2%)** με σκοπό την υψηλότερη δυνατή απόδοση του συστήματος και φέρουν όλες τις απαραίτητες πιστοποιήσεις που απαιτούνται για την σύνδεση τους με το δίκτυο της ΔΕΗ. Το μοντέλο που επιλέχθηκε είναι το **PVS100SX** ισχύος 100Kw 4τμχ.

Τα τεχνικά χαρακτηριστικά του προσφερόμενου inverter επισυνάπτονται στο τέλος της προσφοράς μας.

## ΒΑΣΕΙΣ ΚΑΙ ΘΕΜΕΛΙΩΣΗ

Τα φωτοβολταϊκά πάνελ θα στηριχθούν επί του εδάφους πάνω σε σταθερές μεταλλικές βάσεις από γαλβανισμένα στοιχεία τα οποία θα εδραστούν με την μέθοδο της **πασσαλόμπηξης**, με πιστοποιημένους γαλβανισμένους πασσάλους. Η σχεδίαση του συστήματος επιτρέπει την εύκολη συναρμολόγηση και εγκατάσταση του συστήματος. Η ελάχιστη απόσταση των φωτοβολταϊκών πάνελ από το έδαφος θα είναι περίπου **0,50 m - 1,00 m** ώστε να αποφεύγεται η ρύπανση τους από λάσπη ή η σκίαση τους από αυτοφυή βλάστηση.

## ΣΥΜΠΛΗΡΩΜΑΤΙΚΟΣ ΕΞΟΠΛΙΣΜΟΣ

✓ ***ΤΗΛΕΜΕΤΡΙΑ***

Η τηλεμετρία που επιλέχθηκε είναι του κατασκευαστικού οίκου **ABB**. Το προτεινόμενο σύστημα μας δίνει την δυνατότητα αυτόματου εντοπισμού σφαλμάτων μέσω της συνεχούς εποπτείας του συστήματος.

✓ ***ΘΕΜΕΛΙΑΚΗ ΓΕΙΩΣΗ***

Για την θεμελιακή γείωση επιλέχθηκε η λύση του περιμετρικού κλωβού με ακίδες. Ο περιμετρικός κλωβός θα δημιουργηθεί από ειδική ταινία επιψευδαργυρωμένου χάλυβα **30 X 3,5** η οποία θα εδράζεται επί του εδάφους σε πασσάλους τοποθετημένους ανά **2 m** για την σωστή κάθετη στήριξη αυτής.

✓ ***ΠΙΝΑΚΕΣ DC , AC , Μ.Τ ΚΑΙ ΜΕΤΑΣΧΗΜΑΤΙΣΤΕΣ ΜΕΣΗΣ ΤΑΣΗΣ***

Το ηλεκτρολογικό υλικό που θα χρησιμοποιηθεί στο συνεχές και εναλλασσόμενο ρεύμα χ.τ. και Μ.Τ. θα είναι του **γαλλικού οίκου SCHNEIDER ELECTRIC**.

✓ ***ΠΕΡΙΜΕΤΡΙΚΗ ΠΡΟΣΤΑΣΙΑ***

Για την διασφάλιση της προστασίας του πάρκου από ανεπιθύμητη είσοδο παρείσακτου ή πάσα κακόβουλη πράξη τρίτου έχει υπολογιστεί η χρήση **8 (έξι)** καμερών παρακολούθησης. και αποθήκευση του οπτικού υλικού σε καταγραφικό με σκληρό δίσκο.
Δίνεται δυνατότητα παρακολουθήσεως του σταθμού σε συνθήκες πραγματικού χρόνου με την ύπαρξη ADSL γραμμής ΟΤΕ Εναλλακτικά μέσω συστήματος GSM κινητής τηλεφωνίας. Το σύστημά περιλαμβάνει:

- **8 HD κάμερες ποθετημένες σε ιστό 3 m**
- **4 υπερύθρους προβολείς τοποθετημένες στους ιστούς**
- **1 καταγραφικό με ενσωματωμένο σκληρό δίσκο με δυνατότητα σύνδεσης στο διαδίκτυο**
- **1 τροφοδοτικό με ενσωματωμένη λειτουργία UPS συσσωρευτή**
- **1 ηλεκτρικό πίνακα AC**

✓ ***ΣΥΣΤΗΜΑ ΣΥΝΑΓΕΡΜΟΥ***

Σύστημα συναγερμού 8 ζωνών αποτελούμενο από:

- **κέντρο 8 ζωνών**
- **πληκτρολόγιο με LCD**
- **σειρήνα αυτόνομη τύπου 3L**
- **16 beam για την περιμετρική κάλυψη του πάρκου τοποθετημένα στου ιστούς των καμερών**
- **συσσωρευτές για την αυτόνομη λειτουργία του συστήματος**

- ✓ **ΕΓΚΑΤΑΣΤΑΣΗ**

Όλη η εγκατάσταση θα γίνει από εξουσιοδοτημένους τεχνίτες ενώ θα χρησιμοποιηθούν όλες οι απαραίτητες υποδομές (φρέατια, σωληνώσεις κλπ. ) για την σωστή και απρόσκοπτη λειτουργία του συστήματος ενώ παράλληλα έχει προβλεφθεί η επισκεψιμότητα όλης της εγκατάστασης ώστε να διευκολύνεται η συντήρηση του έργου καθώς και επέμβαση σε πιθανή μελλοντική βλάβη του συστήματος.

Η εγκατάσταση και θέση σε κατάσταση λειτουργίας του φωτοβολταϊκού σταθμού περιλαμβάνει:

1. εργασίες πασσαλόπηξης και εγκατάστασης των φωτοβολταϊκών γεννητριών.
2. ηλεκτρικές εργασίες στο πεδίο DC και τοποθέτηση/σύνδεση των inverter πίσω και κάτω από το ικρίωμα των φωτοβολταϊκών γεννητριών.
3. ηλεκτρικές εργασίες στο πεδίο AC και σύνδεση των inverter με των γενικό πίνακα.
4. εγκατάσταση γενικού πίνακα καθώς και παροχής προς το μετρητή ΔΕΗ.
5. προγραμματισμός inverter και σύνδεση αυτών με το δίκτυο παρουσία εκπροσώπου ΔΕΗ.
6. εργασίες κατασκευής συστήματος γείωσης.
7. Εργασίες Μέσης Τάσης (πίνακες ΜΤ, Μετασχηματιστής)

Το μέγιστο ολικό μήκος παροχής ΔΕΗ ορίζονται τα **20 m** και λοιπά έργα που απαιτηθούν από την ΔΕΗ δεν υπολογίζονται μέσα στην εγκατάσταση.

**ΠΕΡΙΛΑΜΒΑΝΟΝΤΑΙ**

Μεταφορά υλικών, εγκατάσταση υλικών, ασφάλιση, όλες οι εργοδοτικές και ασφαλιστικές εισφορές προσωπικού, φύλαξη και ασφάλιση εργοταξίου.

**ΠΕΡΙΦΡΑΞΗ ΚΑΙ ΦΩΤΙΣΜΟΣ**

Η περιφραξη θα είναι τύπου **ΝΑΤΟ και ύψους 2,5 m**, με κονσερτίνα στο επάνω μέρος και τοιχείο ύψους **20 εκ** στο κάτω μέρος, περιλαμβάνει πόρτα και θα γίνει επί συνολικού μήκους **360 m**.

Ο φωτισμός περιλαμβάνει **6** φωτιστικά σώματα **LED** τοποθετημένα επί της περίφραξης, στις κολώνες.

**ΟΙΚΙΣΚΟΣ**

ΟΙ οικίσκοι θα είναι προκατασκευασμένοι τύπου "**sandwich" διαστάσεων 2,5 Χ 6,0 Χ 2,5 m** τοποθετημένοι σε **2** δοκάρια από σκυρόδεμα.

**ΧΩΜΑΤΟΥΡΓΙΚΑ**

Περιλαμβάνουν εργασίες αποψίλωσης και εξομάλυνσης του εδάφους στην περιοχή τοποθέτησης των φωτοβολταϊκών γεννητριών, δεν περιλαμβάνουν εργασίες πρόσβασης και το τίμημα θα οριστικοποιηθεί με επιμέτρηση με το πέρας του έργου.

## ΣΥΓΚΕΝΤΡΩΤΙΚΟΣ ΠΙΝΑΚΑΣ ΠΡΟΣΦΕΡΟΜΕΝΟΥ ΣΥΣΤΗΜΑΤΟΣ

| ΕΞΟΠΛΙΣΜΟΣ | ΤΕΜΑΧΙΑ |
|---|---|
| ΦΩΤΟΒΟΛΤΑΪΚΑ ΠΑΝΕΛ POLY | 1481 |
| INVERTER ABB | 4 |
| ΒΑΣΕΙΣ ΣΤΗΡΙΞΗΣ | 1 |
| ΠΙΝΑΚΕΣ DC-AC | 8 |
| ΠΙΝΑΚΑΣ Μ.Τ. ΚΑΙ ΜΕΤΑΣΧΗΜΑΤΙΣΤΕΣ | 1 |
| ΕΓΚΑΤΑΣΤΑΣΗ | 1 |
| ***ΕΠΙΠΡΟΣΘΕΤΑ*** | |
| *ΠΕΡΙΦΡΑΞΗ/ΧΩΜΑΤΟΥΡΓΙΚΑ/ΦΩΤΙΣΜΟΣ* | *1* |
| *ΤΗΛΕΜΕΤΡΙΑ* | *1 (ΣΕΤ)* |
| *ΣΥΝΑΓΕΡΜΟΣ/ΚΑΜΕΡΕΣ* | *1 (ΣΕΤ)* |

## ΟΙΚΟΝΟΜΙΚΗ ΠΡΟΣΦΟΡΑ

| | ΠΕΡΙΓΡΑΦΗ | ΤΕΜΑΧΙΑ | ΚΟΣΤΟΣ |
|---|---|---|---|
| 1 | ΦΩΤΟΒΟΛΤΑΪΚΑ ΠΑΝΕΛ | 1481 | € 115.000,00 |
| 2 | INVERTER STP 17000TL | 4 | € 32.000,00 |
| 3 | ΒΑΣΕΙΣ ΣΤΗΡΙΞΗΣ | 1 | €65.000,00 |
| 4 | ΠΙΝΑΚΕΣ DC-AC | 8 | € 20.000,00 |
| 5 | ΠΙΝΑΚΑΣ Μ.Τ. ΚΑΙ ΜΕΤΑΣΧΗΜΑΤΙΣΤΕΣ | 1 | € 35.000,00 |
| 6 | ΕΓΚΑΤΑΣΤΑΣΗ | 1 | € 50.000,00 |
| | ***ΕΠΙΠΡΟΣΘΕΤΑ*** | | |
| *7* | *ΠΕΡΙΦΡΑΞΗ, ΧΩΜΑΤΟΥΡΓΙΚΑ & ΦΩΤΙΣΜΟΣ** | *1* | € 15.000,00 |
| *8* | *ΤΗΛΕΜΕΤΡΙΑ* | *1(ΣΕΤ)* | € 1.000,00 |
| *9* | *ΣΥΝΑΓΕΡΜΟΣ & ΚΑΜΕΡΕΣ* | *1(ΣΕΤ)* | € 3.000,00 |
| | **ΣΥΝΟΛΟ** | | **€ 336.000,00** |
| | *ΚΟΣΤΟΣ ΕΤΗΣΙΑΣ ΣΥΝΤΗΡΗΣΗΣ* | | *2.000,00* |

* Οι παραπάνω τιμές εγκατάστασης αφορούν τη μέθοδο της **''πασσαλόμπηξης´´** και ισχύει κατόπιν αυτοψίας μηχανικού μας στο χώρο.

ΟΙ ΠΑΡΑΠΑΝΩ ΤΙΜΕΣ ΑΦΟΡΟΥΝ ΤΗΝ ΠΑΡΑΓΓΕΛΙΑ ΕΝΟΣ ΦΩΤΟΒΟΛΤΑΪΚΟΥ ΠΑΡΚΟΥ ΙΣΧΥΣ «**400 kW**»ΚΑΙ ΔΕΝ ΠΕΡΙΛΑΜΒΑΝΟΥΝ:

1. το Φ.Π.Α.
2. κόστος διασύνδεσης με το δίκτυο της ΔΕΗ.
3. κόστος παραβόλων, τελών, κλπ., που επιβάλλονται από τις αρμόδιες αρχές κατά και σε σχέση με την εκτέλεση του έργου.
4. πάσα οικοδομική άδεια που θα απαιτηθεί.

5. **ΧΡΟΝΟΣ ΠΑΡΑΔΟΣΗΣ ΕΡΓΟΥ:** ΕΝΤΟΣ 20 ΗΜΕΡΩΝ ΑΠΟ ΤΗΝ ΗΜΕΡΟΜΗΝΙΑ ΚΑΤΑΒΟΛΗΣ ΤΗΣ ΠΡΩΤΗΣ ΔΟΣΗΣ

**ΙΣΧΥΣ ΠΡΟΣΦΟΡΑΣ:** 15 ΗΜΕΡΕΣ

**ΤΡΟΠΟΣ ΠΛΗΡΩΜΗΣ:** **Κατόπιν συμφωνίας**

Την άνωθεν προσφορά αποδέχονται οι κάτωθι συμβαλλόμενοι:

Με εκτίμηση, Για τον εργοδότη,

(σφραγίδα, υπογραφή)

**<u>για να θεωρηθεί έγκυρη η αποδοχή της προσφοράς παρακαλείσθε όπως υπογράψετε στο τέλος κάθε σελίδας</u>**

## ΠΑΡΑΡΤΗΜΑ Ι

## ΤΕΧΝΙΚΑ ΧΑΡΑΚΤΗΡΙΣΤΙΚΑ

9. PV facades: installation cost € 5800 per system, O& M cost €150/system, inverter cost € 2200/per inverter. (phone communication 17/05/2019 with the same company that send the PV plant offer, written confirmation of the prices can be provided under request)

## Wind energy conversion systems

10. HAWT for Italy and Greece complete offer, maintenance cost € 51000/year for Italy and € 65000/year for Greece (acquired 09/04/2019)

**DEMOKRITOS - 2 x wind projects - Enercon project information** 8 messages

From: Yiannis Davilis 09 Apr
To: Tania Georgitsioti
Cc: Vissarion Theodorou Maria Korre

Καλησπέρα κα. Γεωργιτσιώτη,

Παρακάτω παρατίθενται ενδεικτικές (μη δεσμευτικές) τιμές κόστους για τον εξοπλισμού, τη μεταφορά, την εγκατάσταση και θέση σε λειτουργία της Α/Γ κάθε έργου, χωρίς έργα πολιτικού μηχανικού και ηλεκτρολογικά έργα εκτός των Α/Γ.
Ο υπολογισμός τιμής είναι προσεγγιστικός ελλείψει μελετών (route survey, site verification, κλπ.). Έχει θεωρηθεί επίσης ότι δεν απαιτείται ενδιάμεσος χώρος αποθήκευσης του εξοπλισμού, καθώς επίσης δεν έχει ληφθεί υπόψη και η χρήση ειδικών μέσων μεταφοράς όπως "blade-lifter" και "Ro-Ro" (roll in-roll out) ferry.

| | | |
|---|---|---|
| **Capo Passero** | **1 x E-82 E4 hh69m 3,0MW w.cl. IIA** | **2 200 000 €** |
| **Kalamata** | **1 x E-103 EP2 hh98m 2,35MW w.cl. IIIA** | **2 660 000 €** |

Τέλος, αναφορικά με το κόστος συντήρησης, αυτό εξαρτάται από την παραγόμενη ενέργεια κάθε Α/Γ και ανέρχεται σε 12,00 EUR/MWh ετησίως ή κατ' ελάχιστον 51 000 EUR ετησίως για την E-82 E4 και κατ' ελάχιστον 65 000 EUR ετησίως για την E-103 EP2.

Παραμένω στη διάθεση σας για οποιαδήποτε διευκρίνιση.
Με εκτίμηση,

Γιάννης Νταβίλης
Τμήμα Πωλήσεων

ENERCON
ENERGY FOR THE WORLD

ENERCON GmbH
Υποκατάστημα Αλλοδαπής

Γιάννης Νταβίλης

11. VAWT for Italy and Greece

Cost of the system component plus transportation cost to Palermo and Piraeus ports

The exchange rate from USD dollars to Euros was 1 USD= 0.895636 EUR as per 17/05/2019 (acquired 14/02/2019)

# Aeolos Quotations

14/02/2019

| AEOLOS-V 10kW (Grid-on) | Unit Price |
|---|---|
| 10kW Wind Turbine | USD 16200 |
| Grid-On Controller (Hydraulic Brake) | USD 2450 |
| Grid-On Inverter | USD 3500 |
| 12m Monopole Tower | USD 4650 |
| Total After 5% Discount (6 Units) | USD 152760 |
| Freight Cost to PIRAEUS, GREECE by 2x40'GP | USD 5180 |
| **CIF PIRAEUS, GREECE (6 Units)** | **USD 157940** |

| AEOLOS-V 10kW (Grid-on) | Unit Price |
|---|---|
| 10kW Wind Turbine | USD 16200 |
| Grid-On Controller (Hydraulic Brake) | USD 2450 |
| Grid-On Inverter | USD 3500 |
| 12m Monopole Tower | USD 4650 |
| Total After 5% Discount (6 Units) | USD 152760 |
| Freight Cost to PALERMO, ITALY by 2x40'GP | USD 6922 |
| **CIF PALERMO, ITALY (6 Units)** | **USD 159682** |

1) Price:
The price includes packing and shipment, while the installation is excluded.

2) Validity:
The quotation is valid until 20/02/2019.

3) Delivery time:
Production time: Approx. 20 working days after order confirmation.
Delivery time: By shipment, depends on different port with different distance. To PIRAEUS, GREECE, it usually takes approx. 33 days by sea. And to PALERMO, ITALY, it need approx. 45 days by sea.



**LOTUS (Qingdao) ENERGY TECHNOLOGY CO., LTD.**
Tel.: +86 532 8090 3375 Fax: +86 532 8090 3375
Add.: No. 16 Shandong Road, Qingdao, China

4) Payment method:
30% deposit after order confirmation by T/T
70% balance before shipment by T/T

**5) 5 Years Standard Warranty:**

Aeolos carries on a 5 years standard warranty. The wind turbines, controls and towers manufactured by Aeolos are warranted against defects in design, material, and workmanship, under normal use for which intended, ninety (90) days after shipment from the factory. During the warranty period, Aeolos will repair or replace defective components or assemblies. We will also pay one-way shipping charges. Also please note that our 5 years warranty did not include the engineering works that means you only need hire the labor to change the broken parts from your local with our new and free components. And our installation manual which has to be sent after down payment will introduce the operation and maintenance guide.

6) All the towers from Aeolos is high quality such as the surface treatment has three steps which includes steel pipe(Q235, Q345D and Q420D), hot galvanizing and plastic spraying for the excellent corrosion protection for as long as 20 years. And you can also manufacture the tower in your local marker to make the delivery cost lower.


LOTUS (Qingdao) ENERGY TECHNOLOGY CO., LTD.
Tel.: +86 532 8090 3375 Fax: +86 532 8090 3375
Add.: No. 16 Shandong Road, Qingdao, China

Italy

12. VAWT installation, O&M cost and transportation cost from Palermo to Capo Passero(6 days of work assumed for the installation cost € 3740 per WT including 10% VAT) (acquired 24/06/2019)

**R: R: Quotation for Installation- Project PV plants for Italy Sicily and Greece** 14 messages

From: Giuseppe Carlino
To: Tania Georgitsioti
Cc: Carlo Ieva

24 Jun

Gentilissima Tania,
Provo a darti indicativamente i prezzi secondo la mia esperienza:

1. Trasporto da palermo a Capo Passero (SR) a container da 40 GP, € 800,00 oltre iva;
2. montaggio 6 turbine eoliche. Per questa tipologia di lavoro occorre avere 2 persone per 1 giorno + nolo mezzi . € 600,00 al giorno di costo dei dipendenti (escluso vitto e alloggio) + 2.200,00 al giorno di nolo gru e cestello. Se fosse possibile montare prima tutte le turbine a terra e poi procedere con il sollevamento si risparmierebbe almeno 3 giorni di noleggio. Per quest'ultima informazione dovresti sentire il costruttore delle turbine e capire se possibile o farsi mandare lo schema di montaggio.
3. Costi di manutenzione su torre fissa a 18/24 mt di altezza occorre circa € 1500,00 annui. Su torre a ribalta circa € 600,00 annui.

Per tutto il resto penso che non ci siano costi aggiuntivi se non ci sono opere edili da fare tipo il plinto in cemento e posare la gabbia tirafondi (base di appoggio della torre).

Tanto si doveva per vostra conoscenza,
Saluti

Giuseppe Carlino

Edil Progresso O&M s.r.l.
sede Legale: Via delle Begonie, n.2
92019 - Sciacca (AG)
Tel/fax +39.0925.86045
P.IVA: 02830760845
Sito web: www.edilprogresso-oem.it

Greece

13. VAWT installation cost € 11000 per system, O& M cost €100/year/system, transportation cost from Piraeus to Kalamata included(phone communication 17/05/2019 with the same company that send the PV plant offer, written confirmation of the prices can be provided under request)

# XI. Appendix B

www.jinkosolar.com

JinKO Solar
Building Your Trust in Solar

# Eagle PERC 60
## *285-305 Watt*
MONO CRYSTALLINE MODULE

Positive power tolerance of 0~+3%

ISO9001:2008、ISO14001:2004、OHSAS18001 certified factory.
IEC61215、IEC61730 certified products.

PERC
(5BB)

## KEY FEATURES

**5 Busbar Solar Cell:**
5 busbar cell design improves module efficiency and offers better aesthetic appearance for rooftop in stallation.

**High Efficiency:**
Higher module conversion efficiency(up to 18.63%) benefit from Passivated Emmiter Rear Contact (PERC) technology.

**PID RESISTANT:**
Excellent Anti-PID perform ance guarantee limited power degradation for mass production.

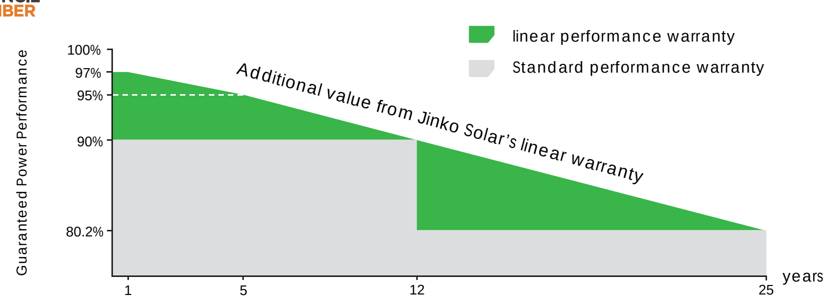
**Low-light Performance:**
Advanced glass and cell surface textured design ensure excellent performance in low-light tenvironment.

**Severe Weather Resilience:**
Certified to withstand: wind load (2400 Pascal) and snow load (5400 Pascal).

**Durability against extreme environmental conditions:**
High salt mist and ammonia resistance certified by TUV NORD.

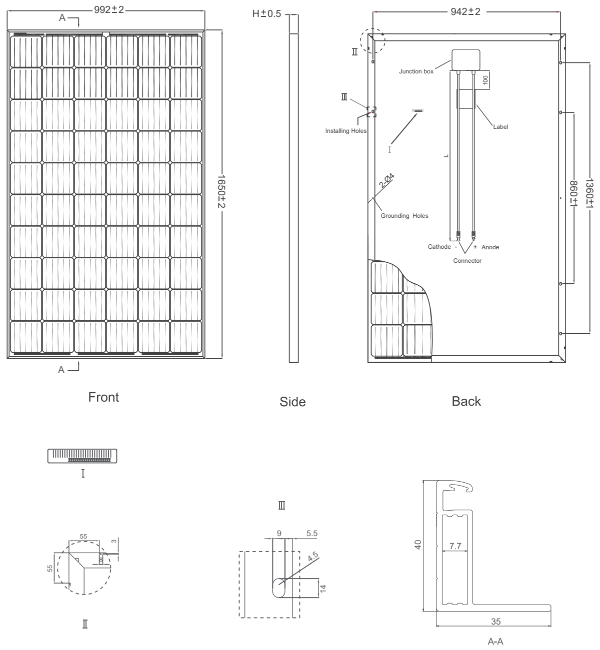
## LINEAR PERFORMANCE WARRANTY

**10 Year Product Warranty • 25 Year Linear Power Warranty**



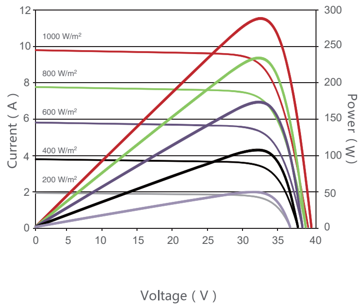

PV CYCLE · TÜVRheinland CERTIFIED · CE · POSITIVE QUALITY Continuous Quality Assurance · CLEAN ENERGY COUNCIL MEMBER

## Engineering Drawings

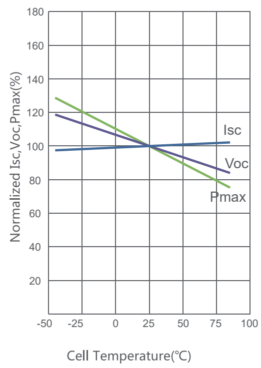



## Electrical Performance & Temperature Dependence

Current-Voltage & Power-Voltage Curves (290W)




Temperature Dependence of Isc,Voc,Pmax




## Mechanical Characteristics

| | |
|---|---|
| Cell Type | Mono-crystalline PERC 156×156mm (6 inch) |
| No.of cells | 60 (6×10) |
| Dimensions | 1650×992×40mm (65.00×39.05×1.57 inch) |
| Weight | 19.0 kg (41.9 lbs) |
| Front Glass | 3.2mm, High Transmission, Low Iron, Tempered Glass |
| Frame | Anodized Aluminium Alloy |
| Junction Box | IP67 Rated |
| Output Cables | TÜV 1×4.0mm², Length: 900mm or Customized Length |

## Packaging Configuration

( Two pallets =One stack )

26pcs/pallet , 52pcs/stack, 728 pcs/40'HQ Container

# SPECIFICATIONS

| Module Type | JKM285M-60 | | JKM290M-60 | | JKM295M-60 | | JKM300M-60 | | JKM305M-60 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | STC | NOCT | STC | NOCT | STC | NOCT | STC | NOCT | STC | NOCT |
| Maximum Power (Pmax) | 285Wp | 212Wp | 290Wp | 216Wp | 295Wp | 220Wp | 300Wp | 224Wp | 305Wp | 227Wp |
| Maximum Power Voltage (Vmp) | 32.0V | 29.9V | 32.2V | 30.2V | 32.5V | 30.5V | 32.6V | 30.7V | 32.8V | 31.0V |
| Maximum Power Current (Imp) | 8.90A | 7.12A | 9.02A | 7.21A | 9.11A | 7.29A | 9.22A | 7.41A | 9.31A | 7.50A |
| Open-circuit Voltage (Voc) | 38.7V | 36.4V | 38.8V | 36.6V | 38.9V | 36.8V | 39.1V | 37.1V | 39.2V | 37.3V |
| Short-circuit Current (Isc) | 9.65A | 7.72A | 9.78A | 7.81A | 9.91A | 7.89A | 10.02A | 7.98A | 10.12A | 8.07A |
| Module Efficiency STC (%) | 17.41% | | 17.72% | | 18.02% | | 18.33% | | 18.63% | |
| Operating Temperature(℃) | -40℃~+85℃ | | | | | | | | | |
| Maximum system voltage | 1000VDC (IEC) | | | | | | | | | |
| Maximum series fuse rating | 15A | | | | | | | | | |
| Power tolerance | 0~+3% | | | | | | | | | |
| Temperature coefficients of Pmax | -0.39%/℃ | | | | | | | | | |
| Temperature coefficients of Voc | -0.29%/℃ | | | | | | | | | |
| Temperature coefficients of Isc | 0.05%/℃ | | | | | | | | | |
| Nominal operating cell temperature (NOCT) | 45±2℃ | | | | | | | | | |

STC: Irradiance 1000W/m² Cell Temperature 25°C AM=1.5

NOCT: Irradiance 800W/m² Ambient Temperature 20°C AM=1.5 Wind Speed 1m/s

* Power measurement tolerance: ± 3%

INVERTERS

# Three Phase Inverter with Synergy Technology

SE50K / SE55K / SE82.8K

10-20 YEAR WARRANTY


## Specifically designed to work with power optimizers

- Easy two-person installation – each unit mounted separately, equipped with cables for simple connection between units
- Balance of System and labor reduction compared to using multiple smaller string inverters
- Independent operation of each unit enables higher uptime and easy serviceability
- No wasted ground area: wall/rail mounted or horizontally mounted under the modules (10˚ inclination)
- Built-in module-level monitoring with Ethernet or cellular GSM
- Fixed voltage inverter for superior efficiency (98.3%) and longer strings
- Integrated Connection Unit with optional integrated DC Safety Switch – eliminates the need for external DC isolators
- Built-in RS485 Surge Protection, to better withstand lightning events

# Three Phase Inverter with Synergy Technology

## SE50K / SE55K / SE82.8K

| | SE50K[1] | SE55K | SE82.8K | |
|---|---|---|---|---|
| **OUTPUT** | | | | |
| Rated AC Power Output | 50000[2] | 55000 | 82800 | VA |
| Maximum AC Power Output | 50000[2] | 55000 | 82800 | VA |
| AC Output Voltage — Line to Line / Line to Neutral (Nominal) | 380/220 ; 400/230 | | | Vac |
| AC Output Voltage — Line to Line Range / Line to Neutral Range | 304 - 437 / 176 - 253 ; 320 - 460 /184 - 264.5 | | | Vac |
| AC Frequency | 50/60 ± 5 | | | Hz |
| Maximum Continuous Output Current (per Phase) @Vac,nom | 76 | 80 | 120 | A |
| Grids Supported — Three Phase | 3 / N / PE (WYE with Neutral) | | | V |
| Maximum Residual Current Injection | 250 per unit[3] | | | mA |
| Utility Monitoring, Islanding Protection, Configurable Power Factor, Country Configurable Thresholds | Yes | | | |
| **INPUT** | | | | |
| Maximum DC Power (Module STC), Inverter / Unit | 67500 / 33750 | 74500 / 37250 | 111750 / 37250 | W |
| Transformer-less, Ungrounded | Yes | | | |
| Maximum Input Voltage | 1000 | | | Vdc |
| Nominal DC Input Voltage | 750 | | | Vdc |
| Maximum Input Current | 74 | 80 | 120 | Adc |
| Reverse-Polarity Protection | Yes | | | |
| Ground-Fault Isolation Detection | 350kΩ Sensitivity per Unit [4] | | | |
| Maximum Inverter Efficiency | 98.3 | | | % |
| European Weighted Efficiency | 98 | | | % |
| Nighttime Power Consumption | < 12 | | | W |
| **ADDITIONAL FEATURES** | | | | |
| Supported Communication Interfaces[5] | RS485, Ethernet, GSM plug-in (optional) | | | |
| RS485 Surge Protection | Built-in | | | |
| **CONNECTION UNIT** | | | | |
| DC Disconnect (optional) | 1000V / 2 x 40A | | 1000V / 3 x 40A | |
| **STANDARD COMPLIANCE** | | | | |
| Safety | IEC-62109, AS3100 | | | |
| Grid Connection Standards[6] | VDE-AR-N-4105, G59/3, AS-4777,EN 50438 , CEI-021,VDE 0126-1-1, CEI-016, BDEW | | | |
| Emissions | IEC61000-6-2, IEC61000-6-3 , IEC61000-3-11, IEC61000-3-12 | | | |
| RoHS | Yes | | | |
| **INSTALLATION SPECIFICATIONS** | | | | |
| Number of Units | 2 | | 3 | |
| AC Output Cable | Cable gland — diameter 22-32; PE gland diameter 10-16 | | Cable gland — diameter 20-38; PE gland diameter 10-16 | mm |
| DC Input[7] | 6 strings, 4-10mm2 DC wire, gland outer diameter 5-10mm / 3 MC4 pairs per unit | | 9 strings, 4-10mm2 DC wire, gland outer diameter 5-10mm / 3 MC4 pairs per unit | |
| AC Output Wire | Aluminum or Copper; L, N: Up to 70, PE: Up to 35 | | Aluminum or Copper; L, N: Up to 95, PE: Up to 50 | $mm^2$ |
| Dimensions (H x W x D) | Primary Unit: 940 x 315 x 260; Secondary Unit: 540 x 315 x 260 | | | mm |
| Weight | Primary Unit: 48; Secondary Unit: 45 | | | kg |
| Operating Temperature Range | -40 to +60[8] | | | ˚C |
| Cooling | Fan (user replaceable) | | | |
| Noise | < 60 | | | dBA |
| Protection Rating | IP65 — Outdoor and Indoor | | | |
| Bracket Mounted (Brackets Provided) | | | | |

[1] Available in the UK, Hungary and Israel
[2] 49990 in the UK
[3] If an external RCD is required, its trip value must be ≥ 300mA per unit (≥ 600mA for SE50K/SE55K; ≥ 900mA for SE82.8K)
[4] Where permitted by local regulations
[5] Refer to Datasheets -> Communications category on Downloads page for specifications of optional communication options: http://www.solaredge.com/groups/support/downloads
[6] For all standards refer to Certifications category on Downloads page: http://www.solaredge.com/groups/support/downloads
[7] The DC input type, MC4 or glands, and DC switch depends on the part number ordered. Inverter with glands and DC switch P/N: SExxK-xx0P0BNG4, inverter with glands and without DC switch P/N: SExxKxx 0P0BNA4, inverter with MC4 and with DC switch P/N: SExxK-xx0P0BNU4, inverter with MC4 and without DC switch P/N: SExxK-xx0P0BNY4
[8] For power de-rating information refer to: https://www.solaredge.com/sites/default/files/se-temperature-derating-note.pdf

# STP270 - 20/Wem
# STP265 - 20/Wem
# STP260 - 20/Wem

SUNTECH
BE UNLIMITED

## 270 Watt
## POLYCRYSTALLINE SOLAR MODULE

### Features

**High module conversion efficiency**
16.6%
Module efficiency up to 16.6% achieved through advanced cell technology and manufacturing capabilities

**High PID resistant**
PID Resistant
Advanced cell technology and qualified materials lead to high resistance to PID

**Positive tolerance**
0/+5W
Positive tolerance of up to 5 W delivers higher output reliablity

**Suntech current sorting process**
2%
System output maximized by reducing mismatch losses up to 2% with modules sorted & packaged by amperage

**Extended wind and snow load tests**
3800 Pa 5400 Pa
Module certified to withstand extreme wind (3800 Pascal) and snow loads (5400 Pascal) *

**High system voltage Compatible**
1500 V
Maximum 1500VDC system voltage saves total system cost

*Certifications and standards:*
*IEC 61215, IEC 61730, conformity to CE*

**

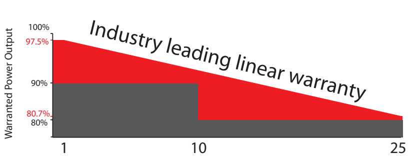
### Trust Suntech to Deliver Reliable Performance Over Time

- World-class manufacturer of crystalline silicon photovoltaic modules
- Unrivaled manufacturing capacity and world-class technology
- Rigorous quality control meeting the highest international standards: ISO 9001: 2008, ISO 14001: 2004 and ISO17025: 2005
- Regular independently checked production process from international accredited institute/company
- Tested for harsh environments (salt mist, ammonia corrosion and sand blowing testing: IEC 61701, IEC 62716, DIN EN 60068-2-68)***
- Long-term reliability tests
- 2 x 100% EL inspection ensuring defect-free modules

### Special 4 busbar design

The unique cell design leads tremendous reduction in electrodes resistance and raise in conversion efficiency. Less residual stress, less cell micro-cracks and hotspot risks.

### Industry-leading Warranty based on nominal power




- 97.5% in the first year, thereafter, for years two (2) through twenty-five (25), 0.7% maximum decrease from MODULE's nominal power output per year, ending with the 80.7% in the 25th year after the defined WARRANTY STARTING DATE.****
- 12-year product warranty
- 25-year linear performance warranty

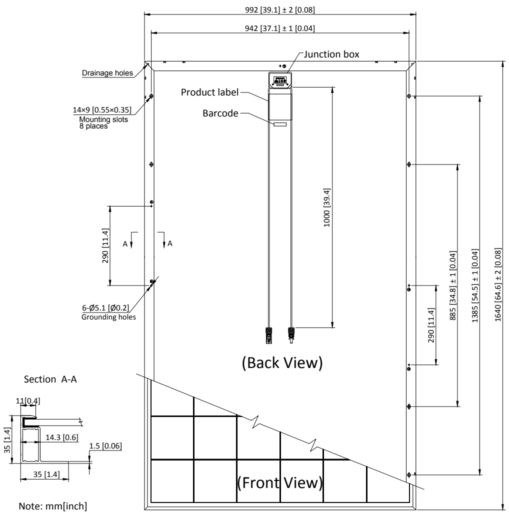
### IP68 Rated Junction Box


The Suntech IP68 rated junction box ensures an outstanding waterproof level, supports installations in all orientations and reduces stress on the cables. High reliable performance, low resistance connectors ensure maximum output for the highest energy production.

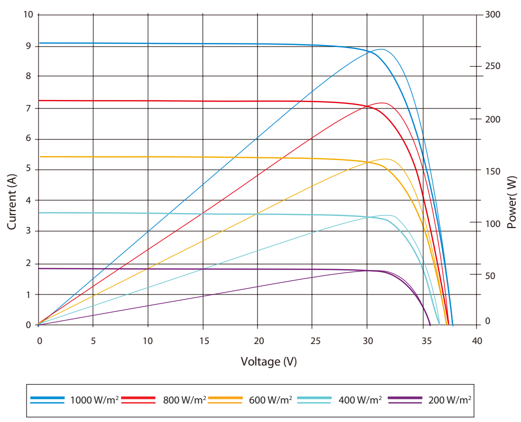
* Please refer to Suntech Standard Module Installation Manual for details. **PV Cycle only for EU market.
*** Please refer to Suntech Product Near-coast Installation Manual for details. **** Please refer to Suntech Product Warranty for details.

# STP270- 20/Wem
# STP265 - 20/Wem
# STP260 - 20/Wem

SUNTECH
BE UNLIMITED




## Current-Voltage & Power-Voltage Curve (270-20)




Excellent performance under weak light conditions: at an irradiation intensity of 200 W/m² (AM 1.5, 25 °C), **96.5%** or higher of the STC efficiency (1000 W/m²) is achieved

## Dealer information

## Electrical Characteristics

| STC | STP270-20/ Wem | STP265-20/ Wem | STP260-20/ Wem |
|---|---|---|---|
| Maximum Power at STC (Pmax) | 270 W | 265 W | 260 W |
| Optimum Operating Voltage (Vmp) | 31.1 V | 31.0 V | 30.9 V |
| Optimum Operating Current (Imp) | 8.69 A | 8.56 A | 8.42 A |
| Open Circuit Voltage (Voc) | 37.9 V | 37.8 V | 37.7 V |
| Short Circuit Current (Isc) | 9.15 A | 9.02 A | 8.89 A |
| Module Efficiency | 16.6% | 16.3% | 16.0% |
| Operating Module Temperature | -40 °C to +85 °C | | |
| Maximum System Voltage | 1500 V DC (IEC) | | |
| Maximum Series Fuse Rating | 20 A | | |
| Power Tolerance | 0/+5 W | | |

STC: Irradiance 1000 W/m², module temperature 25 °C, AM=1.5;
Best in Class AAA solar simulator (IEC 60904-9) used, power measurement uncertainty is within +/- 3%

| NOCT | STP270-20/ Wem | STP265-20/ Wem | STP260-20/ Wem |
|---|---|---|---|
| Maximum Power at NOCT (Pmax) | 198 W | 194 W | 191 W |
| Optimum Operating Voltage (Vmp) | 28.4 V | 28.3 V | 28.2 V |
| Optimum Operating Current (Imp) | 6.97 A | 6.86 A | 6.76 A |
| Open Circuit Voltage (Voc) | 34.9 V | 34.8 V | 34.8 V |
| Short Circuit Current (Isc) | 7.42 A | 7.32 A | 7.19 A |

NOCT: Irradiance 800 W/m², ambient temperature 20 °C, AM=1.5, wind speed 1 m/s;
Best in Class AAA solar simulator (IEC 60904-9) used, power measurement uncertainty is within +/- 3%

## Temperature Characteristics

| | |
|---|---|
| Nominal Operating Cell Temperature (**NOCT**) | 45±2°C |
| Temperature Coefficient of Pmax | -0.41 %/°C |
| Temperature Coefficient of Voc | -0.33 %/°C |
| Temperature Coefficient of Isc | 0.067 %/°C |

## Mechanical Characteristics

| | |
|---|---|
| Solar Cell | Polycrystalline silicon 6 inches |
| No. of Cells | 60 (6 × 10) |
| Dimensions | 1640 × 992 × 35mm (64.6 × 39.1 × 1.4 inches) |
| Weight | 18.2 kgs (40.1 lbs.) |
| Front Glass | 3.2 mm (0.13 inches) tempered glass |
| Frame | Anodized aluminium alloy |
| Junction Box | IP68 rated (3 bypass diodes) |
| Output Cables | TUV (2Pfg1169:2007) |
| | 4.0 mm² (0.006 inches²), symmetrical lengths (-) 1000mm (39.4 inches) and (+) 1000 mm (39.4 inches) |
| Connectors | MC4 compatible |

## Packing Configuration

| Container | 20' GP | 40' HC |
|---|---|---|
| Pieces per pallet | 30 | 30 |
| Pallets per container | 6 | 28 |
| Pieces per container | 180 | 840 |

Information on how to install and operate this product is available in the installation instruction. All values indicated in this data sheet are subject to change without prior announcement. The specifications may vary slightly. All specifications are in accordance with standard EN 50380. Color differences of the modules relative to the figures as well as discolorations of/in the modules which do not impair their proper functioning are possible and do not constitute a deviation from the specification.

SOLAR INVERTERS

# ABB string inverters

## PVS-100/120-TL

The PVS-100/120-TL is ABB's cloud connected three-phase string solution for cost efficient decentralized photovoltaic systems for both ground mounted and large commercial applications.

—
PVS-100/120-TL three-phase outdoor string inverter

This platform, for extreme high power string inverters with power ratings up to 120 kW, maximizes the ROI for decentralized ground mounted and large rooftop applications. With six MPPT energy harvesting is optimized even in shading situations.

**Extreme power with high integration level**
The extreme high power module up to 120 kW saves installation resources as less units are required. Due to its compact size further savings are generated in logistics and in maintenance. Thanks to the integrated DC/AC disconnection, 24 string connections, fuses and surge protection no additional boxes are required.

**Ease of installation**
The horizontal and vertical mounting possibility creates flexibility for both ground mounted and rooftop installations. Covers are equipped with hinges and locks that are fast to open and reduce the risk of damaging the chassis and interior components when commissioning and performing maintenance actions.

Standard wireless access from any mobile device makes the configuration of inverter and plant easier and faster. Improved user experience thanks to a build in User Interface (UI) enables access to advanced inverter configuration settings.

The installer mobile APP, available for Android/iOS devices, further simplifies multi-inverter installations.

The design supports both copper and aluminum cabling even up to 185 $mm^2$ cross section to minimize the energy losses.

**Fast system integration**
Industry standard Modbus/SUNSPEC protocol enables fast system integration. Two ethernet ports enable fast and future proof communication for PV plants.

**ABB plant portfolio integration**
Monitoring your assets is made easy as every inverter is capable to connect to ABB plant portfolio manager to secure your assets and profitability in long term.

**Design flexibility and shade tolerance**
The double stage conversion topology and six MPPT guarantee maximum flexibility for the system design on rooftops or hilly ground.
With this technological choice energy harvesting is optimized even in shading situations.

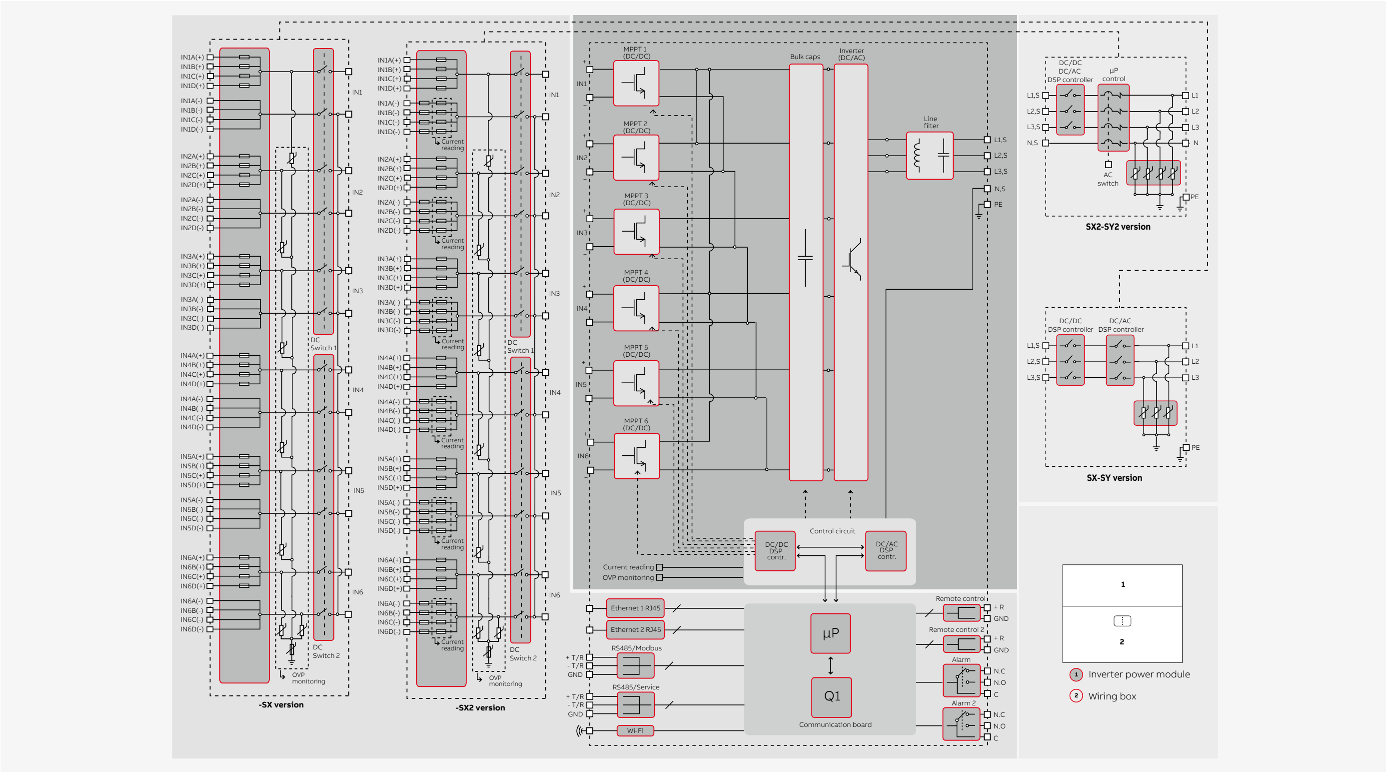
**Highlights**
- 6 independent MPPT
- Transformerless inverter
- 120 kW for 480 Vac and 100 kW for 400 Vac
- Wi-Fi as standard for configuration
- Two ethernet ports for plant level communication
- Large set of specific grid codes available which can be selected directly in the field
- Double stage topology for a wide input range
- Both vertical and horizontal installation
- Separate wiring compartment for fast swap and replacement
- IP66 Environmental protection
- Maximum efficiency up to 98.9%

# ABB string inverters
PVS-100/120-TL
100 to 120 kW

**Technical data and types**

| Type code | PVS-100-TL | PVS-120-TL |
|---|---|---|
| **Input side** | | |
| Absolute maximum DC input voltage ($V_{max,abs}$) | 1000V | |
| Start-up DC input voltage ($V_{start}$) | 420V (400…500 V) | |
| Operating DC input voltage range ($V_{dcmin}$…$V_{dcmax}$) | 360…1000 V | |
| Rated DC input voltage ($V_{dcr}$) | 620V | 720V |
| Rated DC input power ($P_{dcr}$) | 102 000W | 123 000W |
| Number of independent MPPT | 6 | |
| MPPT input DC voltage range at ($V_{MPPTmin}$…$V_{MPPTmax}$) at $P_{acr}$ | 480…850V | 570…850V |
| Maximum DC input power for each MPPT ($P_{MPPT,max}$) | 17500 W [480V≤$V_{MPPT}$≤850V | 20500 W [570V≤$V_{MPPT}$≤850V |
| Maximum DC input current for each MPPT ($I_{dcmax}$) | 36 A | |
| Maximum input short circuit current ($I_{scmax}$) for each MPPT | 50 A [1)] | |
| Number of DC input pairs for each MPPT | 4 | |
| DC connection type | PV quick fit connector [2)] | |
| **Input protection** | | |
| Reverse polarity protection | Yes, from limited current source | |
| Input over voltage protection for each MPPT - replaceable surge arrester | Type II with monitoring only for SX and SX2 versions; Type I+II with monitoring only for SY and SY2 versions | |
| Photovoltaic array isolation control | as per IEC62109 | |
| DC switch rating for each MPPT | 50 A / 1000 V | |
| Fuse rating (versions with fuses) | 15 A / 1000 V [3)] | |
| String current monitoring | SX2, SY2: (24ch) Individual string current monitoring; SX, SY: (6ch) Input current monitoring per MPPT | |
| **Output side** | | |
| AC Grid connection type | Three phase 3W+PE or 4W+PE | |
| Rated AC power ($P_{acr}$ @cos$\phi$=1) | 100 000 W | 120 000 W |
| Maximum AC output power ($P_{acmax}$ @cos$\phi$=1) | 100 000 W | 120 000 W |
| Maximum apparent power ($S_{max}$) | 100 000 VA | 120 000 VA |
| Rated AC grid voltage ($V_{ac,r}$) | 400 V | 480 V |
| AC voltage range | 320...480 V [4)] | 384...576 [3)] |
| Maximum AC output current ($I_{ac,max}$) | 145 A | |
| Rated output frequency ($f_r$) | 50 Hz / 60 Hz | |
| Output frequency range ($f_{min}$...$f_{max}$) | 45...55 Hz / 55...65 Hz [5)] | |
| Nominal power factor and adjustable range | > 0.995, 0…1 inductive/capacitive with maximum $S_{max}$ | |
| Total current harmonic distortion | < 3% | |
| Maximum AC cable | 185mm2 Aluminum and copper | |
| AC connection type | Provided bar for lug connections M10, single core cable glands 4xM40 and M25, multi core cable gland M63 as option | |
| **Output protection** | | |
| Anti-islanding protection | According to local standard | |
| Maximum external AC overcurrent protection | 225 A | |
| Output overvoltage protection - replaceable surge protection device | Type 2 with monitoring | |
| **Operating performance** | | |
| Maximum efficiency ($\eta_{max}$) | 98.4% | 98.9% |
| Weighted efficiency (EURO) | 98.2% | 98.6% |
| **Communication** | | |
| Embedded communication interfaces | 1x RS485, 2x Ethernet (RJ45), WLAN (IEEE802.11 b/g/n @ 2,4 GHz) | |
| User interface | 4 LEDs, Web User Interface | |
| Communication protocol | Modbus RTU/TCP (Sunspec compliant) | |
| Commissioning tool | Web User Interface, Mobile APP/APP for plant level | |
| Remote monitoring services | Aurora Vision® monitoring portal | |
| Advanced features | Embedded logging, direct telemetry data transferring to ABB cloud | |
| **Environmental** | | |
| Ambient temperature range | -25...+60°C /-13...140°F with derating above 40°C / 104 °F | |

### ABB PVS-100/120-TL string inverter block diagram




—

### Technical data and types

| Type code | PVS-100-TL | PVS-120-TL |
|---|---|---|
| Relative humidity | 4%...100% condensing | |
| Sound pressure level, typical | 68dB(A) @ 1m | |
| Maximum operating altitude without derating | 2000 m / 6560 ft | |
| **Physical** | | |
| Environmental protection rating | IP 66 (IP54 for cooling section) | |
| Cooling | Forced air | |
| Dimension (H x W x D) | 869x1086x419 mm / 34.2” x 42.8” x 16.5” | |
| Weight | 70kg / 154 lbs for power module ; ~55kg / 121 lbs for wiring box<br>Overall max 125 kg / 276 lbs | |
| Mounting system | Mounting bracket vertical & horizontal support | |
| **Safety** | | |
| Isolation level | Transformerless | |
| Marking & EMC | CE conformity according to LV and EMC directives | |
| Safety | IEC/EN 62109-1, IEC/EN 62109-2 | |
| Grid standard (check your sales channel for availability) | CEI 0-16, CEI 0-21, IEC 61727, IEC 62116, IEC 60068, IEC 61683, JORDAN IRR-DCC-MV, AS/ NZS4777.2, VDE-AR-N 4105, VDE V 0-126-1-1, VFR 2014, Belg C10-C11, UK59/3, P.O. 12.3, ITC-BT-40, EN50438 Generic +Ireland, CLC-TS 50549-1/2 | |
| **Available products variants** | | |
| Inverter power module | PVS-100-TL-POWERMODULE-400 | PVS-120-TL-POWERMODULE-480 |
| Input with 24 quick fit connectors pairs + String fuses (both positive and negative pole) + DC disconnect switches + AC disconnect switch + AC and DC overvoltage surge arresters (Type II) + individual string monitoring (24 ch.) | WB-SX2-PVS-100-TL | WB-SX2-PVS-120-TL |
| Input with 24 quick fit connectors pairs + String fuses (positive pole) + DC disconnect switches + AC and DC overvoltage surge arresters (Type II) + MPPT level input current monitoring (6 ch.) | WB-SX-PVS-100-TL | WB-SX-PVS-120-TL |
| Input with 24 quick fit connectors pairs + String fuses (positive pole) + DC disconnect switches + AC and DC overvoltage surge arresters (Type II for AC and Type I+II for DC) + MPPT level input current monitoring (6 ch.) | WB-SY-PVS-100-TL | WB-SY-PVS-120-TL |
| Input with 24 quick fit connectors pairs + String fuses (both positive and negative pole) + DC disconnect switches + AC disconnect switch + AC and DC overvoltage surge arresters (Type II for AC and Type I+II for DC) + individual string monitoring (24 ch.) | WB-SY2-PVS-100-TL | WB-SY2-PVS-120-TL |
| **Optional available** | | |
| Support for multi core AC cable M63 + M25 (PE) | AC output panel M63 for wiring box | |
| AC multicore cable gland plate | Supports M63 Ø 37...53mm + M25 Ø 10...17mm | |

1) Maximum number of opening 5 under overloading
2) Please refer to the document “String inverters – Product manual appendix” available at www.abb.com/solarinverters for information on the quick-fit connector brand and model used in the inverter
3) Maximum fuse size supported 20A. Additionally two strings input per MPPT supports 30A fuse size for connecting two strings per input.
4) The AC voltage range may vary depending on specific country grid standard
5) Frequency range may vary depending on specific country grid standard
**Remark. Features not specifically listed in the present data sheet are not included in the product**

—
For more information please contact your local ABB representative or visit:

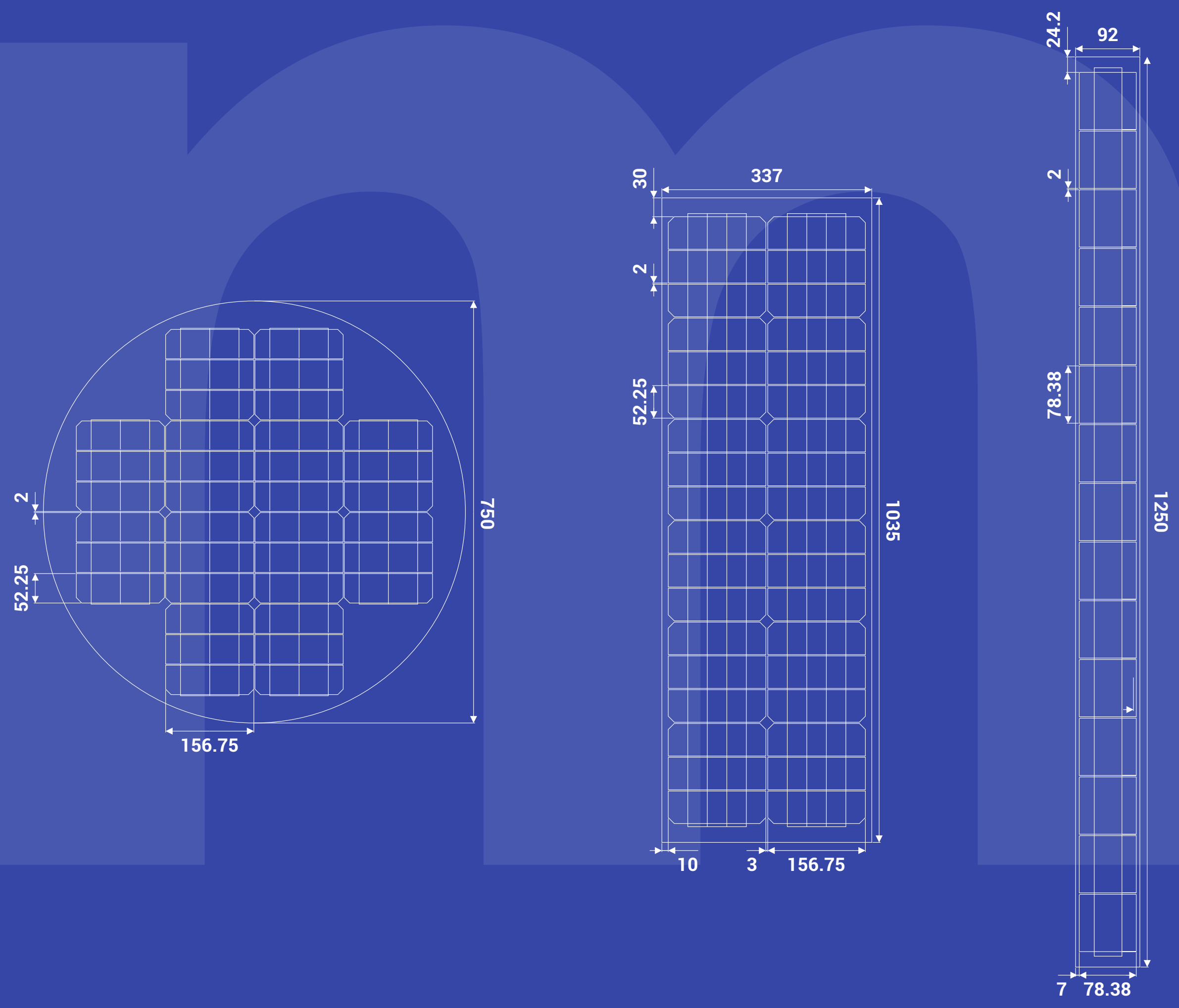
**www.abb.com/solarinverters**
**www.abb.com**

—


BCD.00662_EN REV. I 07.06.2018

# Customization options

Every solar project requires specific technological approach, therefore we provide customizable solar solutions with adjusted size, shape, color/transparency and power options for integration.





Metsolar
Mob.: +370 650 69905
E-mail: sales@metsolar.eu
Web.: www.metsolar.eu

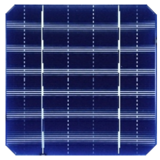
# Solor cells

## Solar cells options

Here we provide the list of the most common solar cell types that are used in our manufacturing process. Only best performing solar cells are used in Metsolar solar panels. We also provide various combinations of colored solar cells together with different types of solar glass, that allow us to achieve one-of-a-kind solution and most organic feel when such module is integrated.

**Monocrystalline 6"**
**156.75 x 156.75 mm**
**Efficiency 20.2%**

**Polycrystalline 6"**
**156.75 x 156.75 mm**
**Efficiency 18.4%**

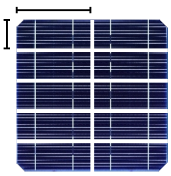


**Monocrystalline 5"**
**125 x 125 mm**
**Efficiency 19.9%**

**Monocrystalline**
**PERC 6"**
**156.75 x 156.75 mm**
**Efficiency 21.7%**

## Solar cells cutting

Solar cell cutting is usually required to achieve desired power options of a solar module. Precision and experience in this field allows us to provide very customized module power characteristics for various solar applications. Using inhouse laser we are able to cut the polycrystalline, monocrystalline and back contact solar cells into almost any desired shape and size.



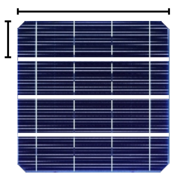
**78.37 x 31.35 mm**

**78.37 x 39.18 mm**

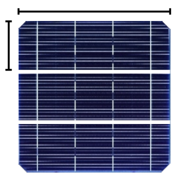
**78.37 x 52.25 mm**

**78.37 x 78.37 mm**

**156.75 x 31.35 mm**



**156.75 x 39.18 mm**



**156.75 x 52.25 mm**

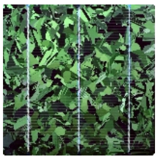
**156.75 x 78.37 mm**

***Other size on demand**

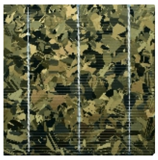
# Color options

## Colored solar cells

Sparkling Gold 6"
156.75 x 156.75 mm
Efficiency 15.8% - 17.2%

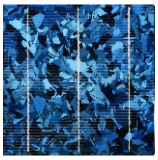


Emerald Green 6"
156.75 x 156.75 mm
Efficiency 17%-18.2%

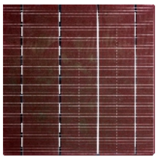


Stone Elegance 6"
156.75 x 156.75 mm
Efficiency 17% - 18.2%

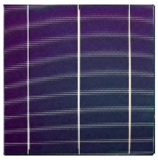
Disco Pink 6"
156.75 x 156.75 mm
Efficiency 17% - 18.2%



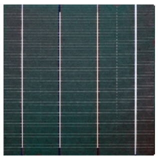
Diamond Blue 6"
156.75 x 156.75 mm
Efficiency 18.3%



Tile Red 6"
156.75 x 156.75 mm
Efficiency 17.0% - 17.4%



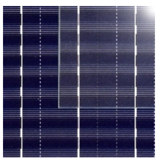
Lavender 6"
156.75 x 156.75 mm
Efficiency 16.6% - 17.2%



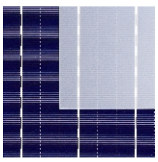
True Steel 6"
156.75 x 156.75 mm
Efficiency 18.2% - 18.6%

Forest Green 6"
156.75 x 156.75 mm
Efficiency 17.4%

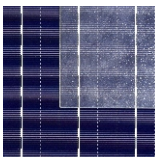
## Glass options



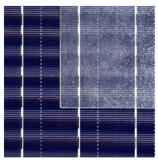
Low Iron Float



Low Iron Satin



Solar mat



Solar mat with ARC

# Color options

## Glass color options

Gray
90% +/-1%

Light-gray
85% +/-1%

Blue
88% +/-1%

Blue-green
88% +/-1%

Green
87% +/-1%

Bronze
89% +/-1%

Gold
86% +/-1%

Terracotta
87% +/-1%

## Backsheet color options

Transparent

White

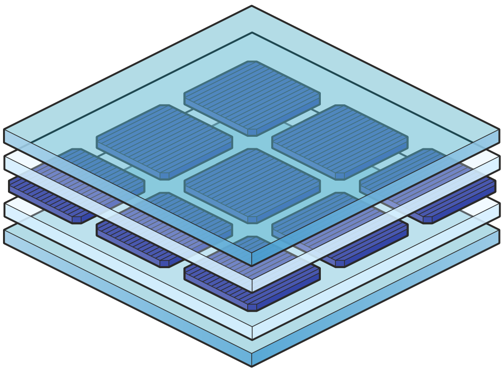
Black

Terracotta

# Technologies

## Glass/glass

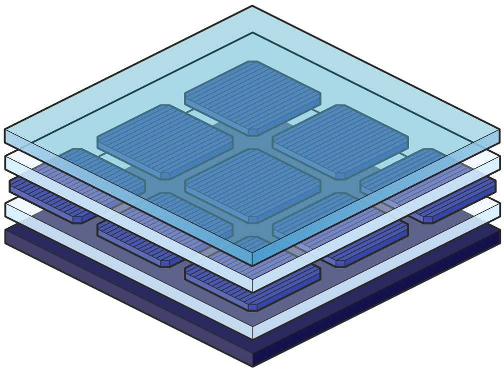
Glass/glass modules are long lasting, very durable and more resistant to various weather conditions, therefore mainly used in BIPV or outdoor furniture applications.



Glass Encapsulant Solar cells

## Glass/backsheet

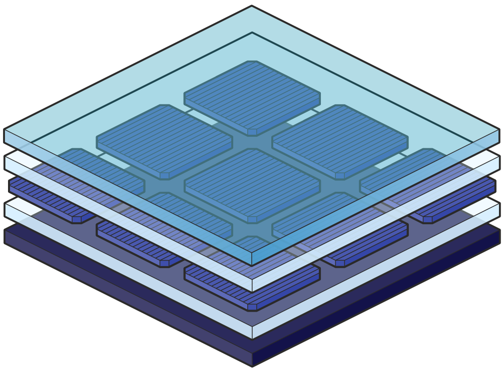
These modules are most commonly used in lighting applications due to wide design flexibility and power options as well as endless possibilities for integration.



Glass Encapsulant Solar cells
Backsheet

## Flexible

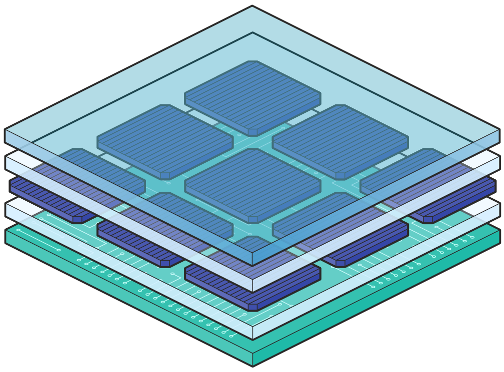
Most thin and lightweight module technology, starting as low as 1.5mm and 2kg/m2. Mainly used in applications where weight and flexible form are crucial factors.



Frontsheet Encapsulant Solar cells
Backsheet

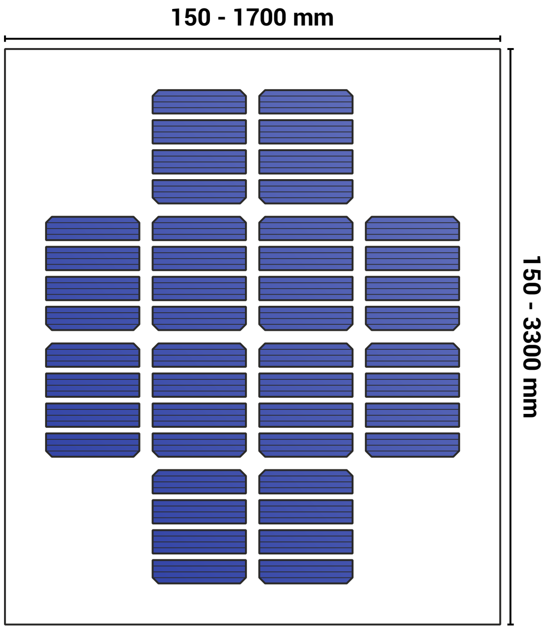
## PCB/frontsheet

PCB technology modules are mostly used for integration to various off-grid electronic devices, due to their environmental resistance and simplified electrical integration.

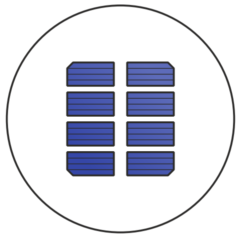


Frontsheet Encapsulant Solar cells
PCB

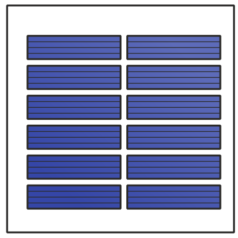
# Shape and size



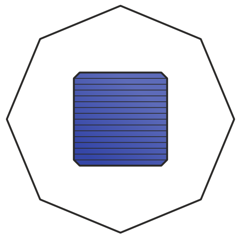

*Other size on demand



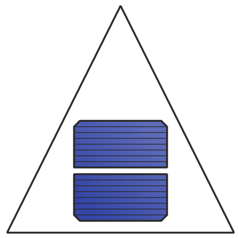
Circle



Rectangle

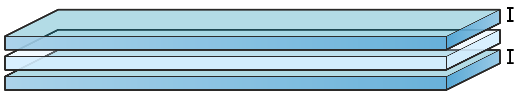


Other shape on demand

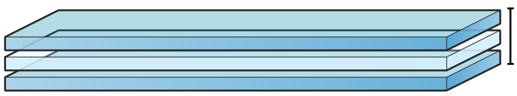


Triangle

## Glass/glass

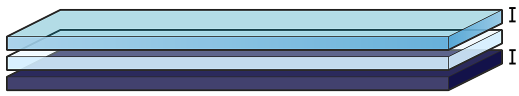


Glass thickness: 3 - 6 mm
*Other thickness on demand

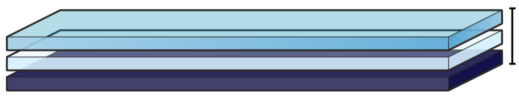


Module thickness: 7.5 - 13.5 mm (+-0.3mm)
*Other thickness on demand

## Glass/backsheet

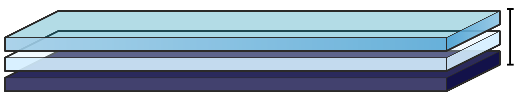


Glass thickness: 3 - 6 mm
*Other thickness on demand



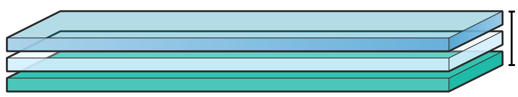
Module thickness: 4.5 - 7.5 mm (+-0.3mm)
*Other thickness on demand

## Flexible



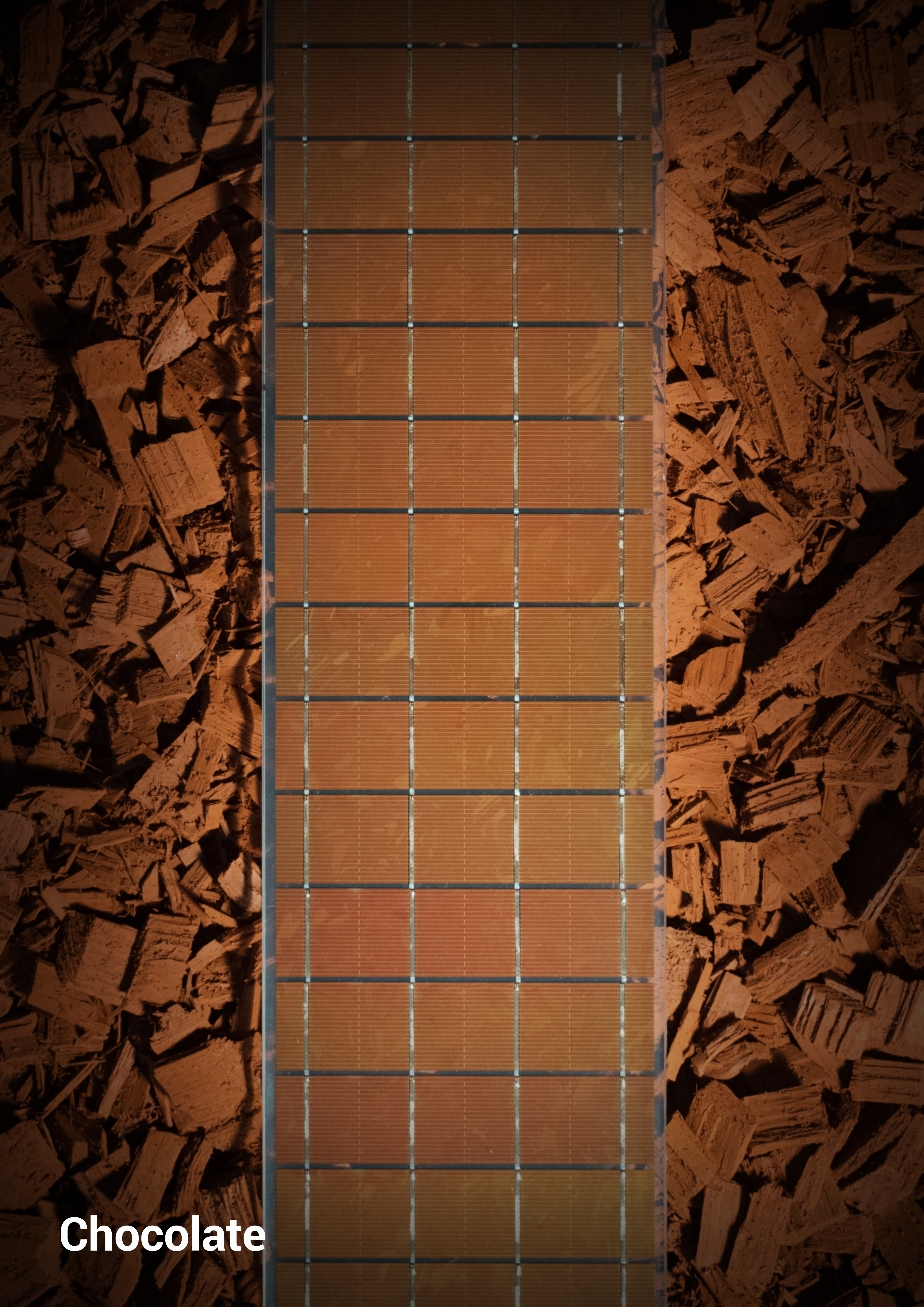
Module thickness: 2.5 mm (+-0.3mm)

## PCB/frontsheet



Module thickness: 2.3 - 3.9 mm (+-0.3mm)


Jungle


Chocolate

# FRONIUS SYMO

## Maximum flexibility for the applications of tomorrow

SnapINverter technology | Integrated data communication | Dynamic Peak Manager | Smart Grid Ready | SuperFlex Design | Zero feed-in

**With power categories ranging from 3.0 to 20.0 kW, the transformerless Fronius Symo is the three-phase inverter for systems of every size. Owing to the SuperFlex Design, the Fronius Symo is the perfect answer to irregularly shaped or multi-oriented roofs.**

The standard interface to the internet via WLAN or Ethernet and the ease of integration of third-party components make the Fronius Symo one of the most communicative inverters on the market. Furthermore, the meter interface permits dynamic feed-in management and a clear visualisation of the consumption overview.

## TECHNICAL DATA FRONIUS SYMO (3.0-3-S, 3.7-3-S, 4.5-3-S, 3.0-3-M, 3.7-3-M, 4.5-3-M)

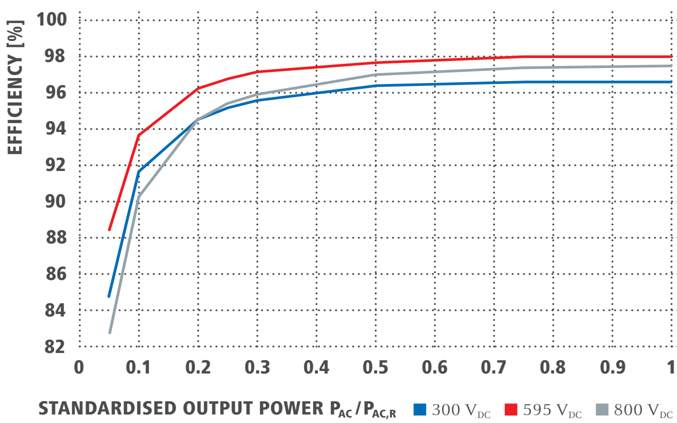
| INPUT DATA | SYMO 3.0-3-S | SYMO 3.7-3-S | SYMO 4.5-3-S | SYMO 3.0-3-M | SYMO 3.7-3-M | SYMO 4.5-3-M |
|---|---|---|---|---|---|---|
| Number MPP trackers | | 1 | | | 2 | |
| Max. input current ($I_{dc\ max\ 1}$ / $I_{dc\ max\ 2}$ [1]) | | 16.0 A | | | 16.0 A / 16.0 A | |
| Max. array short circuit current ($MPP_1$ / $MPP_2$ [1]) | | 24.0 A | | | 24.0 A / 24.0 A | |
| DC input voltage range ($U_{dc\ min}$ - $U_{dc\ max}$) | 150 - 1000 V | | | | | |
| Feed-in start voltage ($U_{dc\ start}$) | 200 V | | | | | |
| Usable MPP voltage range | 150 - 800 V | | | | | |
| Number of DC connections | | 3 | | | 2+2 | |
| Max. PV generator output ($P_{dc\ max}$) | 6.0 $kW_{peak}$ | 7.4 $kW_{peak}$ | 9.0 $kW_{peak}$ | 6.0 $kW_{peak}$ | 7.4 $kW_{peak}$ | 9.0 $kW_{peak}$ |

| OUTPUT DATA | SYMO 3.0-3-S | SYMO 3.7-3-S | SYMO 4.5-3-S | SYMO 3.0-3-M | SYMO 3.7-3-M | SYMO 4.5-3-M |
|---|---|---|---|---|---|---|
| AC nominal output ($P_{ac,r}$) | 3,000 W | 3,700 W | 4,500 W | 3,000 W | 3,700 W | 4,500 W |
| Max. output power | 3,000 VA | 3,700 VA | 4,500 VA | 3,000 VA | 3,700 VA | 4,500 VA |
| AC output current ($I_{ac\ nom}$) | 4.3 A | 5.3 A | 6.5 A | 4.3 A | 5.3 A | 6.5 A |
| Grid connection (voltage range) | 3-NPE 400 V / 230 V or 3-NPE 380 V / 220 V (+20 % / -30 %) | | | | | |
| Frequency (Frequency range) | 50 Hz / 60 Hz (45 - 65 Hz) | | | | | |
| Total harmonic distortion | < 3 % | | | | | |
| Power factor ($\cos \phi_{ac,r}$) | | 0.70 - 1 ind. / cap. | | | 0.85 - 1 ind. / cap. | |

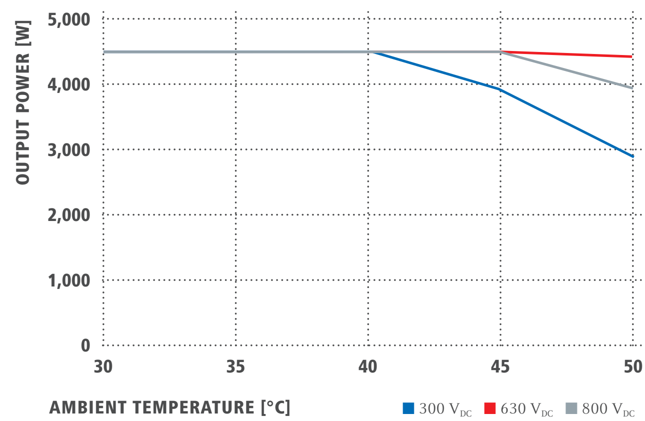
| GENERAL DATA | SYMO 3.0-3-S | SYMO 3.7-3-S | SYMO 4.5-3-S | SYMO 3.0-3-M | SYMO 3.7-3-M | SYMO 4.5-3-M |
|---|---|---|---|---|---|---|
| Dimensions (height x width x depth) | 645 x 431 x 204 mm | | | | | |
| Weight | | 16.0 kg | | | 19.9 kg | |
| Degree of protection | IP 65 | | | | | |
| Protection class | 1 | | | | | |
| Overvoltage category (DC / AC) [2] | 2 / 3 | | | | | |
| Night time consumption | < 1 W | | | | | |
| Inverter design | Transformerless | | | | | |
| Cooling | Regulated air cooling | | | | | |
| Installation | Indoor and outdoor installation | | | | | |
| Ambient temperature range | -25 - +60 °C | | | | | |
| Permitted humidity | 0 - 100 % | | | | | |
| Max. altitude | 2,000 m / 3,400 m (unrestricted / restricted voltage range) | | | | | |
| DC connection technology | | 3x DC+ and 3x DC- screw terminals 2.5 - 16 mm² | | | 4x DC+ and 4x DC- screw terminals 2.5 - 16mm² [3] | |
| AC connection technology | | 5-pole AC screw terminals 2.5 - 16 mm² | | | 5-pole AC screw terminals 2.5 - 16mm² [3] | |
| Certificates and compliance with standards | ÖVE / ÖNORM E 8001-4-712, DIN V VDE 0126-1-1/A1, VDE AR N 4105, IEC 62109-1/-2, IEC 62116, IEC 61727, AS 3100, AS 4777-2, AS 4777-3, CER 06-190, G83/2, UNE 206007-1, SI 4777 [1], CEI 0-21 [1], NRS 097 | | | | | |

[1] This applies to Fronius Symo 3.0-3-M, 3.7-3-M and 4.5-3-M. [2] According to IEC 62109-1.
[3] 16 mm² without wire end ferrules. Further information regarding the availability of the inverters in your country can be found at **www.fronius.com.**

## FRONIUS SYMO 4.5-3-S EFFICIENCY CURVE




## FRONIUS SYMO 4.5-3-S TEMPERATURE DERATING




## TECHNICAL DATA FRONIUS SYMO (3.0-3-S, 3.7-3-S, 4.5-3-S, 3.0-3-M, 3.7-3-M, 4.5-3-M)

| EFFICIENCY | SYMO 3.0-3-S | SYMO 3.7-3-S | SYMO 4.5-3-S | SYMO 3.0-3-M | SYMO 3.7-3-M | SYMO 4.5-3-M |
|---|---|---|---|---|---|---|
| Max. efficiency | 98.0 % | | | | | |
| European efficiency (ηEU) | 96.2 % | 96.7 % | 97.0 % | 96.5 % | 96.9 % | 97.2 % |
| MPP adaptation efficiency | > 99.9 % | | | | | |

| PROTECTIVE DEVICES | SYMO 3.0-3-S | SYMO 3.7-3-S | SYMO 4.5-3-S | SYMO 3.0-3-M | SYMO 3.7-3-M | SYMO 4.5-3-M |
|---|---|---|---|---|---|---|
| DC insulation measurement | Yes | | | | | |
| Overload behaviour | Operating point shift. power limitation | | | | | |
| DC disconnector | Yes | | | | | |
| Reverse polarity protection | Yes | | | | | |

| INTERFACES | SYMO 3.0-3-S | SYMO 3.7-3-S | SYMO 4.5-3-S | SYMO 3.0-3-M | SYMO 3.7-3-M | SYMO 4.5-3-M |
|---|---|---|---|---|---|---|
| WLAN / Ethernet LAN | Fronius Solar.web, Modbus TCP SunSpec, Fronius Solar API (JSON) | | | | | |
| 6 inputs and 4 digital in/out | Interface to ripple control receiver | | | | | |
| USB (A socket) [1] | Datalogging, inverter update via USB flash drive | | | | | |
| 2x RS422 (RJ45 socket) [1] | Fronius Solar Net | | | | | |
| Signalling output [1] | Energy management (potential-free relay output) | | | | | |
| Datalogger and Webserver | Included | | | | | |
| External input [1] | S0-Meter Interface / Input for overvoltage protection | | | | | |
| RS485 | Modbus RTU SunSpec or meter connection | | | | | |

[1] Also available in the light version.

## TECHNICAL DATA FRONIUS SYMO (5.0-3-M, 6.0-3-M, 7.0-3-M, 8.2-3-M)

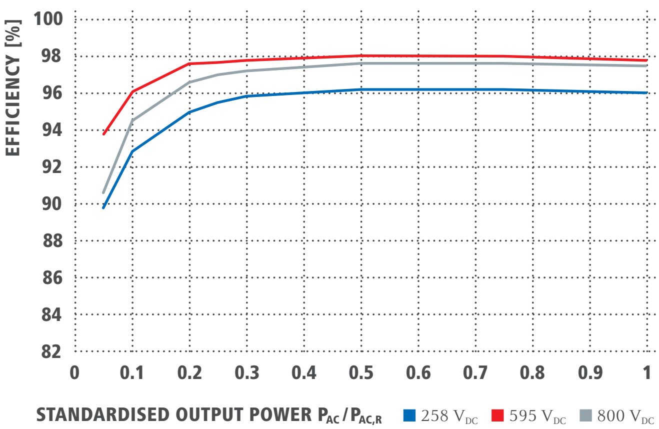
| INPUT DATA | SYMO 5.0-3-M | SYMO 6.0-3-M | SYMO 7.0-3-M | SYMO 8.2-3-M |
|---|---|---|---|---|
| Number MPP trackers | 2 | | | |
| Max. input current ($I_{dc\ max\ 1}$ / $I_{dc\ max\ 2}$) | 16.0 A / 16.0 A | | | |
| Max. array short circuit current ($MPP_1$/$MPP_2$) | 24.0 A / 24.0 A | | | |
| DC input voltage range ($U_{dc\ min}$ - $U_{dc\ max}$) | 150 - 1000 V | | | |
| Feed-in start voltage ($U_{dc\ start}$) | 200 V | | | |
| Usable MPP voltage range | 150 - 800 V | | | |
| Number of DC connections | 2+2 | | | |
| Max. PV generator output ($P_{dc\ max}$) | 10.0 $kW_{peak}$ | 12.0 $kW_{peak}$ | 14.0 $kW_{peak}$ | 16.4 $kW_{peak}$ |

| OUTPUT DATA | SYMO 5.0-3-M | SYMO 6.0-3-M | SYMO 7.0-3-M | SYMO 8.2-3-M |
|---|---|---|---|---|
| AC nominal output ($P_{ac,r}$) | 5,000 W | 6,000 W | 7,000 W | 8,200 W |
| Max. output power | 5,000 VA | 6,000 VA | 7,000 VA | 8,200 VA |
| AC output current ($I_{ac\ nom}$) | 7.2 A | 8.7 A | 10.1 A | 11.8 A |
| Grid connection (voltage range) | 3-NPE 400 V / 230 V or 3-NPE 380 V / 220 V (+20 % / -30 %) | | | |
| Frequency (Frequency range) | 50 Hz / 60 Hz (45 - 65 Hz) | | | |
| Total harmonic distortion | < 3 % | | | |
| Power factor (cos $\phi_{ac,r}$) | 0.85 - 1 ind. / cap. | | | |

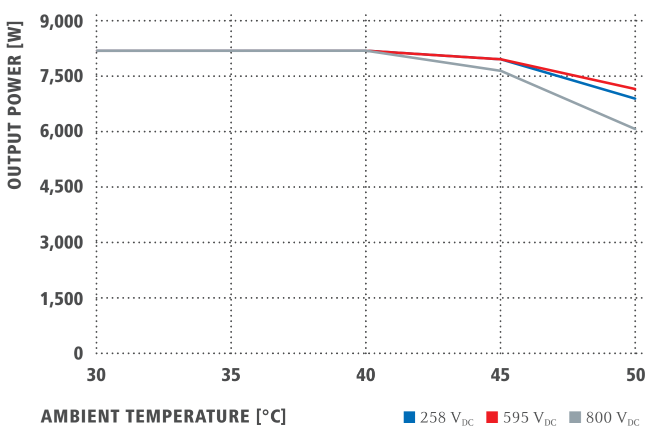
| GENERAL DATA | SYMO 5.0-3-M | SYMO 6.0-3-M | SYMO 7.0-3-M | SYMO 8.2-3-M |
|---|---|---|---|---|
| Dimensions (height x width x depth) | 645 x 431 x 204 mm | | | |
| Weight | 19.9 kg | | 21.9 kg | |
| Degree of protection | IP 65 | | | |
| Protection class | 1 | | | |
| Overvoltage category (DC / AC) [1] | 2 / 3 | | | |
| Night time consumption | < 1 W | | | |
| Inverter design | Transformerless | | | |
| Cooling | Regulated air cooling | | | |
| Installation | Indoor and outdoor installation | | | |
| Ambient temperature range | -25 - +60 °C | | | |
| Permitted humidity | 0 - 100 % | | | |
| Max. altitude | 2,000 m / 3,400 m (unrestricted / restricted voltage range) | | | |
| DC connection technology | 4x DC+ and 4x DC- Screw terminals 2.5 - 16mm² [2] | | | |
| AC connection technology | 5-pole AC Screw terminals 2.5 - 16mm² [2] | | | |
| Certificates and compliance with standards | ÖVE / ÖNORM E 8001-4-712, DIN V VDE 0126-1-1/A1, VDE AR N 4105, IEC 62109-1/-2, IEC 62116, IEC 61727, AS 3100, AS 4777-2, AS 4777-3, CER 06-190, G83/2, UNE 206007-1, SI 4777, CEI 0-21, NRS 097 | | | |

[1] According to IEC 62109-1.
[2] 16 mm² without wire end ferrules.
Further information regarding the availability of the inverters in your country can be found at **www.fronius.com.**

## FRONIUS SYMO 8.2-3-M EFFICIENCY CURVE




## FRONIUS SYMO 8.2-3-M TEMPERATURE DERATING




## TECHNICAL DATA FRONIUS SYMO (5.0-3-M, 6.0-3-M, 7.0-3-M, 8.2-3-M)

| EFFICIENCY | SYMO 5.0-3-M | SYMO 6.0-3-M | SYMO 7.0-3-M | SYMO 8.2-3-M |
|---|---|---|---|---|
| Max. efficiency | 98.0 % | | | |
| European efficiency (ηEU) | 97.3 % | 97.5 % | 97.6 % | 97.7 % |
| MPP adaptation efficiency | > 99.9 % | | | |

| PROTECTIVE DEVICES | SYMO 5.0-3-M | SYMO 6.0-3-M | SYMO 7.0-3-M | SYMO 8.2-3-M |
|---|---|---|---|---|
| DC insulation measurement | Yes | | | |
| Overload behaviour | Operating point shift. power limitation | | | |
| DC disconnector | Yes | | | |
| Reverse polarity protection | Yes | | | |

| INTERFACES | SYMO 5.0-3-M | SYMO 6.0-3-M | SYMO 7.0-3-M | SYMO 8.2-3-M |
|---|---|---|---|---|
| WLAN / Ethernet LAN | Fronius Solar.web, Modbus TCP SunSpec, Fronius Solar API (JSON) | | | |
| 6 inputs and 4 digital in/out | Interface to ripple control receiver | | | |
| USB (A socket) [1)] | Datalogging, inverter update via USB flash drive | | | |
| 2x RS422 (RJ45 socket) [1)] | Fronius Solar Net | | | |
| Signalling output [1)] | Energy management (potential-free relay output) | | | |
| Datalogger and Webserver | Included | | | |
| External input [1)] | S0-Meter Interface / Input for overvoltage protection | | | |
| RS485 | Modbus RTU SunSpec or meter connection | | | |

[1)] Also available in the light version.

## TECHNICAL DATA FRONIUS SYMO (10.0-3-M, 12.5-3-M, 15.0-3-M, 17.5-3-M, 20.0-3-M)

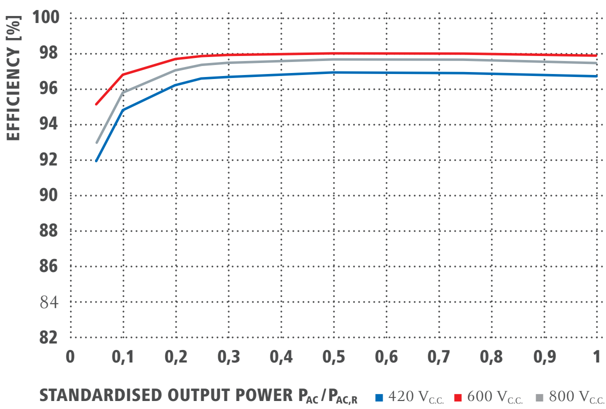
| INPUT DATA | SYMO 10.0-3-M | SYMO 12.5-3-M | SYMO 15.0-3-M | SYMO 17.5-3-M | SYMO 20.0-3-M |
|---|---|---|---|---|---|
| Number MPP trackers | 2 | | | | |
| Max. input current ($I_{dc\,max\,1}$ / $I_{dc\,max\,2}$) | 27.0 A / 16.5 A [1] | | 33.0 A / 27.0 A | | |
| Max. usable input current total ($I_{dc\,max\,1}$ + $I_{dc\,max\,2}$) | 43.5 A | | 51.0 A | | |
| Max. array short circuit current ($MPP_1$/$MPP_2$) | 40.5 A / 24.8 A | | 49.5 A / 40.5 A | | |
| DC input voltage range ($U_{dc\,min}$ - $U_{dc\,max}$) | 200 - 1000 V | | | | |
| Feed-in start voltage ($U_{dc\,start}$) | 200 V | | | | |
| Usable MPP voltage range | 200 - 800 V | | | | |
| Number of DC connections | 3+3 | | | | |
| Max. PV generator output ($P_{dc\,max}$) | 15.0 $kW_{peak}$ | 18.8 $kW_{peak}$ | 22.5 $kW_{peak}$ | 26.3 $kW_{peak}$ | 30.0 $kW_{peak}$ |

| OUTPUT DATA | SYMO 10.0-3-M | SYMO 12.5-3-M | SYMO 15.0-3-M | SYMO 17.5-3-M | SYMO 20.0-3-M |
|---|---|---|---|---|---|
| AC nominal output ($P_{ac,r}$) | 10,000 W | 12,500 W | 15,000 W | 17,500 W | 20,000 W |
| Max. output power | 10,000 VA | 12,500 VA | 15,000 VA | 17,500 VA | 20,000 VA |
| AC output current ($I_{ac\,nom}$) | 14.4 A | 18.0 A | 21.7 A | 25.3 A | 28.9 A |
| Grid connection (voltage range) | 3-NPE 400 V / 230 V or 3~NPE 380 V / 220 V (+20 % / -30 %) | | | | |
| Frequency (Frequency range) | 50 Hz / 60 Hz (45 - 65 Hz) | | | | |
| Total harmonic distortion | 1.8 % | 2.0 % | 1.5 % | 1.5 % | 1.3 % |
| Power factor ($\cos \phi_{ac,r}$) | 0 - 1 ind. / cap. | | | | |

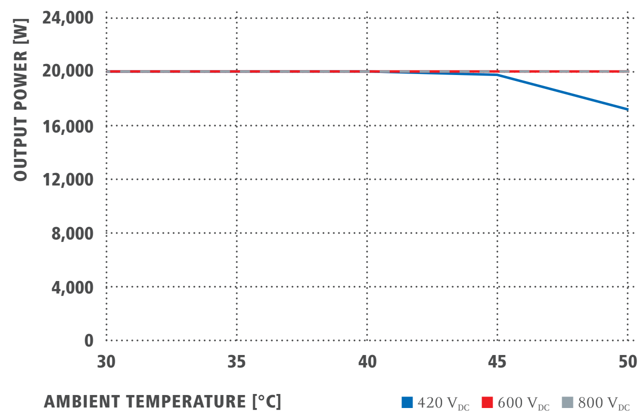
| GENERAL DATA | SYMO 10.0-3-M | SYMO 12.5-3-M | SYMO 15.0-3-M | SYMO 17.5-3-M | SYMO 20.0-3-M |
|---|---|---|---|---|---|
| Dimensions (height x width x depth) | 725 x 510 x 225 mm | | | | |
| Weight | 34.8 kg | | 43.4 kg | | |
| Degree of protection | IP 66 | | | | |
| Protection class | 1 | | | | |
| Overvoltage category (DC / AC) [2] | 2 / 3 | | | | |
| Night time consumption | < 1 W | | | | |
| Inverter design | Transformerless | | | | |
| Cooling | Regulated air cooling | | | | |
| Installation | Indoor and outdoor installation | | | | |
| Ambient temperature range | -40 - +60 °C | | | | |
| Permitted humidity | 0 - 100 % | | | | |
| Max. altitude | 2,000 m / 3,400 m (unrestricted / restricted voltage range) | | | | |
| DC connection technology | 6x DC+ and 6x DC- screw terminals 2.5 - 16 $mm^2$ | | | | |
| AC connection technology | 5-pole AC screw terminals 2.5 - 16 $mm^2$ | | | | |
| Certificates and compliance with standards | ÖVE / ÖNORM E 8001-4-712, DIN V VDE 0126-1-1/A1, VDE AR N 4105, IEC 62109-1/-2, IEC 62116, IEC 61727, AS 3100, AS 4777-2, AS 4777-3, CER 06-190, G83/2, UNE 206007-1, SI 4777, CEI 0-16, CEI 0-21, NRS 097 | | | | |

[1] 14.0 A for voltages < 420 V
[2] According to IEC 62109-1. DIN rail for optional type 1 + 2 or type 2 surge protection device available.
Further information regarding the availability of the inverters in your country can be found at **www.fronius.com.**

## FRONIUS SYMO 20.0-3-M EFFICIENCY CURVE




## FRONIUS SYMO 20.0-3-M TEMPERATURE DERATING




## TECHNICAL DATA FRONIUS SYMO (10.0-3-M, 12.5-3-M, 15.0-3-M, 17.5-3-M, 20.0-3-M)

| EFFICIENCY | SYMO 10.0-3-M | SYMO 12.5-3-M | SYMO 15.0-3-M | SYMO 17.5-3-M | SYMO 20.0-3-M |
|---|---|---|---|---|---|
| Max. efficiency | 98.0 % | | | 98.1 % | |
| European efficiency (ηEU) | 97.4 % | 97.6 % | 97.8 % | 97.8 % | 97.9 % |
| MPP adaptation efficiency | > 99.9 % | | | | |

| PROTECTIVE DEVICES | SYMO 10.0-3-M | SYMO 12.5-3-M | SYMO 15.0-3-M | SYMO 17.5-3-M | SYMO 20.0-3-M |
|---|---|---|---|---|---|
| DC insulation measurement | Yes | | | | |
| Overload behaviour | Operating point shift. power limitation | | | | |
| DC disconnector | Yes | | | | |
| Reverse polarity protection | Yes | | | | |

| INTERFACES | SYMO 10.0-3-M | SYMO 12.5-3-M | SYMO 15.0-3-M | SYMO 17.5-3-M | SYMO 20.0-3-M |
|---|---|---|---|---|---|
| WLAN / Ethernet LAN | Fronius Solar.web, Modbus TCP SunSpec, Fronius Solar API (JSON) | | | | |
| 6 inputs and 4 digital inputs/outputs | Interface to ripple control receiver | | | | |
| USB (A socket) [1)] | Datalogging, inverter update via USB flash drive | | | | |
| 2x RS422 (RJ45-socket) [1)] | Fronius Solar Net | | | | |
| Signalling output [1)] | Energy management (potential-free relay output) | | | | |
| Datalogger and Webserver | Included | | | | |
| External input [1)] | S0-Meter Interface / Input for overvoltage protection | | | | |
| RS485 | Modbus RTU SunSpec or meter connection | | | | |

[1)] Also available in the light version.
Further information and technical data can be found at **www.fronius.com.**

/ Perfect Welding / Solar Energy / Perfect Charging

### THREE BUSINESS UNITS, ONE GOAL: TO SET THE STANDARD THROUGH TECHNOLOGICAL ADVANCEMENT.

What began in 1945 as a one-man operation now sets technological standards in the fields of welding technology, photovoltaics and battery charging. Today, the company has around 3,800 employees worldwide and 1,242 patents for product development show the innovative spirit within the company. Sustainable development means for us to implement environmentally relevant and social aspects equally with economic factors. Our goal has remained constant throughout: to be the innovation leader.

Further information about all Fronius products and our global sales partners and representatives can be found at **www.fronius.com** v08 Aug 2017 EN



**Fronius India Private Limited**
GAT no 312, Nanekarwadi
Chakan, Taluka - Khed District
Pune 410501
India
pv-sales-india@fronius.com
www.fronius.in

**Fronius Australia Pty Ltd.**
90-92 Lambeck Drive
Tullamarine VIC 3043
Australia
pv-sales-australia@fronius.com
www.fronius.com.au

**Fronius UK Limited**
Maidstone Road, Kingston
Milton Keynes, MK10 0BD
United Kingdom
pv-sales-uk@fronius.com
www.fronius.co.uk

**Fronius International GmbH**
Froniusplatz 1
4600 Wels
Austria
pv-sales@fronius.com
www.fronius.com

M,06,0092,EN v20 Apr 2018 as17

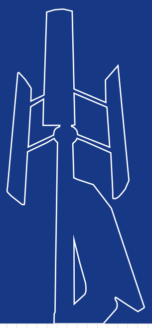
AEOLOS
wind turbine
Aeolos -V Series

# Vertical Wind Turbine Brochure

Aeolos wind turbine
SINCE 1986

Aeolos-V 10kW

windturbinestar.com



AEOLOS
wind turbine

**Aeolos -V Series**

windturbinestar.com

**Aeolos wind turbine SINCE 1986**

## Specification

| | |
|---|---|
| Generator Type: | Three Phase Permanent Magnet |
| Rotor Height: | 6.0 m (19.7 ft) |
| Rotor Width: | 5.5 m (18.0 ft) |
| Turbine Weight: | 680 kg (1499.1 lbs) |
| Blade Material: | Aluminum Alloy |
| Blade Quantity: | 3 pcs |
| Working Temperature: | -20 ℃ to 50 ℃ |
| Design Lifetime: | 20 years |

## Performance

| | |
|---|---|
| Rated Power: | 10 kW |
| Max Output Power: | 12 kW |
| Cut In Wind Speed: | 2.5 m/s (5.6 mph) |
| Rated Wind Speed: | 11 m/s (24.6 mph) |
| Survival Wind Speed: | 52.5 m/s (117.4 mph) |
| Generator Efficiency: | 96% |
| Noise Level: | <45 dB(A) |
| Warranty: | 5 years |

## Safety

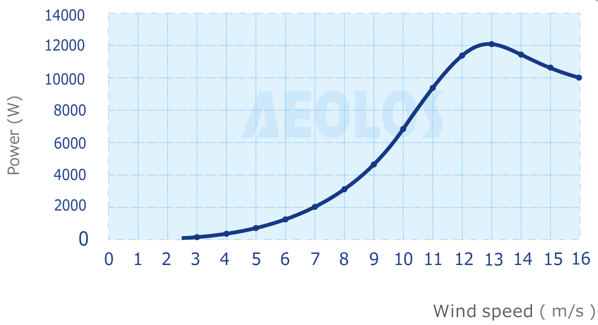
| | |
|---|---|
| Blades RPM Limitation: | 150 RPM |
| PWM Dump Load: | 12kW Box |
| Mechanical Brake: | Auto/Manual |

## Optional

Remote Monitoring System ( Internet/Wireless)
Auto Hydraulic Brake System ( Unattended Site )

| | |
|---|---|
| Off Grid : | 96/120 V |
| Grid Tied : | 450 V |

### Aeolos-V 10kW Power Curve




### Aeolos-V 10kW Wind Turbine Annual Energy Output

| Wind Speed(m/s) | Annual Energy Output (Kwh) | Wind Speed(m/s) | Annual Energy Output (KWh) |
|---|---|---|---|
| 3 m/s | 3618 kWh | 8 m/s | 40061 kWh |
| 4 m/s | 8158 kWh | 9 m/s | 46968 kWh |
| 5 m/s | 15026 kWh | 10 m/s | 52770 kWh |
| 6 m/s | 23434 kWh | 11 m/s | 57576 kWh |
| 7 m/s | 32088 kWh | 12 m/s | 61544 kWh |





**5 YEAR WARRANTY**


Aeolos Wind Energy, Ltd (UK)
27 Old Gloucester Street, London WC1N 3AX
United Kingdom
Tel:+44 208 242 1884
E-mail:sales@windturbinestar.com

Aeolos wind turbine
SINCE 1986

# Why Choose Aeolos-V 10kW Wind Turbine?

## Triple Safety Protection

Special Blade Design: Aeolos blades use the special aerodynamic design which limits the max rotating speed to 150 rpm even the wind speed is 30m/s or 40m/s. It is safer and more reliable than traditional vertical axis wind turbine.

PWM Dump Load: Aeolos-V 10kW wind turbine has the 12kW dump load box with PWM loading function. This will consume the over power output and control the voltage in strong wind speed.

Mechanical Brake: The manual mechanical brake can stop the wind turbine for maintenance or typhoon coming. We have the auto hydraulic brake system for remote installation site without people checking as optional fuction.

## High Efficiency

Low Cut-in Wind Speed: Aeolos-V 10kW could start up with 1.5m/s wind speed and has the power output in 2.5m/s to inverter. This is more efficient than the vertical wind turbines with a 3.5m/s or even 4.5m/s cut in wind speed.

More Annual Output: According to EN61400-2(IEC 61400-2) standard, Aeolos-V 10kW annual output is 15026 kWh at 5m/s wind speed. The annual output at 10m/s is 52770 kWh.

MPPT Charger for Off Grid: Aeolos-V 10kW use 96V/120V MPPT charging controller to increase the charging efficiency to 94%. It can charge the battery bank when wind speed is above 3.5 m/s.

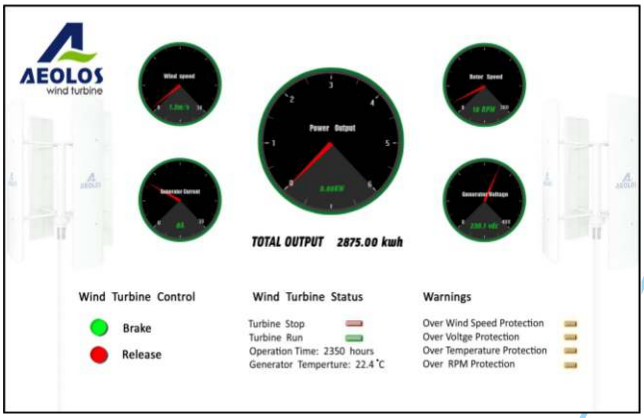
5 YEAR WARRANTY

CE

Aeolos wind turbine
SINCE 1986


## Intelligence Control

Remote Monitoring System: Customer can remote monitor the wind turbine operation, wind speed and power output in office, home, airport and anywhere through the internet.

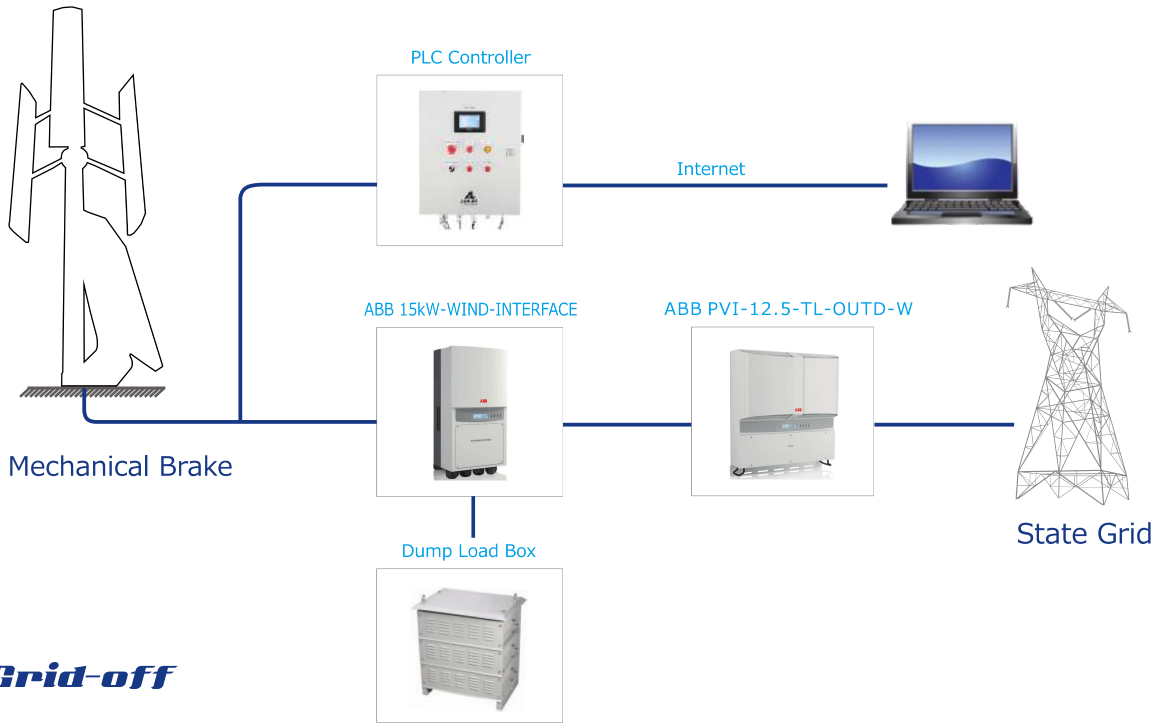



Auto Hydraulic Brake System: It is suitable for the remote installation sites, like the island, telecommunication tower station which does not have people checking and monitoring. This system can auto stop the wind turbine in over voltage, over wind speed, generator over temperature and all any other faults. It can auto release the wind turbine to run after the abnormal warnings.

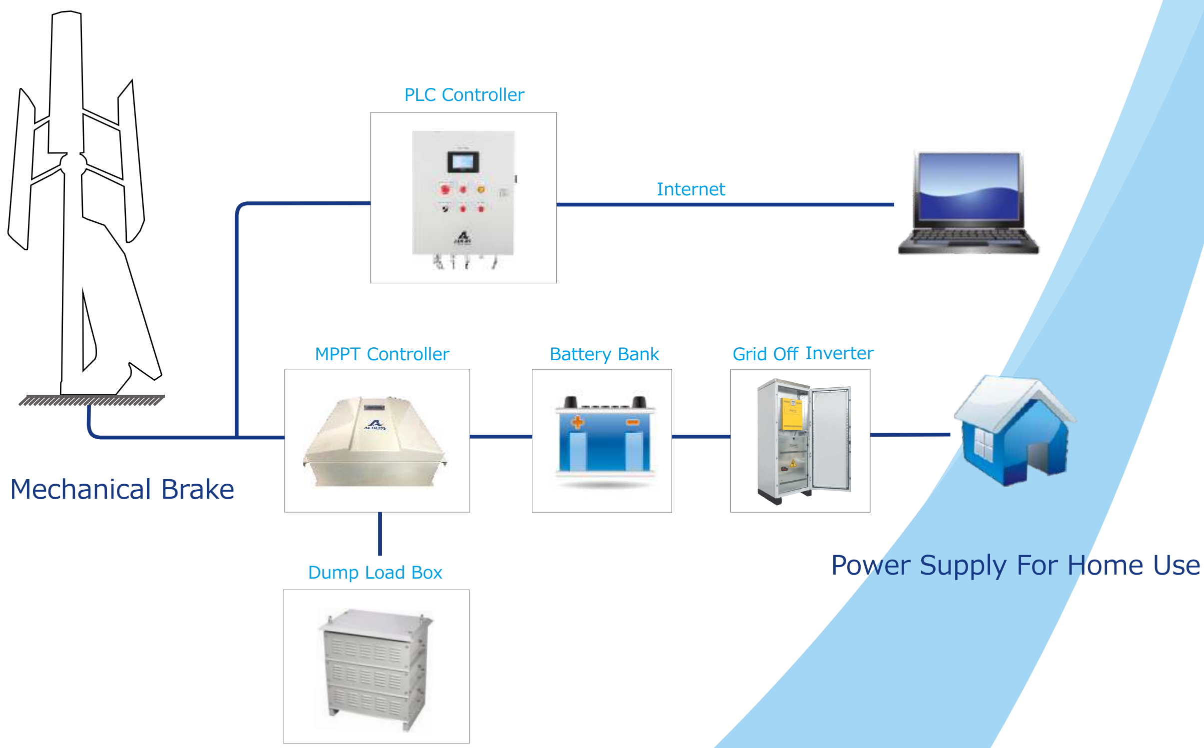
Aeolos wind turbine
SINCE 1986

## Wiring Diagram

### Grid-on




### Grid-off



ENERCON

# PRODUCT PORTFOLIO

## TECHNICAL DATA SHEETS (LAST UPDATED 09/2018)

| | IEC/EN IA (STRONG) | IEC/EN IIA (MEDIUM) | IEC/EN IIIA (LOW) |
|---|---|---|---|
| > 4 MW | L136 | L147 | E-138 EP3 E2<br>L160 |
| ≤ 4 MW | E-115 EP3 | E-126 EP3<br>E-115<br>E-101 | E-138 EP3 |
| ≤ 3 MW | E-82 E4<br>E-70 | E-92<br>E-82 E2 | E-103 |
| < 1 MW | E-44 | E-48 | E-53 |

www.enercon.de

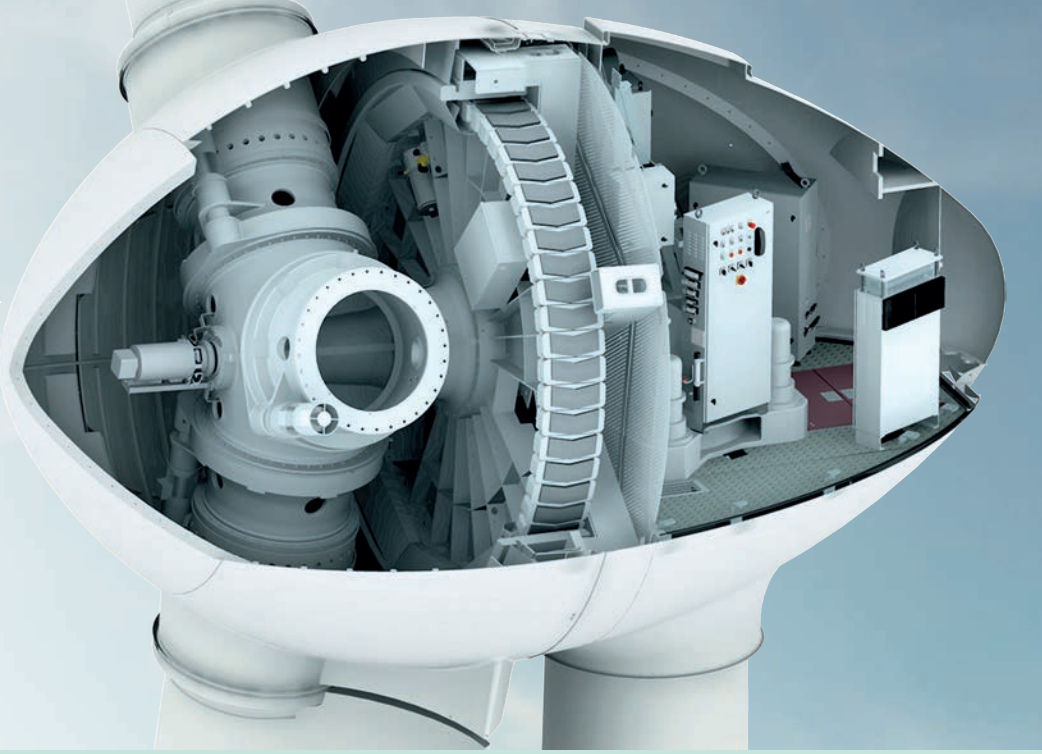
ENERCON
ENERGY FOR THE WORLD

# E-44

900 kW

www.enercon.de

ENERCON
ENERGY FOR THE WORLD



TECHNICAL DATA

# E-44

## GENERAL

| | |
|---|---|
| **Nominal power** | 900 kW |
| **Wind class (IEC)** | IEC IA |
| **Wind zone (DIBt)** | WZ 4 GK I |
| **Turbine concept** | gearless, variable speed, full power converter |
| **Design service life** | 20 years |
| **Cut in wind speed** | 2.5 m/s |
| **Cut out wind speed** | 34 m/s |
| **Extreme wind speed at hub height (3-second gust)** | 70 m/s |
| **Rotational speed** | 14.0 - 33.1 rpm |
| **Ambient temperature for normal operation** | -10 °C to +40 °C |
| **Extreme temperature range** | -20 °C to +50 °C |
| **Grid feed / control system** | ENERCON inverter |
| **Grid frequency** | 50 Hz / 60 Hz |
| **Sound power level** | 100.7 - 103.0 dB(A)* Yield and noise-optimised operation. Further modes on request. |

## ROTOR

| | |
|---|---|
| **Rotor diameter** | 44 m |
| **Swept area** | 1,521 m² |
| **Type** | upwind rotor with active pitch control |

## TOWER

| | IEC IA | IEC IIA | IEC IIIA |
|---|---|---|---|
| **Hub height** | 45 m | | |
| | 55 m | | |

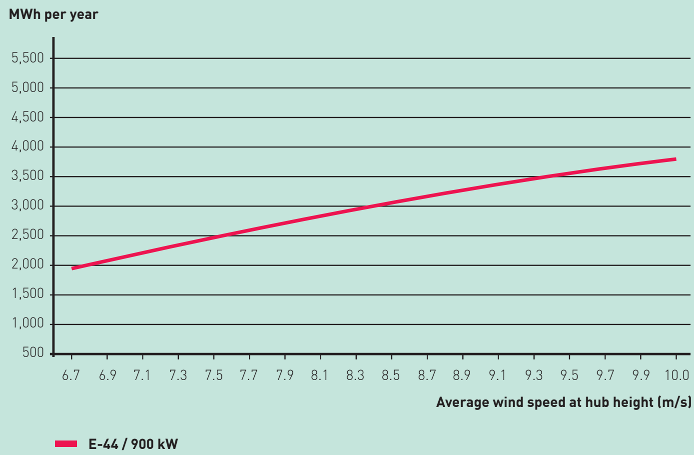
## GENERATOR

| | |
|---|---|
| **Type** | directly driven, separately excited annular generator |
| **Cooling system** | air cooling system |

## FEATURES

| | STANDARD | OPTIONAL |
|---|---|---|
| FACTS and transmission | X | |
| ENERCON SCADA | X | |
| ENERCON storm control | X | |
| Ice detection system<br>Power curve method | X | |
| Low radar reflectivity rotor blades | | X |
| Additional ice detection system | | X |
| Blade heating system | | X |
| Hot-Climate | | X |
| Shadow shutdown | | X |
| ENERCON SCADA bat protection | | X |
| STATCOM | | X |
| Inertia Emulation | | X |
| Sector management for wind farms | | X |
| Beacon management for wind farms | | X |

## ANNUAL ENERGY YIELD



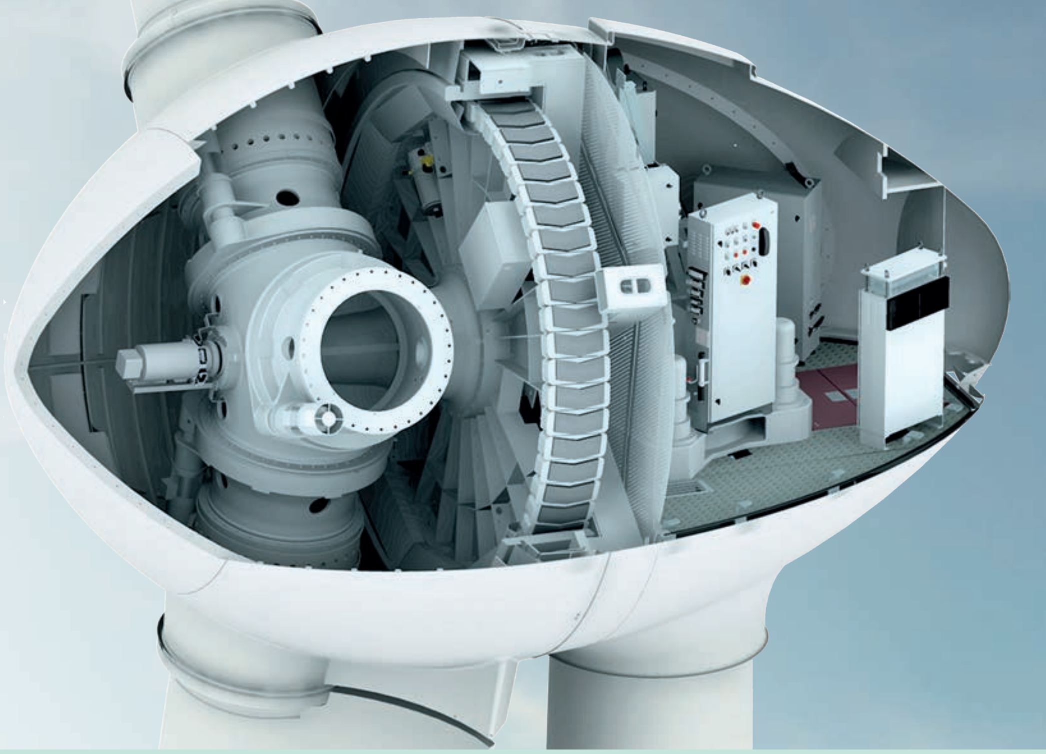

* dependent on hub height

# E-48

800 kW

www.enercon.de

ENERCON
ENERGY FOR THE WORLD



TECHNICAL DATA

# E-48

## GENERAL

| | |
|---|---|
| **Nominal power** | 800 kW |
| **Wind class (IEC)** | IEC IIA |
| **Wind zone (DIBt)** | WZ III |
| **Turbine concept** | gearless, variable speed, full power converter |
| **Design service life** | 20 years |
| **Cut in wind speed** | 2.5 m/s |
| **Cut out wind speed** | 34 m/s |
| **Extreme wind speed at hub height (3-second gust)** | 59.5 m/s |
| **Rotational speed** | 11.0 - 29.8 rpm |
| **Ambient temperature for normal operation** | -10 °C to +40 °C |
| **Extreme temperature range** | -20 °C to +50 °C |
| **Grid feed / control system** | ENERCON inverter |
| **Grid frequency** | 50 Hz / 60 Hz |
| **Sound power level** | 89.0 - 102.5 dB(A)* Yield and noise-optimised operation. Further modes on request. |

## ROTOR

| | |
|---|---|
| **Rotor diameter** | 48 m |
| **Swept area** | 1,810 m² |
| **Type** | upwind rotor with active pitch control |

## TOWER

| | IEC IA | IEC IIA | IEC IIIA |
|---|---|---|---|
| **Hub height** | | 50 m | |
| | | 56 m | |
| | | 60 m | |

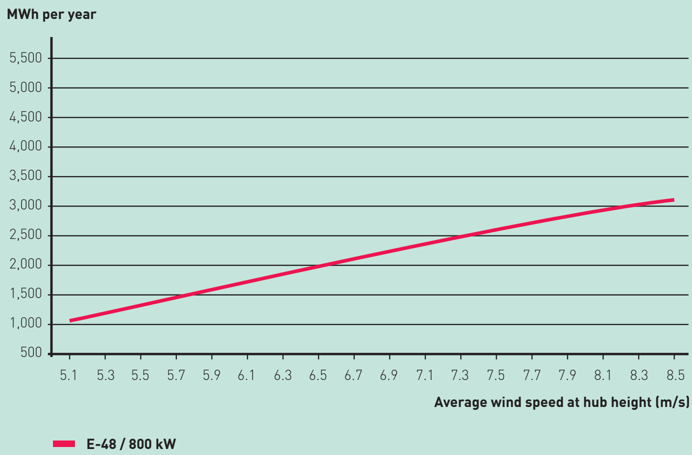
## GENERATOR

| | |
|---|---|
| **Type** | directly driven, separately excited annular generator |
| **Cooling system** | air cooling system |

## FEATURES

| FEATURES | STANDARD | OPTIONAL |
|---|---|---|
| FACTS and transmission | X | |
| ENERCON SCADA | X | |
| ENERCON storm control | X | |
| Ice detection system<br>Power curve method | X | |
| Low radar reflectivity rotor blades | | X |
| Additional ice detection system | | X |
| Blade heating system | | X |
| Hot-Climate | | X |
| Shadow shutdown | | X |
| ENERCON SCADA bat protection | | X |
| STATCOM | | X |
| Inertia Emulation | | X |
| Sector management for wind farms | | X |
| Beacon management for wind farms | | X |

## ANNUAL ENERGY YIELD



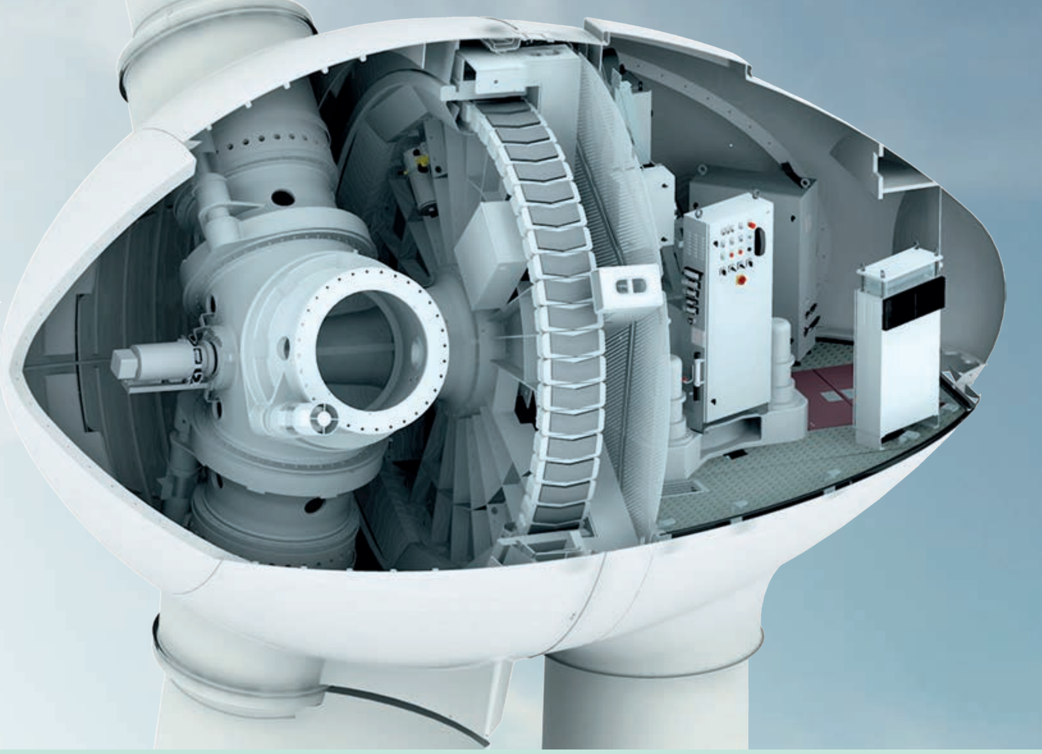

* dependent on hub height

# E-53

800 kW

www.enercon.de

ENERCON
ENERGY FOR THE WORLD



# TECHNICAL DATA
# E-53

## GENERAL

| | |
|---|---|
| **Nominal power** | 800 kW |
| **Wind class (IEC)** | IEC SA |
| **Wind zone (DIBt)** | WZ II exp. / WZ 3 GK I / WZ 4 GK II |
| **Turbine concept** | gearless, variable speed, full power converter |
| **Design service life** | 20 years |
| **Cut in wind speed** | 2.5 m/s |
| **Cut out wind speed** | 34 m/s |
| **Extreme wind speed at hub height (3-second gust)** | 57 m/s (HH 60 / 73 m)<br>55 m/s (HH 50 m) |
| **Rotational speed** | 10.0 - 27.7 rpm |
| **Ambient temperature for normal operation** | -10 °C to +40 °C |
| **Extreme temperature range** | -20 °C to +50 °C |
| **Grid feed / control system** | ENERCON inverter |
| **Grid frequency** | 50 Hz / 60 Hz |
| **Sound power level** | 87.3 - 102.5 dB(A)*<br>Yield and noise-optimised operation. Further modes on request. |

## ROTOR

| | |
|---|---|
| **Rotor diameter** | 52.9 m |
| **Swept area** | 2,198 m² |
| **Type** | upwind rotor with active pitch control |

## TOWER

| **Hub height** | **IEC IA** | **IEC IIA** | **IEC IIIA** |
|---|---|---|---|
| | | | 50 m |
| | | | 60 m |
| | | | 73 m |

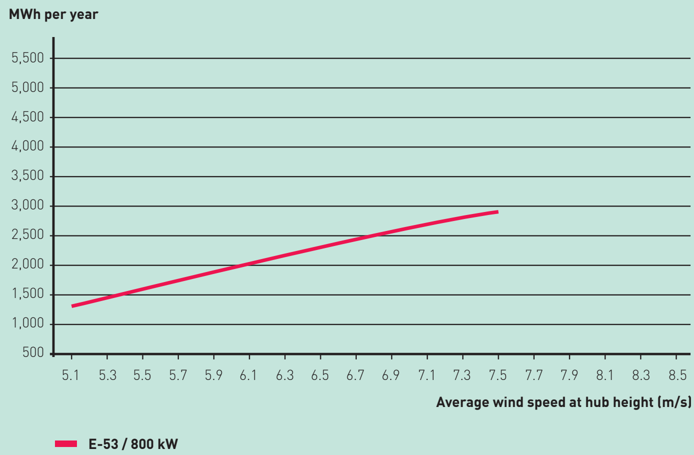
## GENERATOR

| | |
|---|---|
| **Type** | directly driven, separately excited annular generator |
| **Cooling system** | air cooling system |

## FEATURES

| | STANDARD | OPTIONAL |
|---|---|---|
| FACTS and transmission | X | |
| ENERCON SCADA | X | |
| ENERCON storm control | X | |
| Ice detection system<br>Power curve method | X | |
| Low radar reflectivity rotor blades | | X |
| Additional ice detection system | | X |
| Blade heating system | | X |
| Hot-Climate | | X |
| Shadow shutdown | | X |
| ENERCON SCADA bat protection | | X |
| STATCOM | | X |
| Inertia Emulation | | X |
| Sector management for wind farms | | X |
| Beacon management for wind farms | | X |

## ANNUAL ENERGY YIELD



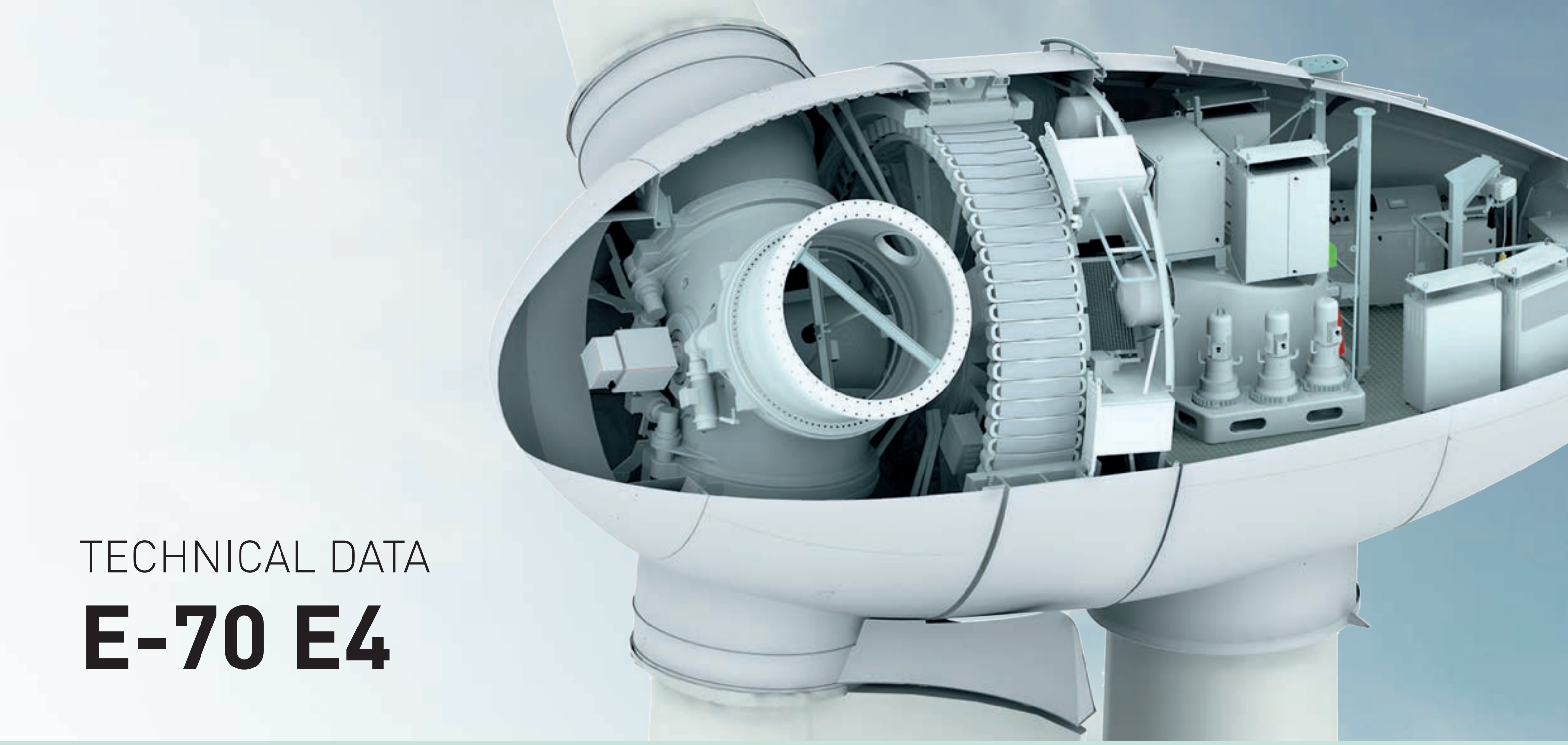

* dependent on hub height

# E-70 E4

2,300 kW

www.enercon.de

ENERCON
ENERGY FOR THE WORLD



TECHNICAL DATA

# E-70 E4

## GENERAL

| | |
|---|---|
| **Nominal power** | 2,300 kW |
| **Wind class (IEC)** | IEC IA and IEC IIA |
| **Wind zone (DIBt)** | WZ III / WZ 4 GK I |
| **Turbine concept** | gearless, variable speed, full power converter |
| **Design service life** | 20 years |
| **Cut in wind speed** | 2.5 m/s |
| **Cut out wind speed** | 34 m/s |
| **Extreme wind speed at hub height (3-second gust)** | 59.5 m/s (IEC IIA)<br>70 m/s (IEC IA) |
| **Rotational speed** | 6.0 - 20.5 rpm |
| **Ambient temperature for normal operation** | -10 °C to +40 °C |
| **Extreme temperature range** | -20 °C to +50 °C |
| **Grid feed / control system** | ENERCON inverter |
| **Grid frequency** | 50 Hz / 60 Hz |
| **Sound power level** | 93.6 - 104.5 dB(A)* (IEC IA)<br>94.1 - 104.5 dB(A)* (IEC IIA)<br>Yield and noise-optimised operation. Further modes on request. |

## ROTOR

| | |
|---|---|
| **Rotor diameter** | 71 m |
| **Swept area** | 3,959 m² |
| **Type** | upwind rotor with active pitch control |

## TOWER

| | IEC IA | IEC IIA | IEC IIIA |
|---|---|---|---|
| **Hub height** | 57 m | 85 m | |
| | 64 m | 98 m | |
| | 75 m | | |

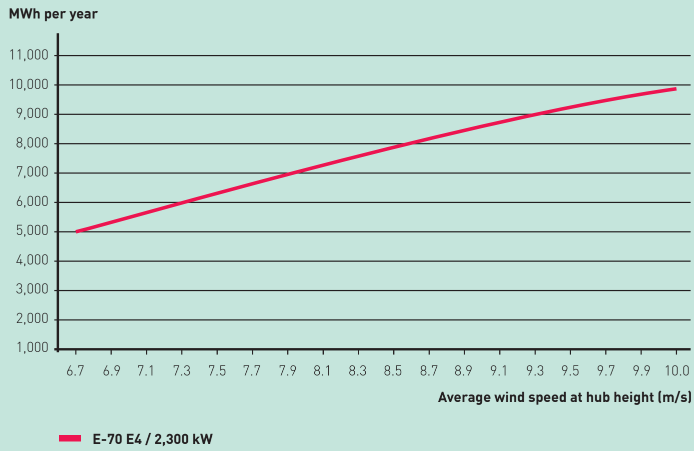
## GENERATOR

| | |
|---|---|
| **Type** | directly driven, separately excited annular generator |
| **Cooling system** | air cooling system |

## FEATURES

| | STANDARD | OPTIONAL |
|---|---|---|
| FACTS and transmission | X | |
| ENERCON SCADA | X | |
| ENERCON storm control | X | |
| Ice detection system<br>Power curve method | X | |
| Low radar reflectivity rotor blades | | X |
| Additional ice detection system | | X |
| Blade heating system | | X |
| Hot-Climate | | X |
| Shadow shutdown | | X |
| ENERCON SCADA bat protection | | X |
| STATCOM | | X |
| Inertia Emulation | | X |
| Sector management for wind farms | | X |
| Beacon management for wind farms | | X |

## ANNUAL ENERGY YIELD



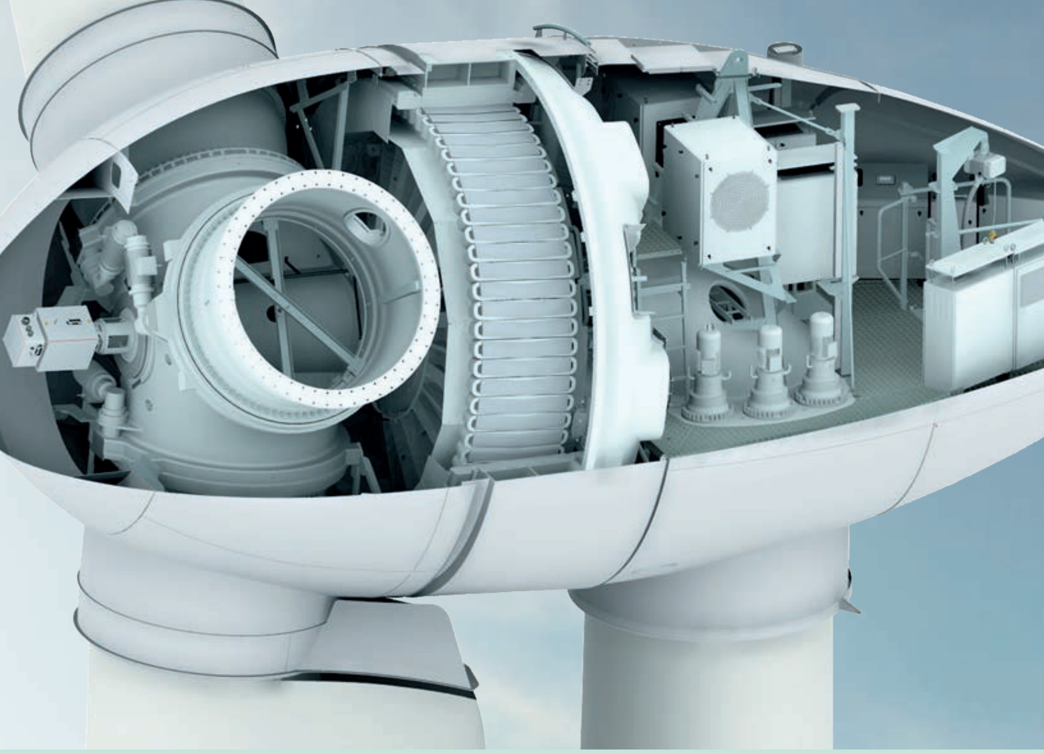

* dependent on hub height

# E-82 E2

2,000 kW / 2,300 kW

www.enercon.de

ENERCON
ENERGY FOR THE WORLD



TECHNICAL DATA

# E-82 E2

## GENERAL

| | |
|---|---|
| **Nominal power** | 2,000 kW / 2,300 kW |
| **Wind class (IEC)** | IEC IIA |
| **Wind zone (DIBt)** | WZ 4 GK I |
| **Turbine concept** | gearless, variable speed, full power converter |
| **Design service life** | 20 years |
| **Cut in wind speed** | 2.5 m/s |
| **Cut out wind speed** | 34 m/s |
| **Extreme wind speed at hub height (3-second gust)** | 59.5 m/s |
| **Rotational speed** | 5.0 - 17.4 rpm (2,000 kW)<br>5.0 - 17.5 rpm (2,300 kW) |
| **Ambient temperature for normal operation** | -10 °C to +40 °C |
| **Extreme temperature range** | -20 °C to +50 °C |
| **Grid feed / control system** | ENERCON inverter |
| **Grid frequency** | 50 Hz / 60 Hz |
| **Sound power level** | 86.8 - 106.0 dB(A)*<br>Yield and noise-optimised operation. Further modes on request. |

## ROTOR

| | |
|---|---|
| **Rotor diameter** | 82 m |
| **Swept area** | 5,281 m² |
| **Type** | upwind rotor with active pitch control |

## TOWER

| **Hub height** | **IEC IA** | **IEC IIA** | **IEC IIIA** |
|---|---|---|---|
| | | 78 m | |
| | | 84 m | |
| | | 85 m | |
| | | 98 m | |
| | | 108 m | |
| | | 138 m | |

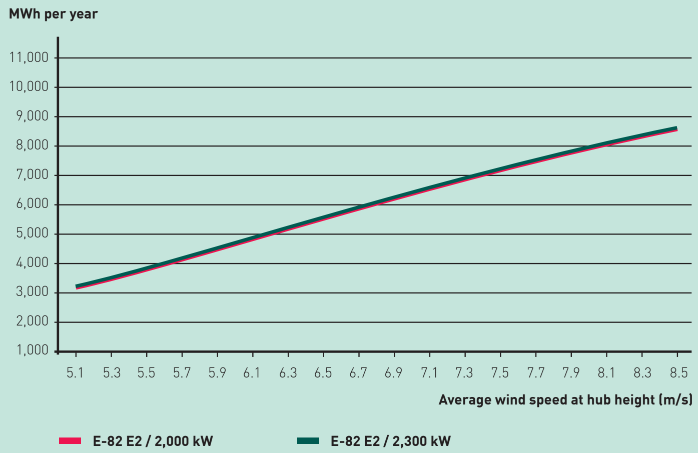
## GENERATOR

| | |
|---|---|
| **Type** | directly driven, separately excited annular generator |
| **Cooling system** | air/water cooling system |

## FEATURES

| FEATURES | STANDARD | OPTIONAL |
|---|---|---|
| FACTS and transmission | X | |
| ENERCON SCADA | X | |
| ENERCON storm control | X | |
| Low radar reflectivity rotor blades | X | |
| Ice detection system<br>Power curve method | X | |
| Additional ice detection system | | X |
| Blade heating system | | X |
| Hot-Climate | | X |
| Shadow shutdown | | X |
| ENERCON SCADA bat protection | | X |
| STATCOM | | X |
| Inertia Emulation | | X |
| Sector management for wind farms | | X |
| Beacon management for wind farms | | X |

## ANNUAL ENERGY YIELD




* dependent on hub height

# E-82 E4

2,350 kW / 3,000 kW

www.enercon.de

ENERCON
ENERGY FOR THE WORLD


# TECHNICAL DATA
# E-82 E4

## GENERAL

| | | |
|---|---|---|
| **Nominal power** | | 2,350 kW / 3,000 kW |
| **Wind class (IEC)** | | IEC IA and IEC IIA |
| **Wind zone (DIBt)** | | WZ 4 GK I |
| **Turbine concept** | | gearless, variable speed, full power converter |
| **Design service life** | | 25 years |
| **Cut in wind speed** | | 2.5 m/s |
| **Cut out wind speed** | | 34 m/s |
| **Extreme wind speed at hub height (3-second gust)** | | 70 m/s (IEC IA)<br>59.5 m/s (IEC IIA) |
| **Rotational speed** | | 5.0 - 17.5 rpm |
| **Ambient temperature for normal operation** | | -10 °C to +40 °C |
| **Extreme temperature range** | | -20 °C to +50 °C |
| **Grid feed / control system** | | ENERCON inverter |
| **Grid frequency** | | 50 Hz / 60 Hz |
| **Sound power level** | **IEC IA:** | 87.4 - 104.0 dB(A)* (2,350 kW)<br>87.6 - 106.0 dB(A)* (3,000 kW) |
| | **IEC IIA:** | 86.6 - 104.0 dB(A)* (2,350 kW)<br>86.8 - 106.0 dB(A)* (3,000 kW)<br>Yield and noise-optimised operation. Further modes on request. |

## ROTOR

| | |
|---|---|
| **Rotor diameter** | 82 m |
| **Swept area** | 5,281 m² |
| **Type** | upwind rotor with active pitch control |

## TOWER

| | **IEC IA** | **IEC IIA** | **IEC IIIA** |
|---|---|---|---|
| **Hub height** | 78 m | 59 m | |
| | 84 m | 69 m | |

* dependent on hub height

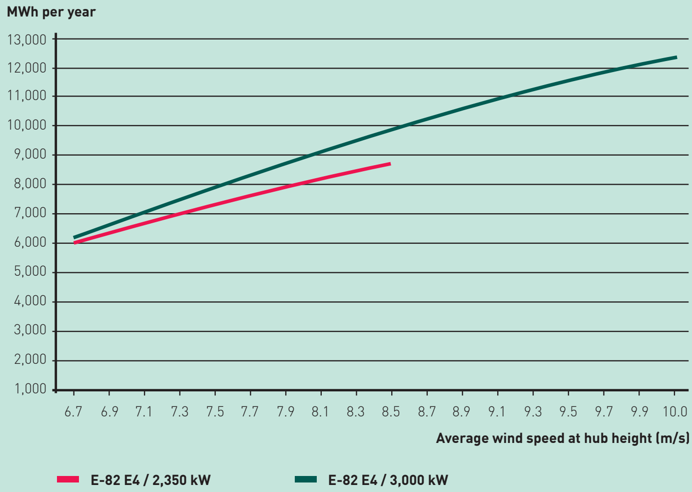
## GENERATOR

| | |
|---|---|
| **Type** | directly driven, separately excited annular generator |
| **Cooling system** | air/water cooling system |

## FEATURES

| | STANDARD | OPTIONAL |
|---|---|---|
| FACTS and transmission | X | |
| ENERCON SCADA | X | |
| ENERCON storm control | X | |
| Low radar reflectivity rotor blades | X | |
| Ice detection system<br>Power curve method | X | |
| Additional ice detection system | | X |
| Blade heating system | | X |
| Hot-Climate | | X |
| Shadow shutdown | | X |
| ENERCON SCADA bat protection | | X |
| STATCOM | | X |
| Inertia Emulation | | X |
| Sector management for wind farms | | X |
| Beacon management for wind farms | | X |

## ANNUAL ENERGY YIELD

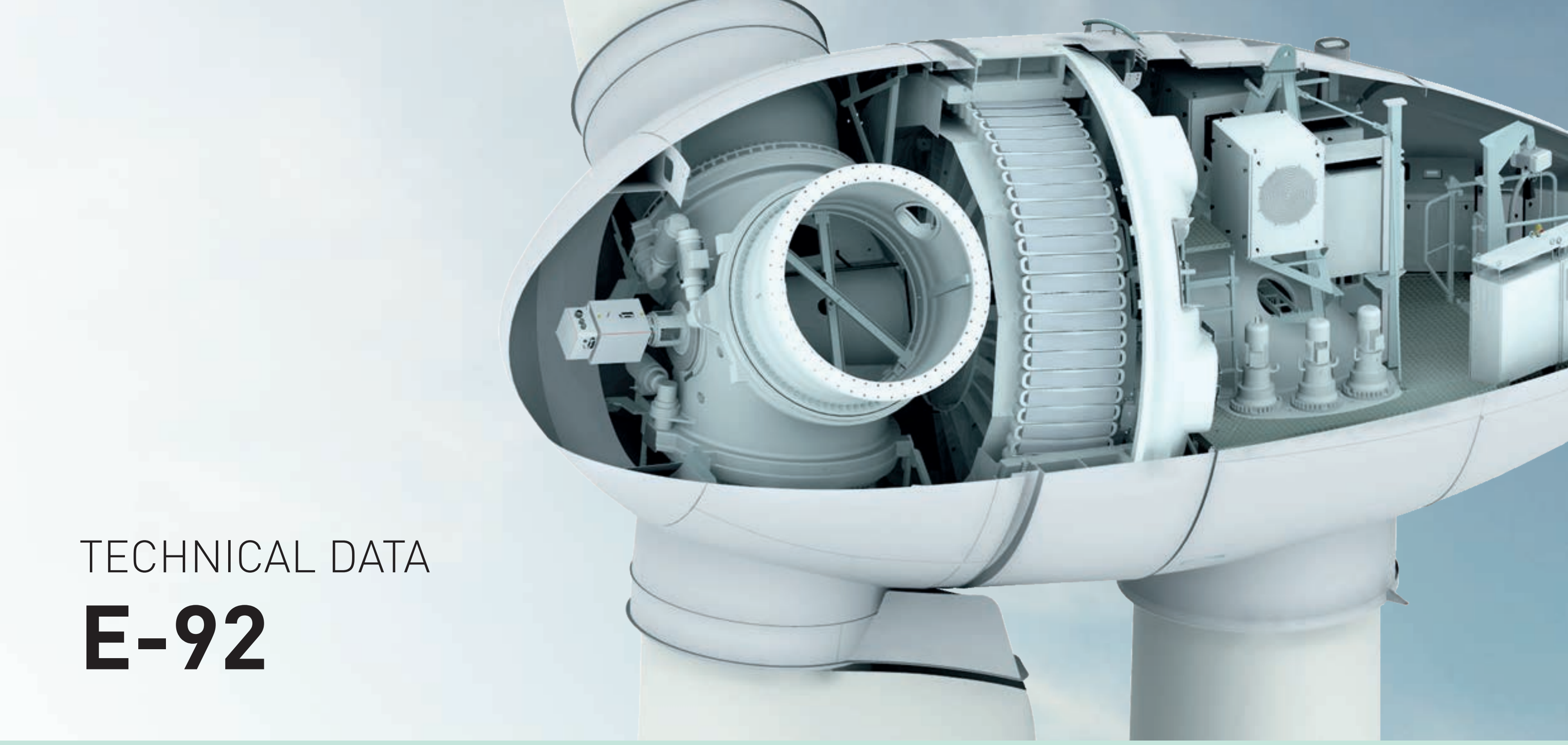


# E-92

2,350 kW

www.enercon.de

ENERCON
ENERGY FOR THE WORLD



TECHNICAL DATA

# E-92

## GENERAL

| | |
|---|---|
| **Nominal power** | 2,350 kW |
| **Wind class (IEC)** | IEC IIA |
| **Wind zone (DIBt)** | WZ 4 GK I + II |
| **Turbine concept** | gearless, variable speed, full power converter |
| **Design service life** | 25 years |
| **Cut in wind speed** | 2.5 m/s |
| **Cut out wind speed** | 34 m/s |
| **Extreme wind speed at hub height (3-second gust)** | 59.5 m/s |
| **Rotational speed** | 5.0 - 16.5 rpm |
| **Ambient temperature for normal operation** | -10 °C to +40 °C |
| **Extreme temperature range** | -20 °C to +50 °C |
| **Grid feed / control system** | ENERCON inverter |
| **Grid frequency** | 50 Hz / 60 Hz |
| **Sound power level** | 91.0 - 105.0 dB(A)* Yield and noise-optimised operation. Further modes on request. |

## ROTOR

| | |
|---|---|
| **Rotor diameter** | 92 m |
| **Swept area** | 6,648 m² |
| **Type** | upwind rotor with active pitch control |

## TOWER

| **Hub height** | **IEC IA** | **IEC IIA** | **IEC IIIA** |
|---|---|---|---|
| | | 69 m | |
| | | 78 m | |
| | | 84 m | |
| | | 85 m | |
| | | 98 m | |
| | | 104 m | |
| | | 108 m | |
| | | 138 m | |

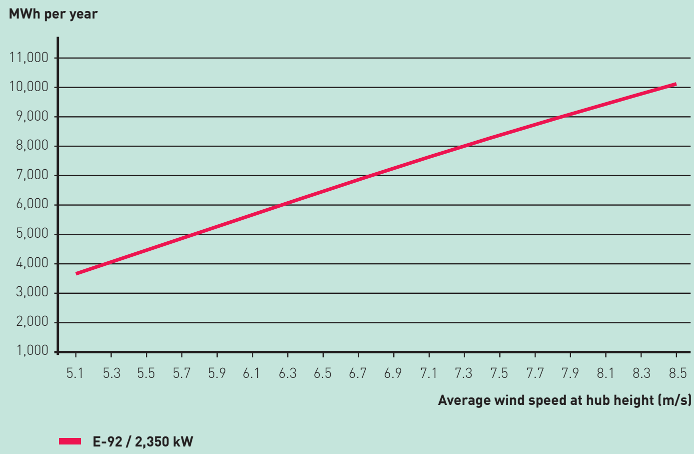
## GENERATOR

| | |
|---|---|
| **Type** | directly driven, separately excited annular generator |
| **Cooling system** | air cooling system |

## FEATURES

| | STANDARD | OPTIONAL |
|---|---|---|
| FACTS and transmission | X | |
| ENERCON SCADA | X | |
| ENERCON storm control | X | |
| Low radar reflectivity rotor blades | X | |
| Ice detection system<br>Power curve method | X | |
| Additional ice detection system | | X |
| Blade heating system | | X |
| Hot-Climate | | X |
| Shadow shutdown | | X |
| ENERCON SCADA bat protection | | X |
| STATCOM | | X |
| Inertia Emulation | | X |
| Sector management for wind farms | | X |
| Beacon management for wind farms | | X |

## ANNUAL ENERGY YIELD



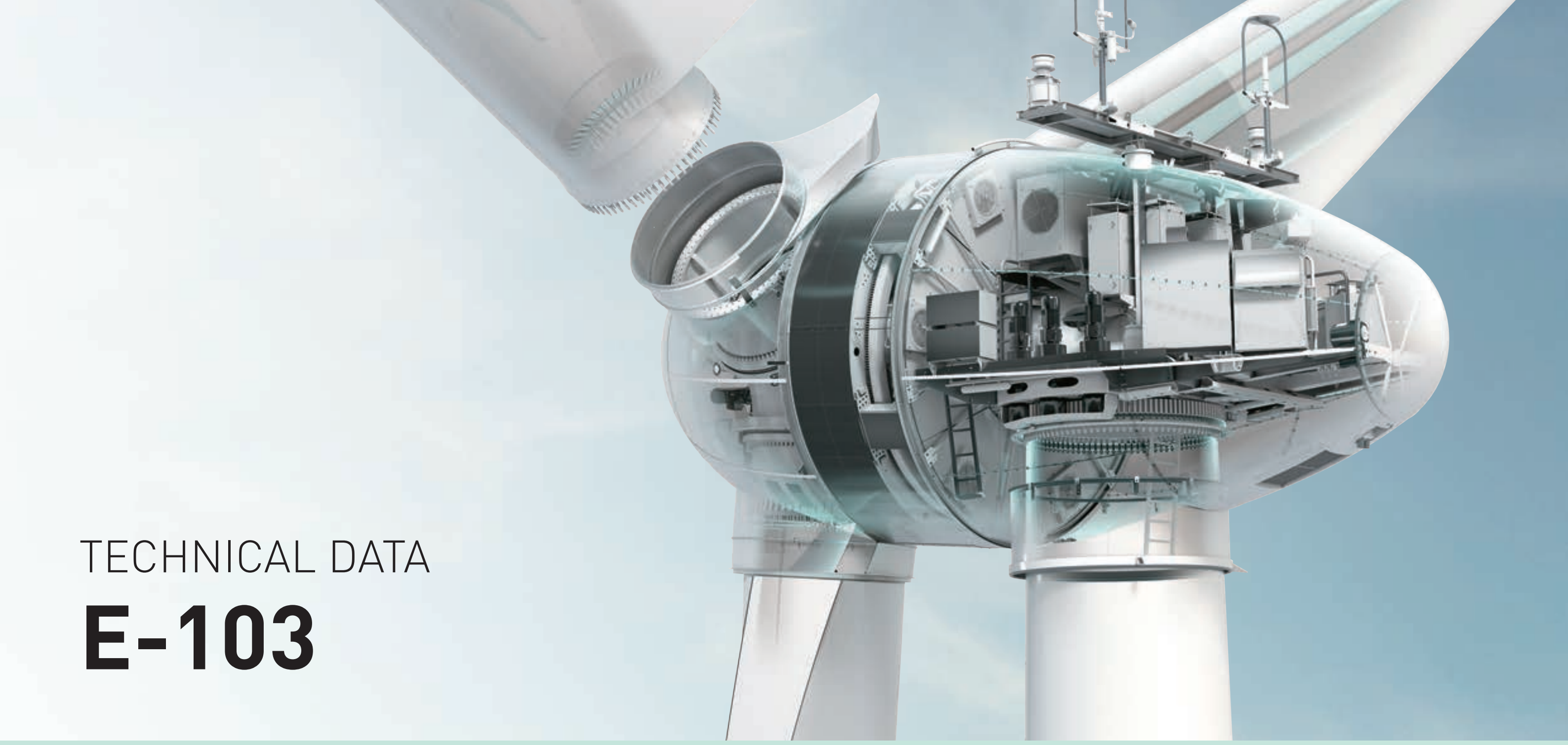

* dependent on hub height

# E-103

2,350 kW

www.enercon.de

ENERCON
ENERGY FOR THE WORLD



TECHNICAL DATA

# E-103

## GENERAL

| | |
|---|---|
| **Nominal power** | 2,350 kW |
| **Wind class (IEC)** | IEC IIIA |
| **Wind zone (DIBt)** | WZ 2 GK I + II |
| **Turbine concept** | gearless, variable speed, full power converter |
| **Design service life** | 25 years |
| **Cut in wind speed** | 2.5 m/s |
| **Cut out wind speed** | 34 m/s |
| **Extreme wind speed at hub height (3-second gust)** | 52.5 m/s |
| **Rotational speed** | 4.8 - 14.6 rpm |
| **Ambient temperature for normal operation** | -10 °C to +40 °C |
| **Extreme temperature range** | -20 °C to +50 °C |
| **Grid feed / control system** | ENERCON inverter |
| **Grid frequency** | 50 Hz / 60 Hz |
| **Sound power level** | 90.5 - 105.0 dB(A)* Yield and noise-optimised operation. Further modes on request. |

## ROTOR

| | |
|---|---|
| **Rotor diameter** | 103 m |
| **Swept area** | 8,332 m² |
| **Type** | upwind rotor with active pitch control |

## TOWER

| **Hub height** | **IEC IA** | **IEC IIA** | **IEC IIIA** |
|---|---|---|---|
| | | | 78 m |
| | | | 85 m |
| | | | 98 m |
| | | | 108 m |
| | | | 138 m |

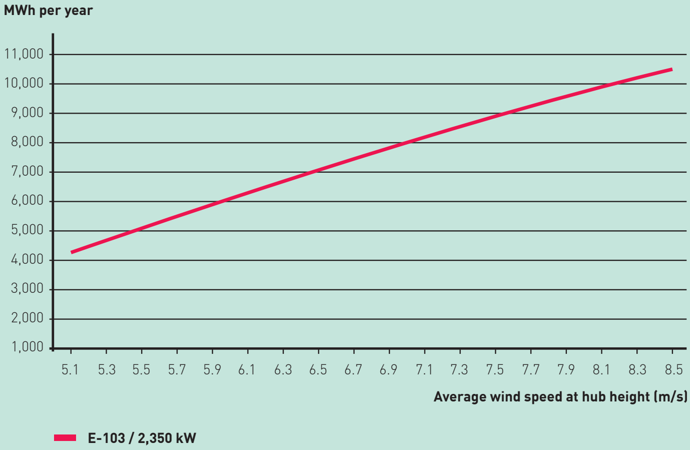
## GENERATOR

| | |
|---|---|
| **Type** | directly driven, separately excited annular generator |
| **Cooling system** | air cooling system |

## FEATURES

| | **STANDARD** | **OPTIONAL** |
|---|---|---|
| FACTS and transmission | X | |
| ENERCON SCADA | X | |
| ENERCON storm control | X | |
| Low radar reflectivity rotor blades | X | |
| Ice detection system<br>Power curve method | X | |
| Additional ice detection system | | X |
| Blade heating system | | X |
| Hot-Climate | | X |
| Shadow shutdown | | X |
| ENERCON SCADA bat protection | | X |
| STATCOM | | X |
| Inertia Emulation | | X |
| Sector management for wind farms | | X |
| Beacon management for wind farms | | X |

## ANNUAL ENERGY YIELD




* dependent on hub height

# E-101

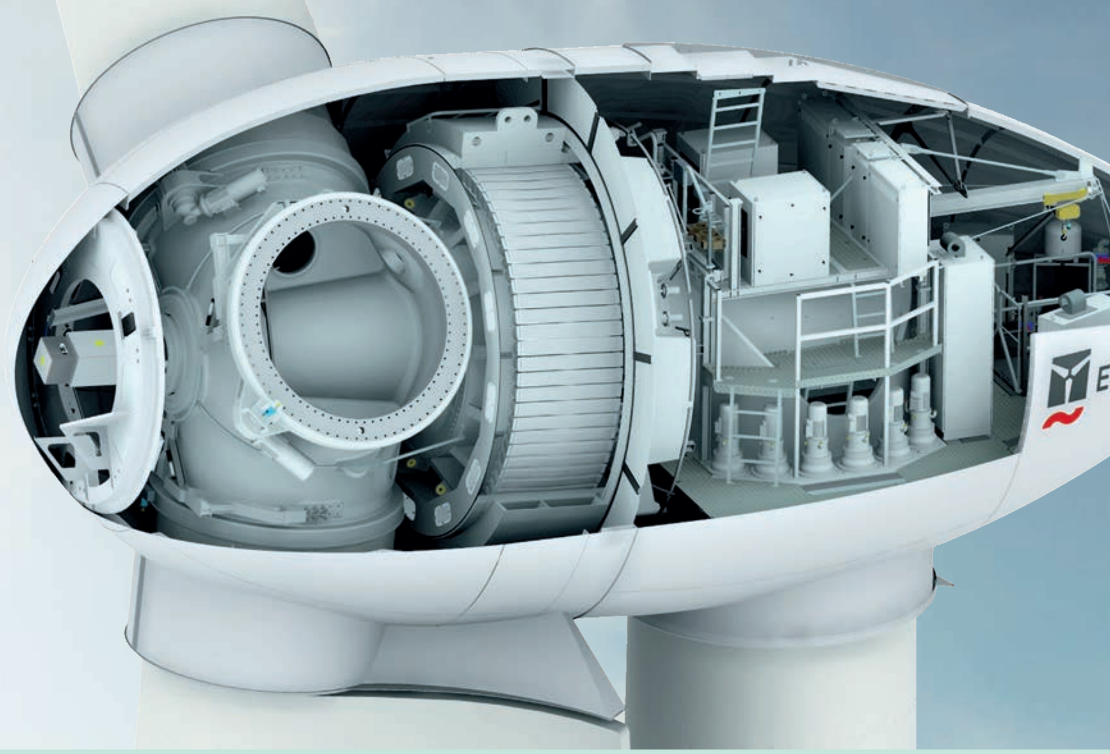
3,050 kW

www.enercon.de

ENERCON
ENERGY FOR THE WORLD

# TECHNICAL DATA

# E-101



## GENERAL

| | |
|---|---|
| **Nominal power** | 3,050 kW |
| **Wind class (IEC)** | IEC IIA |
| **Wind zone (DIBt)** | WZ III / WZ 4 GK I |
| **Turbine concept** | gearless, variable speed, full power converter |
| **Design service life** | 20 years |
| **Cut in wind speed** | 2.5 m/s |
| **Cut out wind speed** | 34 m/s |
| **Extreme wind speed at hub height (3-second gust)** | 59.5 m/s |
| **Rotational speed** | 4.8 - 14.2 rpm |
| **Ambient temperature for normal operation** | -10 °C to +40 °C |
| **Extreme temperature range** | -20 °C to +50 °C |
| **Grid feed / control system** | ENERCON inverter |
| **Grid frequency** | 50 Hz / 60 Hz |
| **Sound power level** | 87.5 - 104.5 dB(A)* Yield and noise-optimised operation. Further modes on request. |

## ROTOR

| | |
|---|---|
| **Rotor diameter** | 101 m |
| **Swept area** | 8,012 m² |
| **Type** | upwind rotor with active pitch control |

## TOWER

| **Hub height** | **IEC IA** | **IEC IIA** | **IEC IIIA** |
|---|---|---|---|
| | | 99 m | |
| | | 124 m | |
| | | 135 m | |
| | | 149 m | |

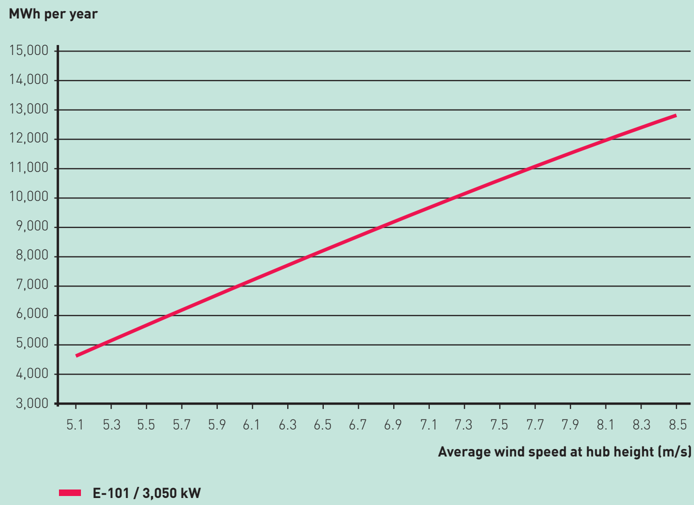
## GENERATOR

| | |
|---|---|
| **Type** | directly driven, separately excited annular generator |
| **Cooling system** | air/water cooling system |

## FEATURES

| | **STANDARD** | **OPTIONAL** |
|---|---|---|
| FACTS and transmission | X | |
| ENERCON SCADA | X | |
| ENERCON storm control | X | |
| Low radar reflectivity rotor blades | X | |
| Ice detection system<br>Power curve method | X | |
| Additional ice detection system | | X |
| Blade heating system | | X |
| Hot-Climate | | X |
| Shadow shutdown | | X |
| ENERCON SCADA bat protection | | X |
| STATCOM | | X |
| Inertia Emulation | | X |
| Sector management for wind farms | | X |
| Beacon management for wind farms | | X |

## ANNUAL ENERGY YIELD




* dependent on hub height

# E-115

3,000 kW / 3,200 kW

www.enercon.de

ENERCON
ENERGY FOR THE WORLD

# TECHNICAL DATA
# E-115

## GENERAL

| | |
|---|---|
| **Nominal power** | 3,000 kW / 3,200 kW |
| **Wind class (IEC)** | IEC IIA |
| **Wind zone (DIBt)** | WZ III / WZ 4 GK I + II (3,000 kW)<br>WZ 4 GK I + II (3,200 kW) |
| **Turbine concept** | gearless,<br>variable speed,<br>full power converter |
| **Design service life** | 25 years |
| **Cut in wind speed** | 2.5 m/s |
| **Cut out wind speed** | 34 m/s |
| **Extreme wind speed at hub height (3-second gust)** | 59.5 m/s |
| **Rotational speed** | 4.4 - 12.4 rpm (3,000 kW)<br>4.4 - 12.8 rpm (3,200 kW) |
| **Ambient temperature for normal operation** | -10 °C to +40 °C |
| **Extreme temperature range** | -20 °C to +50 °C |
| **Grid feed / control system** | ENERCON inverter |
| **Grid frequency** | 50 Hz / 60 Hz |
| **Sound power level** | 91.0 - 105.0 dB(A)* (3,000 kW)<br>91.0 - 105.5 dB(A)* (3,200 kW)<br>Yield and noise-optimised operation. Further modes on request. |

## ROTOR

| | |
|---|---|
| **Rotor diameter** | 115.7 m |
| **Swept area** | 10,515.5 m² |
| **Type** | upwind rotor with active pitch control |

## TOWER

| | IEC IA | IEC IIA | IEC IIIA |
|---|---|---|---|
| **Hub height** | | 92 m | |
| | | 122 m | |
| | | 135 m | |
| | | 149 m | |

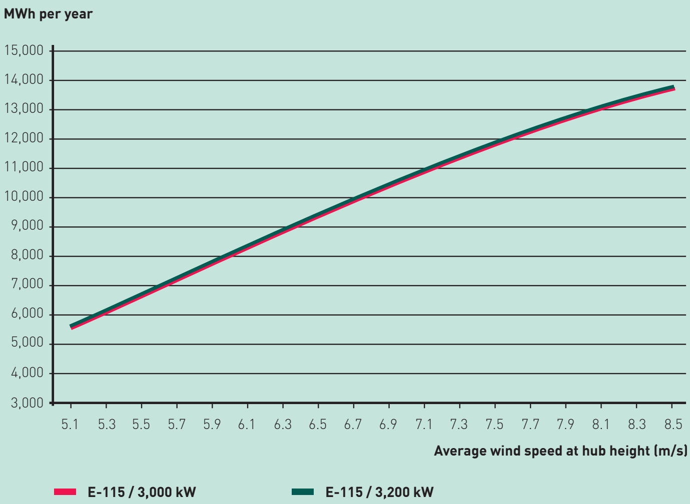
## GENERATOR

| | |
|---|---|
| **Type** | directly driven, separately excited annular generator |
| **Cooling system** | air/water cooling system |

## FEATURES

| | STANDARD | OPTIONAL |
|---|---|---|
| FACTS and transmission | X | |
| ENERCON SCADA | X | |
| ENERCON storm control | X | |
| Low radar reflectivity rotor blades | X | |
| Ice detection system<br>Power curve method | X | |
| Additional ice detection system | | X |
| Blade heating system | | X |
| Hot-Climate | | X |
| Shadow shutdown | | X |
| ENERCON SCADA bat protection | | X |
| STATCOM | | X |
| Inertia Emulation | | X |
| Sector management for wind farms | | X |
| Beacon management for wind farms | | X |

## ANNUAL ENERGY YIELD




* dependent on hub height


# E-115 EP3

3,000 kW / 4,000 kW

www.enercon.de

ENERCON
ENERGY FOR THE WORLD

# TECHNICAL DATA

# E-115 EP3

The new EP3 range represents a radical cut in ENERCON's wind energy converter design. Compact and efficient with consistently optimised processes from production, transport and logistics to installation – these are the key characteristics of this WEC generation and ENERCON's response to new market requirements.

NEW WEC GENERATION

## GENERAL

| | |
|---|---|
| **Nominal power** | 3,000 kW / 4,000 kW |
| **Wind class (IEC)** | IEC IA<br>IEC IIA |
| **Wind zone (DIBt)** | - |
| **Turbine concept** | gearless,<br>variable speed,<br>full power converter |
| **Design service life** | 25 years |
| **Cut in wind speed** | 2.5 m/s |
| **Cut out wind speed** | 34 m/s |
| **Extreme wind speed at hub height (3-second gust)** | 59.5 m/s (IEC IIA)<br>70 m/s (IEC IA) |
| **Rotational speed** | 4.4 - 12.8 rpm (3,000 kW)<br>4.4 - 13.2 rpm (4,000 kW) |
| **Ambient temperature for normal operation** | -10 °C to +40 °C |
| **Extreme temperature range** | -20 °C to +50 °C |
| **Grid feed / control system** | ENERCON inverter |
| **Grid frequency** | 50 Hz / 60 Hz |
| **Sound power level** | 87.6 - 106.0 dB(A)*<br>Yield and noise-optimised operation. Further modes on request. |

## ROTOR

| | |
|---|---|
| **Rotor diameter** | 115.7 m |
| **Swept area** | 10,516 m² |
| **Type** | upwind rotor with active pitch control |

## TOWER

| | IEC IA | IEC IIA | IEC IIIA |
|---|---|---|---|
| **Hub height** | 67 m | 122 m | |
| | 87 m | 135 m | |
| | 92 m | 149 m | |

* dependent on hub height

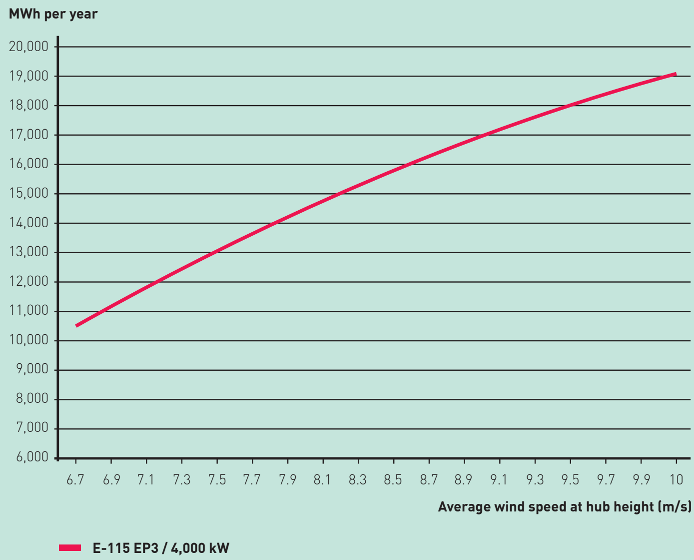
## GENERATOR

| | |
|---|---|
| **Type** | directly driven, separately excited annular generator |
| **Cooling system** | air/water cooling system |

## FEATURES

| FEATURES | STANDARD | OPTIONAL |
|---|---|---|
| FACTS and transmission | X | |
| ENERCON SCADA | X | |
| ENERCON storm control | X | |
| Low radar reflectivity rotor blades | X | |
| Ice detection system<br>Power curve method | X | |
| Additional ice detection system | | X |
| Blade heating system | | X |
| Hot-Climate | | X |
| Shadow shutdown | | X |
| ENERCON SCADA bat protection | | X |
| STATCOM | | X |
| Inertia Emulation | | X |
| Sector management for wind farms | | X |
| Beacon management for wind farms | | X |

## ANNUAL ENERGY YIELD



# E-126 EP3

3,000 kW / 3,500 kW / 4,000 kW

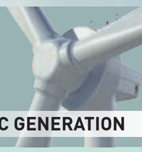
www.enercon.de

ENERCON
ENERGY FOR THE WORLD

TECHNICAL DATA

# E-126 EP3

The new EP3 range represents a radical cut in ENERCON's wind energy converter design. Compact and efficient with consistently optimised processes from production, transport and logistics to installation – these are the key characteristics of this WEC generation and ENERCON's response to new market requirements.



**NEW WEC GENERATION**

## GENERAL

| | |
|---|---|
| **Nominal power** | 3,000 kW / 3,500 kW / 4,000 kW |
| **Wind class (IEC)** | IEC IIA |
| **Wind zone (DIBt)** | WZ 4 GK I + II<br>WZ 3 GK I + II |
| **Turbine concept** | gearless,<br>variable speed,<br>full power converter |
| **Design service life** | 25 years |
| **Cut in wind speed** | 2.5 m/s |
| **Cut out wind speed** | 34 m/s |
| **Extreme wind speed at hub height (3-second gust)** | 59.5 m/s |
| **Rotational speed** | 4.4 - 11.7 rpm (3,000 kW)<br>4.4 - 11.9 rpm (3,500 kW)<br>4.4 - 12.1 rpm (4,000 kW) |
| **Ambient temperature for normal operation** | -10 °C to +40 °C |
| **Extreme temperature range** | -20 °C to +50 °C |
| **Grid feed / control system** | ENERCON inverter |
| **Grid frequency** | 50 Hz / 60 Hz |
| **Sound power level** | 88.1 - 106.1 dB(A)*<br>Yield and noise-optimised operation. Further modes on request. |

## ROTOR

| | |
|---|---|
| **Rotor diameter** | 127 m |
| **Swept area** | 12,668 m² |
| **Type** | upwind rotor with active pitch control |

## TOWER

| | IEC IA | IEC IIA | IEC IIIA |
|---|---|---|---|
| **Hub height** | | 86 m<br>99 m<br>116 m<br>135 m | |

* dependent on hub height

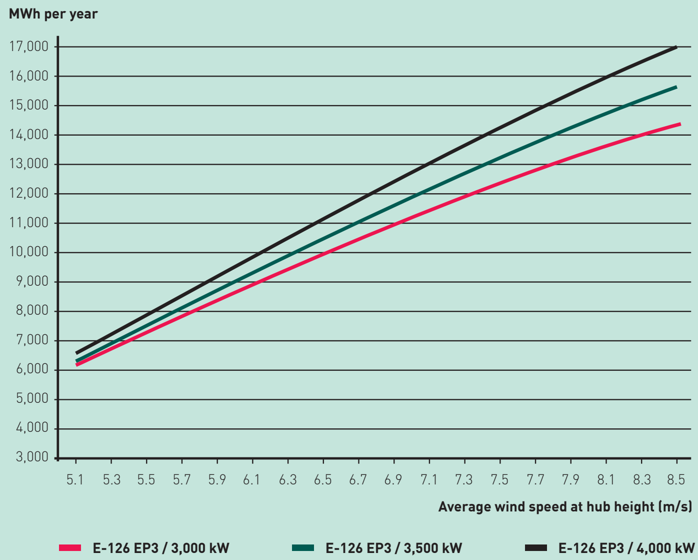
## GENERATOR

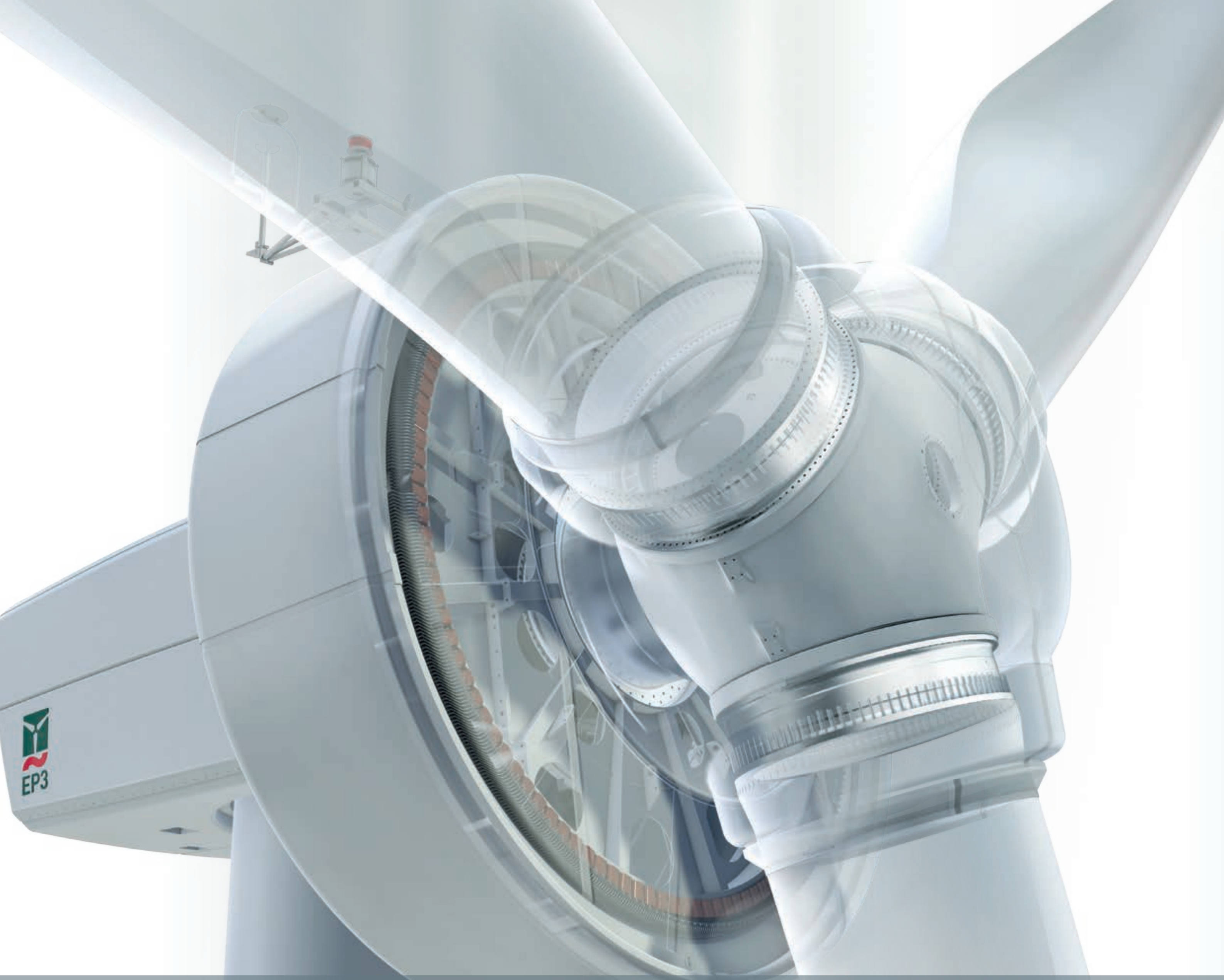
| | |
|---|---|
| **Type** | directly driven, separately excited annular generator |
| **Cooling system** | air cooling system |

## FEATURES

| | STANDARD | OPTIONAL |
|---|---|---|
| FACTS and transmission | X | |
| ENERCON SCADA | X | |
| ENERCON storm control | X | |
| Low radar reflectivity rotor blades | X | |
| Ice detection system<br>Power curve method | X | |
| Additional ice detection system | | X |
| Blade heating system | | X |
| Hot-Climate | | X |
| Shadow shutdown | | X |
| ENERCON SCADA bat protection | | X |
| STATCOM | | X |
| Inertia Emulation | | X |
| Sector management for wind farms | | X |
| Beacon management for wind farms | | X |

## ANNUAL ENERGY YIELD






# E-138 EP3

3,500 kW / 4,200 kW

www.enercon.de

ENERCON
ENERGY FOR THE WORLD

# TECHNICAL DATA
# E-138 EP3

The new EP3 range represents a radical cut in ENERCON's wind energy converter design. Compact and efficient with consistently optimised processes from production, transport and logistics to installation – these are the key characteristics of this WEC generation and ENERCON's response to new market requirements.

**NEW WEC GENERATION**

## GENERAL

| | |
|---|---|
| **Nominal power** | 3,500 kW / 4,200 kW (E2) |
| **Wind class (IEC)** | IEC IIIA |
| **Wind zone (DIBt)** | WZ 2 GK II |
| **Turbine concept** | gearless, variable speed, full power converter |
| **Design service life** | 25 years |
| **Cut in wind speed** | 2.5 m/s |
| **Cut out wind speed** | 34 m/s |
| **Extreme wind speed at hub height (3-second gust)** | 52.5 m/s |
| **Rotational speed** | 4.4 / 5 * - 10.5 rpm (3,500 kW)<br>4.4 / 5 * - 10.8 rpm (4,200 kW) |
| **Ambient temperature for normal operation** | -10 °C to +40 °C |
| **Extreme temperature range** | -20 °C to +50 °C |
| **Grid feed / control system** | ENERCON inverter |
| **Grid frequency** | 50 Hz / 60 Hz |
| **Sound power level** | 93.4 - 106.0 dB(A)*<br>Yield and noise-optimised operation. Further modes on request. |

## ROTOR

| | |
|---|---|
| **Rotor diameter** | 138.6 m |
| **Swept area** | 15,085 m² |
| **Type** | upwind rotor with active pitch control |

## TOWER

| **Hub height** | **IEC IA** | **IEC IIA** | **IEC IIIA** |
|---|---|---|---|
| | | | 81 m |
| | | | 111 m |
| | | | 131 m |
| | | | 160 m |

## GENERATOR

| | |
|---|---|
| **Type** | directly driven, separately excited annular generator |
| **Cooling system** | air cooling system |

## FEATURES

| | STANDARD | OPTIONAL |
|---|---|---|
| FACTS and transmission | X | |
| ENERCON SCADA | X | |
| ENERCON storm control | X | |
| Low radar reflectivity rotor blades | X | |
| Ice detection system<br>Power curve method | X | |
| Additional ice detection system | | X |
| Blade heating system | | X |
| Hot-Climate | | X |
| Shadow shutdown | | X |
| ENERCON SCADA bat protection | | X |
| STATCOM | | X |
| Inertia Emulation | | X |
| Sector management for wind farms | | X |
| Beacon management for wind farms | | X |

## ANNUAL ENERGY YIELD


* dependent on hub height

# L136

4,500 kW

www.lagerwey.com

TECHNICAL DATA

# L136

## GENERAL

| | |
|---|---|
| **Nominal power** | 4,500 kW |
| **Wind class (IEC)** | IEC IA / S |
| **Turbine concept** | gearless, variable speed, full power converter |
| **Design service life** | 20 years |
| **Cut in wind speed** | 2.5 m/s |
| **Cut out wind speed** | 25 m/s |
| **Extreme wind speed at hub height (3-second gust)** | 70 m/s |
| **Rotational speed** | 6.0 - 11.0 rpm |
| **Ambient temperature for normal operation** | -10 °C to +40 °C |
| **Extreme temperature range** | -20 °C to +50 °C |
| **Grid feed / control system** | IGBT-Control |
| **Grid frequency** | 50 Hz / 60 Hz |
| **Sound power level** | 106.9 dB(A)* Yield and noise-optimised operation. Further modes on request. |

## ROTOR

| | |
|---|---|
| **Rotor diameter** | 136 m |
| **Swept area** | 14,584 m² |
| **Type** | upwind rotor with active pitch control |

## TOWER

| | **IEC IA** | **IEC IIA** | **IEC IIIA** |
|---|---|---|---|
| **Hub height** | 120 m | | |
| | 132 m | | |

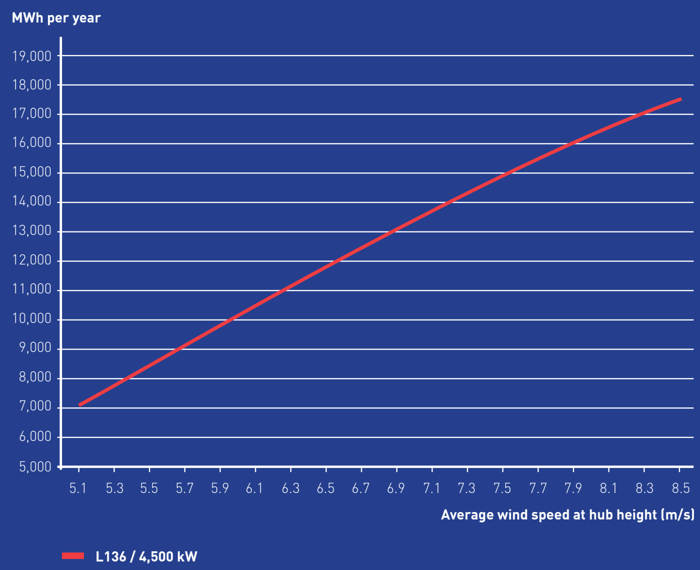
## GENERATOR

| | |
|---|---|
| **Type** | Lagerwey multi-pole synchronous generator |
| **Cooling system** | air cooling system |

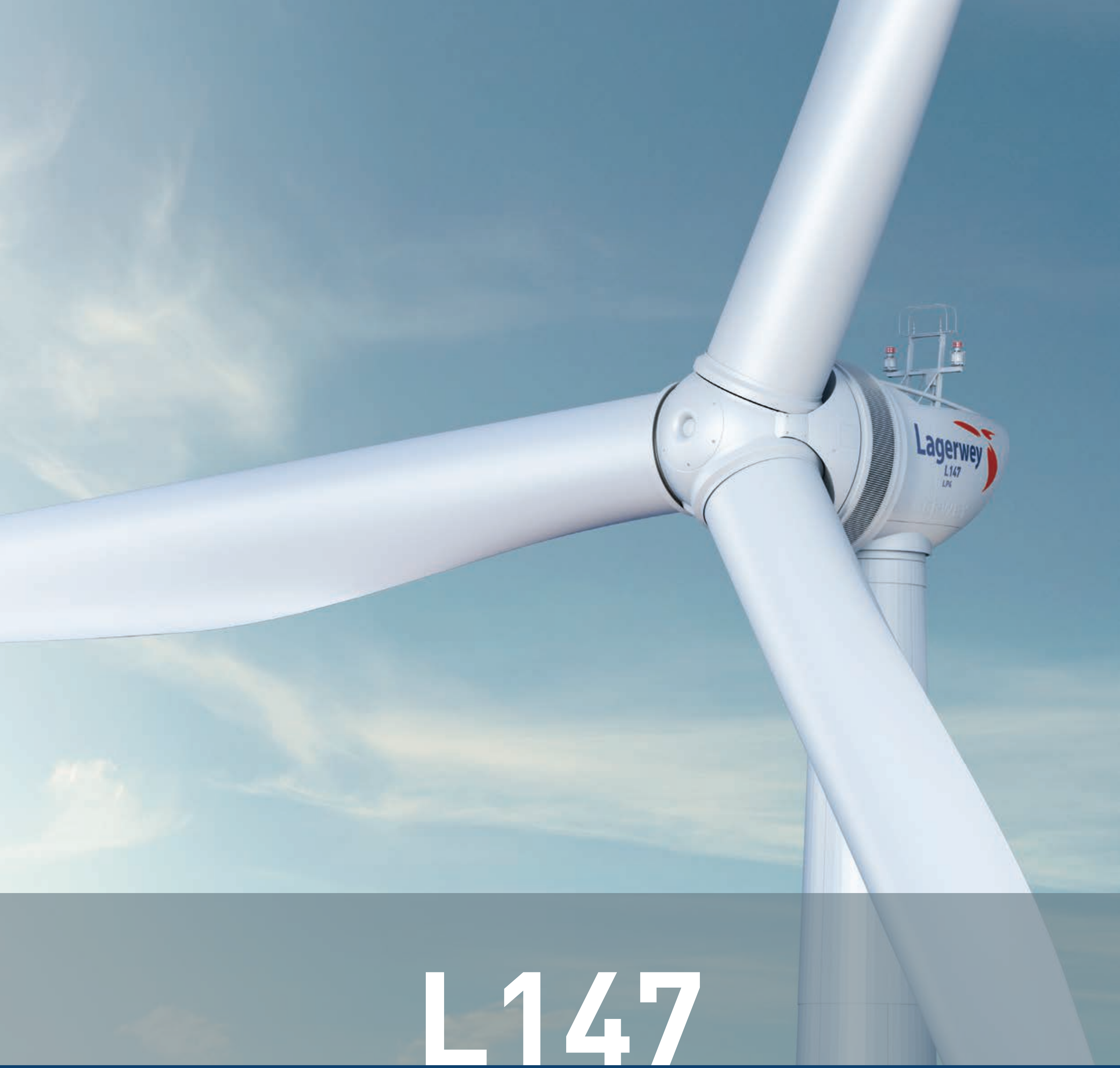
## FEATURES

| | STANDARD | OPTIONAL |
|---|---|---|
| Service lift | X | |
| Rescue module gondola | X | |
| Noise reduction | X | |
| Obstacle light/marking | | X |
| Ice management system | | X |
| Shadow shutdown | | X |

## ANNUAL ENERGY YIELD




* dependent on hub height




# L147

4,300 kW

www.lagerwey.com

Lagerwey

# TECHNICAL DATA

# L147

## GENERAL

| | |
|---|---|
| **Nominal power** | 4,300 kW |
| **Wind class (IEC)** | IEC IIA |
| **Turbine concept** | gearless, variable speed, full power converter |
| **Design service life** | 20 years |
| **Cut in wind speed** | 2.5 m/s |
| **Cut out wind speed** | 25 m/s |
| **Extreme wind speed at hub height (3-second gust)** | 59,5 m/s |
| **Rotational speed** | 3.9 - 10.4 rpm |
| **Ambient temperature for normal operation** | -10 °C to +40 °C |
| **Extreme temperature range** | -20 °C to +50 °C |
| **Grid feed / control system** | IGBT-Control |
| **Grid frequency** | 50 Hz / 60 Hz |
| **Sound power level** | 106.7 dB(A)* Yield and noise-optimised operation. Further modes on request. |

## ROTOR

| | |
|---|---|
| **Rotor diameter** | 147 m |
| **Swept area** | 16,972 m² |
| **Type** | upwind rotor with active pitch control |

## TOWER

| | IEC IA | IEC IIA | IEC IIIA |
|---|---|---|---|
| **Hub height** | | 126 m<br>155 m | |

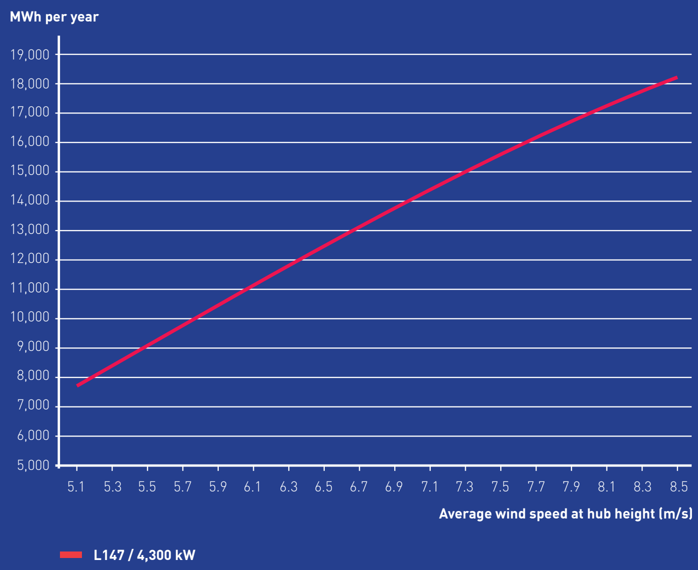
## GENERATOR

| | |
|---|---|
| **Type** | Lagerwey multi-pole synchronous generator |
| **Cooling system** | air cooling system |

## FEATURES

| FEATURES | STANDARD | OPTIONAL |
|---|---|---|
| Service lift | X | |
| Rescue module gondola | X | |
| Noise reduction | X | |
| Obstacle light/marking | | X |
| Ice management system | | X |
| Shadow shutdown | | X |

## ANNUAL ENERGY YIELD




* dependent on hub height


# L160

4,000 kW

www.lagerwey.com

Lagerwey

# TECHNICAL DATA

# L160

## GENERAL

| | |
|---|---|
| **Nominal power** | 4,000 kW |
| **Wind class (IEC)** | IEC IIIA |
| **Turbine concept** | gearless, variable speed, full power converter |
| **Design service life** | 20 years |
| **Cut in wind speed** | 2.5 m/s |
| **Cut out wind speed** | 25 m/s |
| **Extreme wind speed at hub height (3-second gust)** | 52,5 m/s |
| **Ambient temperature for normal operation** | -10 °C to +40 °C |
| **Extreme temperature range** | -20 °C to +50 °C |
| **Grid feed / control system** | IGBT-Control |
| **Grid frequency** | 50 Hz / 60 Hz |

## ROTOR

| | |
|---|---|
| **Rotor diameter** | 160 m |
| **Swept area** | 20,106 m² |
| **Type** | upwind rotor with active pitch control |

## TOWER

| | IEC IA | IEC IIA | IEC IIIA |
|---|---|---|---|
| **Hub height** | | | 120 m |
| | | | 166 m |

## GENERATOR

| | |
|---|---|
| **Type** | Lagerwey multi-pole synchronous generator |
| **Cooling system** | air/water cooling system |

## FEATURES

| | STANDARD | OPTIONAL |
|---|---|---|
| Service lift | X | |
| Rescue module gondola | X | |
| Noise reduction | X | |
| Obstacle light/marking | | X |
| Ice management system | | X |
| Shadow shutdown | | X |