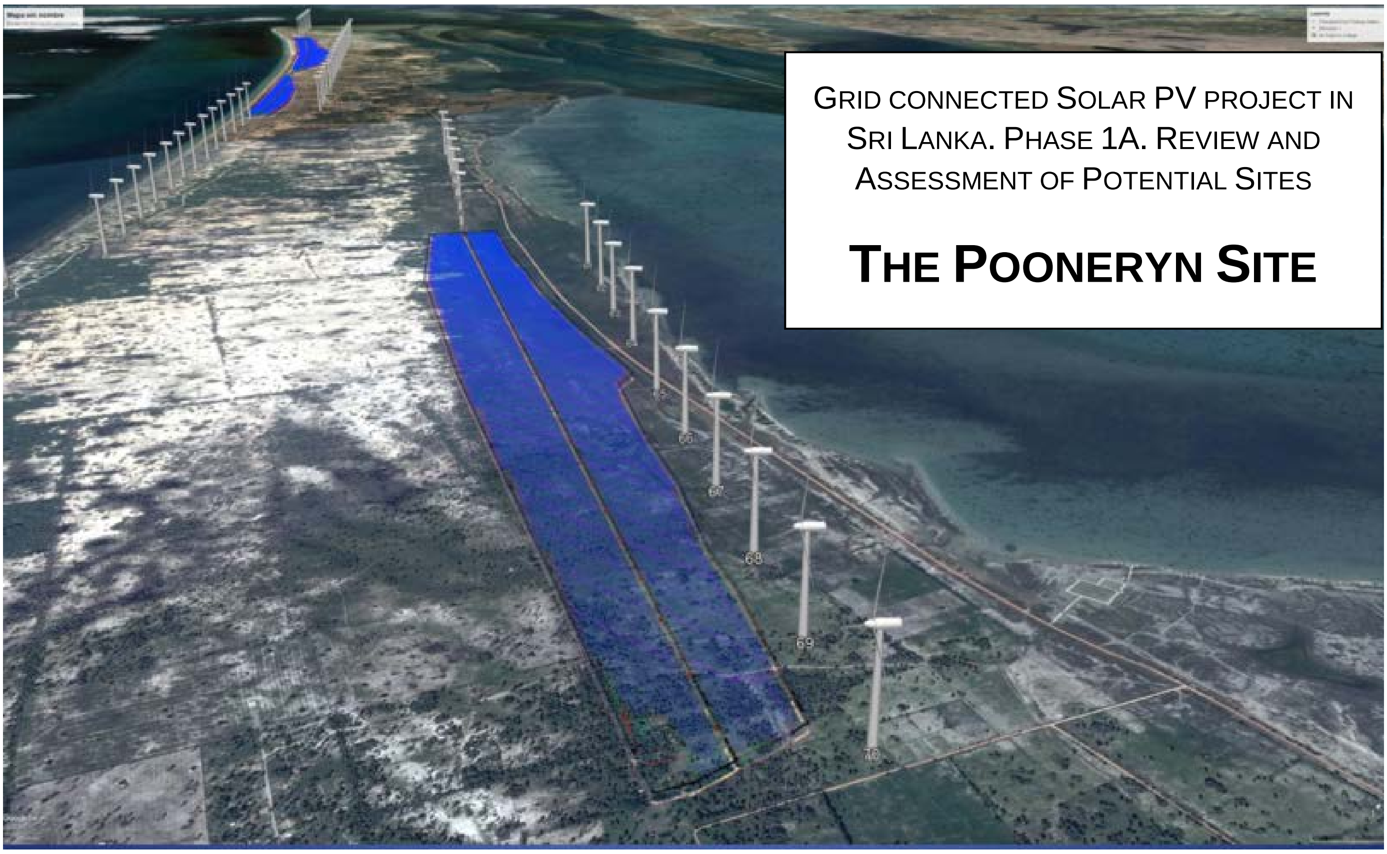

GRID CONNECTED SOLAR PV PROJECT IN SRI LANKA. PHASE 1A. REVIEW AND ASSESSMENT OF POTENTIAL SITES

THE POONERYN SITE

*

■ QUALITY CONTROL SHEET			
DOCUMENT	SP2530-IN-01-Phase1A-Assessment-of-Sites-Pooneryn Part Ed4		
PROJECT	Grid Connected Solar PV Project in Sri Lanka		
CODE	IFC project Contract 7182182		
AUTHOR	Initials	CGS/JPG	
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	Date	31st May 2018	
RECIPIENT	International Finance Corporation (IFC)		
NOTES	*Ed.2 First complete and reviewed, version submitted to IFC for review and comment*. The document covers the description of the Pooneryn site and provides an initial feasibility assessment about the deployment of sizeable utility-scale PV and a wind project. *Ed.3 Reviewed version, after consideration of comments provided by IFC/WB group, reordering sections, some new information and errata correction and syntax improvement* *Ed 4 Typo corrections, revoming duplicate table of contents*		

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EXECUTIVE SUMMARY

The International Finance Corporation (IFC) has been invited by the Government of Sri Lanka (GoSL) to provide transaction advisory services in relation to utility-scale solar Photovoltaic (PV) IPP (Independent Power Producer) projects In this framework, IFC has engaged TYPSA to provide consulting services in relation to energy engineering, environmental and social aspects.

The services to be provided by TYPSA are structured in two phases. Phase 1, refers to conducting due diligence on a number of candidate sites and supporting the preparation of the transaction structure. The first step, in Phase 1 is to assess the potential suitability of candidate sites, from the technical, environmental and social points of view. Results corresponding to this first step are reported in this document.

The Sri Lanka Sustainable Energy Authority (SEA) has been the nominated as the Agency responsible for providing candidate sites. Three sites had been proposed for consideration:

- Pooneryn site
- Monaragala sites 1 and 2

This edition of the document pertains to the Pooneryn site. A separate report has been published that covers the Moneragala sites (both in the Monaragala region, in the south-east part of the country).

The Pooneryn site is situated just west of the village of Pooneryn in the northern tip of the Island. The site offers attractive solar and wind resources for renewable energy generation. The site also exhibits distinct environmental values, mainly a rich dune landscape and several seasonal water bodies that interacting with the northern bordering lagoon to host a varied bird species population.

Typsa thinks that it is possible to find ways to develop the Pooneryn peninsula for renewable energy in economically attractive terms while reducing the environmental impacts to acceptable levels. Any such development needs to do the utmost to preserve the valuable dune environment in the Pooneryn peninsula and minimize the effect on the incumbent bird population.

These project development constraints need to be supplemented by considerations relative to available options to export the large quantities of electricity that would be generated in the Pooneryn peninsula.

As seen in this report, the 132kV line that joins the Kilinochchi and the Chunnakam substations offers, in the short term and at relatively low cost, a viable option to interconnect a future Gen-Tie line coming from the Pooneryn peninsula. This report proposes to do this by opening the existing 132kV line and setting up a new switching substation north of Kilinochchi, as a point of interconnection. Under this arrangement, in a relatively simple way, the Pooneryn peninsula should be able to significantly contribute to the energy availability in the northern part of Sri Lanka's grid.

The discussion about the export capacity of a new Gen-Tie line and the carry away capacity of the grid, needs to be completed with an analysis of the robustness of the grid at the point of interconnection. In other words, with a consideration of the ability of the grid to cope with intermittent, non-dispatchable power electronic converter base energy generation systems (such as solar and wind systems).

Short Circuit Power values at the point of interconnection can be used as a proxy to estimate the electrical grid strength, Short Circuit Power available at the Kilinochchi substation, is currently in the

range of 500 MVA. This leads us to suggest that solar a plant of some 100MW to 150MW could be taken in by Sri Lanka's grid as of now, without any significant reinforcements.
As a result of the interconnection and environmental circumstances relevant to the Pooneryn project, Typsa has proposed, and discussed with a variety of local stakeholders in Sri Lanka, a phased approach, by which there would be a first phase consisting of a large-scale solar PV plant at Pooneryn (up to 150MW) that would connect to the existing grid. And, second wind phase (up to 250MW), to be implemented once the Kilinochchi substation is linked via a new 220 kV line with the Vavuniya and Anuradhapura substations.

From a technical point of view, this phased approach can be made in a way by which almost all the equipment and infrastructure build for Phase I, will be kept and used during Phase II, thereby leading to an economically efficient project.

But, for the project to move forward in its entirety, the proposed approach needs to be made compatible with the environmental values of the Pooneryn peninsula. In this context, the first solar part of the project can be anticipated to have a reduced and manageable ecological impact. While, the second phase, the wind phase can only be undertaken once a proper detailed evaluation of the effects that a substantial wind turbine field would have on the bird communities in the area.

As a result, both interconnection and environmental criteria suggest that a sensible way to exploit the excellent energy resources in the Pooneryn peninsula would be to launch a solar project first and do so in a way that would allow starting later a large-scale wind project.

As a summary, our team thinks that it is possible to develop a large utility-scale renewable energy project in the Pooneryn peninsula, with both a solar and a wind component, that would improve the energy supply in the area, in an economically attractive way; and to deploy the assets in the ground in a form that would be respectful to the existing valuable environmental elements present in the Pooneryn peninsula and nearby areas.

TABLE OF CONTENTS

0. REFERENCE MATERIAL

0.A List of acronyms

CAPEX	Capital Expenditure
CEA	Sri Lanka Central Environmental Authority
CEB	Ceylon Electricity Board
CSP	Concentrated Solar Power
FDSL	Forest Department Sri Lanka
LCOE	Levelized Cost of Energy
MoPRE	Ministry of Power and Renewable Energy
OHL	Over Head Line
OPEX	Operational Expenditure
PV	Photovoltaic
SC	Short circuit
SCL	Short Circuit Level
SCR	Short Circuit Ratio
SEA:	Sri Lanka Sustainable Energy Authority
ToR:	Terms of Reference

0.B List of figures

Note: figure numbers are composed by two numbers separated by a hyphen (like a-b). The first indicate the document section where the figure is located and the second the order in which the figure is displayed in that section

0.C List of TABLES

Note: table numbers are composed by two digits separated by a hyphen (like a-b). The first indicate the document section where the figure is located and the second the order in which the figure is displayed in that section

1. INTRODUCTION

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This document just pertains to the Pooneryn site. A separate report has been published that covers the Moneragala sites (both located in the Monaragala region, in the south-east part of the country).

The Pooneryn site is situated just west of the village of Pooneryn in the northern tip of the Island. The site offer unique renewable energy possibilities, and it has been analysed as a site that could potentially host a combined large-scale solar and wind project.

The Typsa team has visited these three sites and conducted a series of meetings with SEA, Ceylon Electricity Board (CEB), the Central Environmental Authority (CEA), the Sri Lanka Forest Department (FDSL) and the Ministry of Power and Renewable Energy (MoPRE). As a result, Typsa has prepared a first assessment of the three candidate sites.

2. PROJECT BACKGROUND

Sri Lanka has been enjoying a fast economic growth for more than a decade with a GDP growth rate (in local currency units) mostly placed above the 4% mark for more than a decade (see figure 2-1).

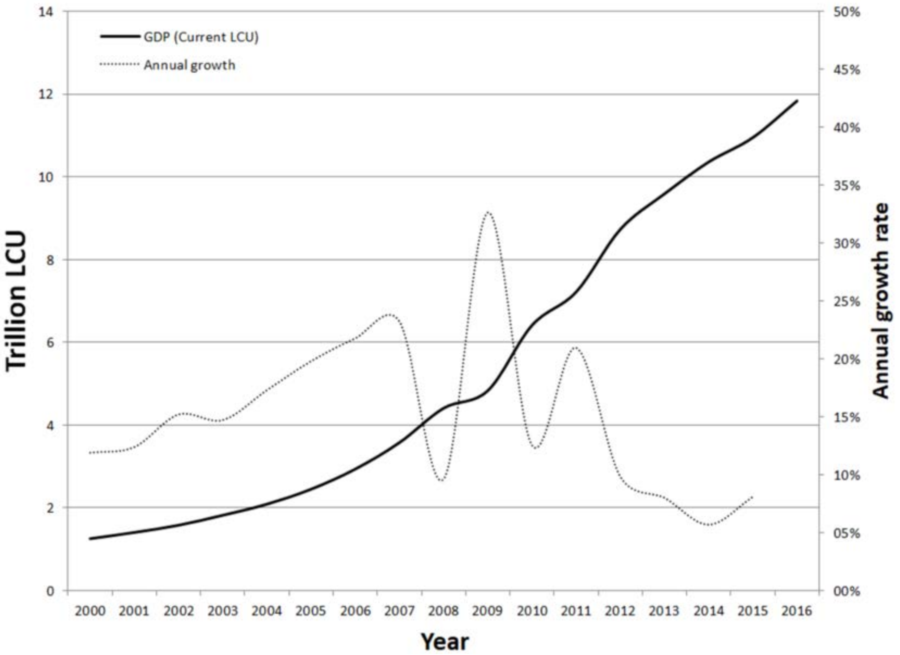


Figure 2-1 Evolution of the GDP in Sri Lanka

As a natural sequel energy demand has been growing (25% from 2005 to 2017), see figure 2-2. At the same time the power demand has been mostly met by conventional energy sources.

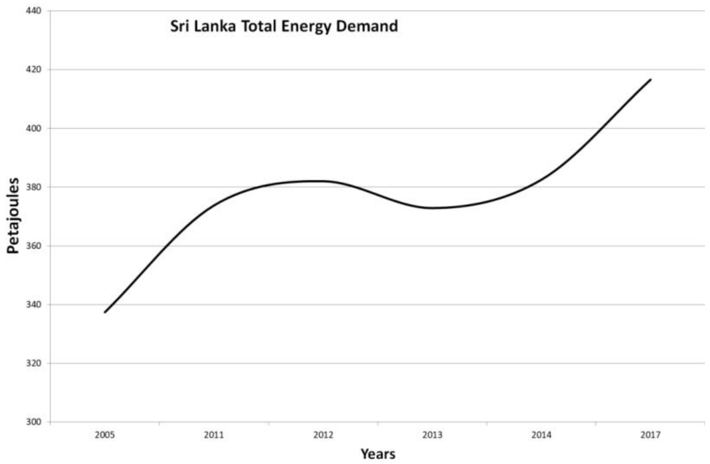


Figure 2-2 Yearly evolution of the energy demand in Sri Lanka

Sri Lanka primary energy generation mix is primarily based on a set of traditional sources, such as oil (39%), Coal (10%) and local biomass (39%). The electricity component of the energy mix is also significantly dependent on non-renewable thermal technology, as well as on major renewable hydro plants (see figure 2-3). Nowadays, renewable energy sources play a modest role in the electricity generation mix.

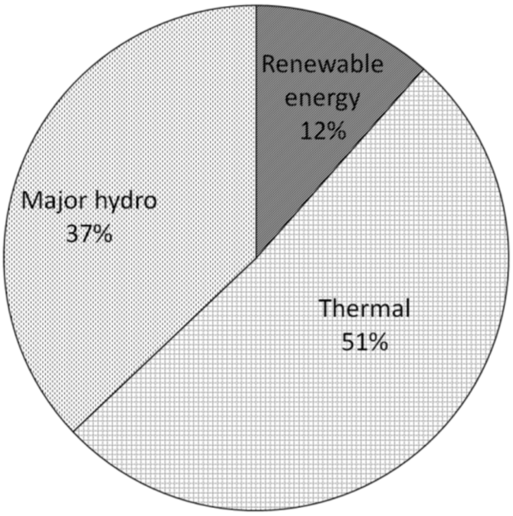


Figure 2-3 Sri Lanka Electricity Generation Mix (2015)

The described energy generation situation entails a high cost, both in terms of fuel imports and greenhouse emissions. As a result, the GoSL plans to augment the share of cost-competitive renewable energy sources, such as wind and solar.

In this scenario, IFC has been invited by Sri Lanka Sustainable Energy Authority (SEA) to provide transaction advisory services in relation to a solar Photovoltaic (PV) project of at least 100 MW.

This project would be structured as DBFOT, where a private sector actor will develop, build, finance and operate the project and SEA would provide access to suitable land resources. As part of this scheme, Ceylon Electricity Board (CEB) will purchase the generated electricity as per a Power Purchase Agreement (PPA). CEB would also cooperate in the development of the required transmission infrastructure.

CEB, is a state-owned integrated utility in Sri Lanka and system operator in most of the country. CEB's transmission system comprises of 220kV and 132kV transmission network interconnected to switching stations, grid substations and power stations. CEB generation is made of hydro, thermal and wind power plants connected to the transmission system at the above-mentioned voltage levels.

The total installed capacity of all hydropower stations owned and operated by CEB is 1377 MW. The total installed capacity of all thermal power plants owned by CEB is 1444MW. In addition, 671 MW of private thermal power plants are connected to the system.

Approximately 437 MW of embedded Non-Convectional Renewable Energy plants are connected to the national grid. Out of this, 288 MW of mini hydro plants, 128 MW of wind power plants, 19.6 MW of Wood fuel power plants and 1.4MW Solar power plants are presently connected to the system. At the end of

2014, total installed capacity of the system is 3932 MW. A representation of CEB's transmission system is shown below (figure 2-4):

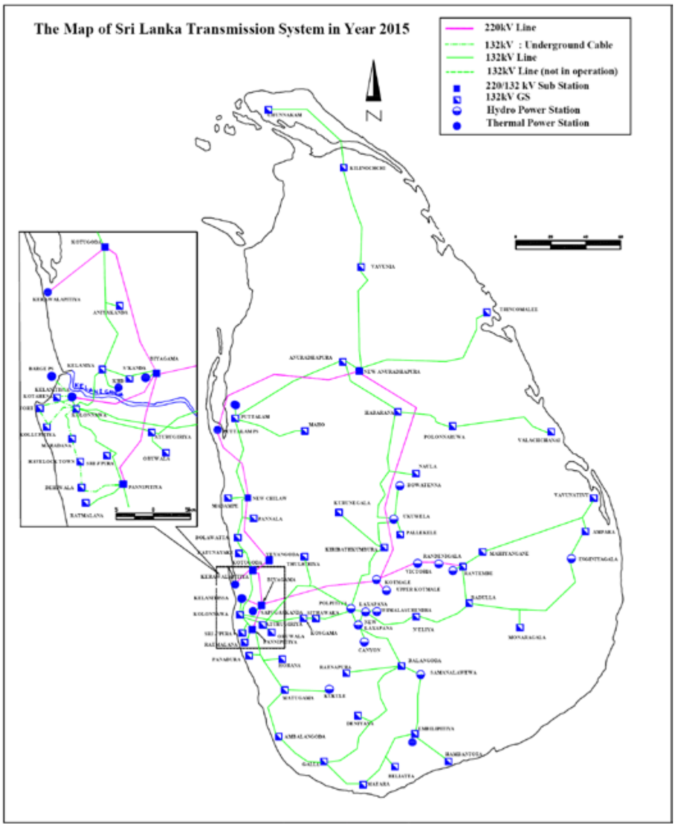


Figure 2-4 Sri Lanka 2011 electricity transmission system scheme

The Sri Lanka demand curve follows profile with typically two peaks, the highest one at night (19:30) with around 2100 MW and a second one during the day (11:30) with around 1750 MW (see figure 2-5):

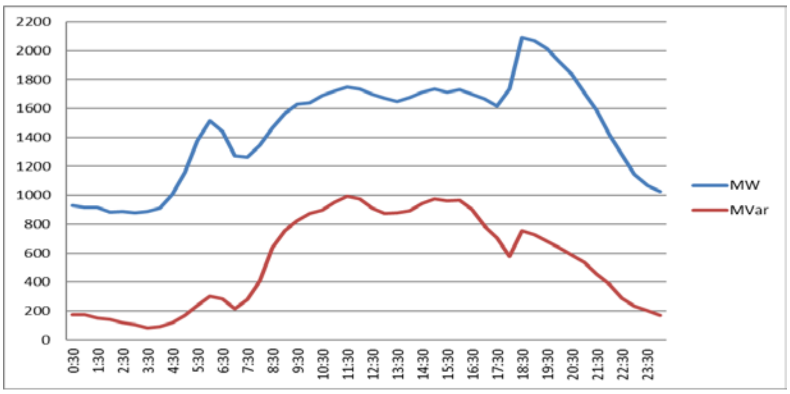


Figure 2-5 Sri Lanka typical electricity demand profile

Due to the expected growth of the electrical demand in coming years, CEB has prepared a long term investment plan in order to assure the demand coverage and grid stability through new generation (including renewable) and grid expansion and interconnections. In this context, some steady state and transient studies have been performed under different scenarios using PSS/E models of the grid.

To assure the safe connection of the new facilities (new generation and new significant loads) a grid code has been prepared (last version dated January 2018), that it is to supersede the actual CEB Guide for Grid Interconnection for Embedded Generators dated December 2000 (*this grid code is analysed by Typsa in a separate document, and briefly commented hereinafter).*

3. ACCOUNT OF STAKEHOLDER MEETINGS AND FIELD WORK`

Within the scope of this project, the Typsa team has visited Sri Lanka on three different occasions. In each of these visits, Typsa's team has: (i) had several meetings in Colombo with crucial stakeholders (ii) made field trips to the sites to conduct visual inspection.

3.1. MEETINGS

This is the account of the meetings held in Colombo during the three trips done, so far, in the course of the contract.

Trip #	Date	Stakeholder	Scope of the meeting
1	February 27th, 2017	IFC	Kick off meeting
1	February 27th, 2017	CEB	Discussion of the project program
1	February 27th, 2017	SEA	Discussion of the project program
1	March 2nd, 2018	CEB	Discussion of interconnection issues
2	December 21st, 2917	Ministry of Energy and CEB	Presentation of preliminary findings.
3	March 13th, 2018	SEA	Pooneryn combined project
3	March 14th, 2018	CEB	Discussion of interconnection issues
3	March 14th, 2018	Central Environmental Agency	Discussion with CEA
3	March 15th, 2018	CEB	Discussion of interconnection issues
3	March 15th, 2018	Ministry of Finance & Media. National Agency for Public-Private Partnership	Presentation of preliminary findings.

Table 3-1 Account of stakeholder interaction

3.2. BRIEF ACCOUNT OF FIELD WORK PERFORMED

Visit to all of the three sites was done in all cases, by a team consultants (2 or 3 consultants) from Typsa. The exact dates in which these sites visits where completed are shown here below:

Date	Site
February 28th and March 1st, 2017	Moneragala 1 site & Substation
December 19th and 20th, 2018	Pooneryn site & Kilinochchi Substation
March 14th and 15th, 2018	Moneragala 2 site

Table 3-2 Account of fieldwork dates

4. THE POONERYN SITE

In this report, the Pooneryn site[1] refers to an elongated peninsula some 19km situated just to the North-West of the Pooneryn town, in the Poonakary Divisional Secretariat of the Kilinochchi District in Northern Province. The peninsula looks like a bar, oriented in the North-West direction as seen from the Pooneryn town, having some 3km width in the section closest to Pooneryn and less than 1km width at the tip (see figure 4-1). It is a narrow sub-continent extending into the Indian Ocean that forms the southern boundary of the Jaffna Lagoon.

Figure 4-1 The Pooneryn Peninsula location relative to the Pooneryn town

The centre of the peninsula would be approximately located at coordinates 9º34’12.9”N 80º6’46.746”.

4.1. TOPOGRAPHIC AND GEOTECHNICAL FEATURES

The peninsula is mostly a flat bar of sand deposited on a substrate of limestone (the so-called *Miocene-Jaffna limestone*). The information gathered from public available sources indicate limestone is the common substrate to the north part of the Sri Lanka Island (see figure 4-2).

[1] Three sites have been proposed by SEA: the Pooneryn site and the Monaragala 1 and 2 sites. This edition of the report presents and discusses the Pooneryn site. The two Monaragala sites are both in the Monaragala district and relatively close to each other. As a result, there are some features which are common to both sites (e.g. the interconnection is to be done in both cases at the Monaragala substation).Description and evaluation of the Monaragala sites has been done in a separate report..

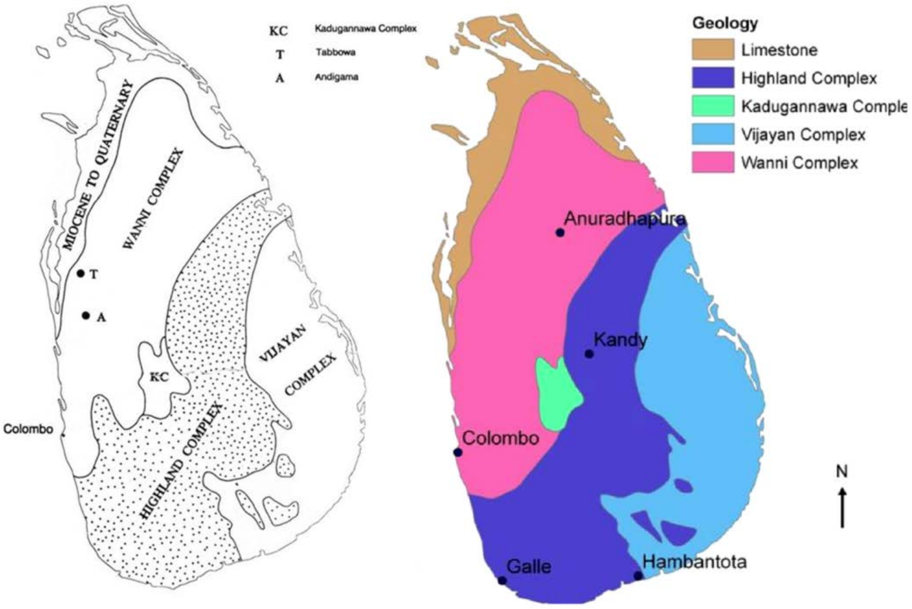


Figure 4-2 Geological maps of Sri Lanka

Within the Jaffna limestone area, typical of the north of the country, the Pooneryn peninsula exhibits unique aspects. In particular, the top layer appears to be mostly sand of unknown depth.

Figure 4-3 The top layer at the Pooneryn peninsula appears to be primarily sandy

It would be essential to assess the depth of the sandy layer and the phreatic level to eventually design the adequate foundation for any solar or wind project that the peninsula might host in the future. The only way to be precise about the depth profile along the peninsula would be to carry a geotechnical survey, perhaps using geophysical means and dynamic penetration methods.

During the background research conducted by Typsa, one of the topics we tried to gather some intelligence about was the risk of having the Pooneryn peninsula be affected by future tsunamis. Unfortunately, Sri Lanka has been subjected to devastating tsunamis in the past (e.g. the 2004 tsunami) so this is an aspect to which some consideration should be given.

The 2004 tsunami affected the Pooneryn area (see picture 5-4), even if it was not the area most exposed to the phenomenon (see Figure 4-4). Tsunami risk could be an aspect to consider while conceiving the facilities to be hosted in the Peninsula. It could also be an aspect to consider at the time of incorporating insurance policies into any future project in the area.

Recently, some new findings seem to indicate that risk of earthquakes and tsunamis might be higher than what has been traditionally considered. Sri Lanka lies in the large Indo-Australian plate seemingly far away from any of the plate boundaries. This has made people to think that Sri Lanka was relatively safe from earthquakes. However, recent geological studies, most notably by James Cochran of the Lamont-Doherty Earth Observatory, have found evidence for a long-suspected geological phenomenon: The Indo-Australian plate could be splitting, thereby severely increasing the exposure of Sri Lanka to future earthquakes and tsunamis (see figure 4-5).

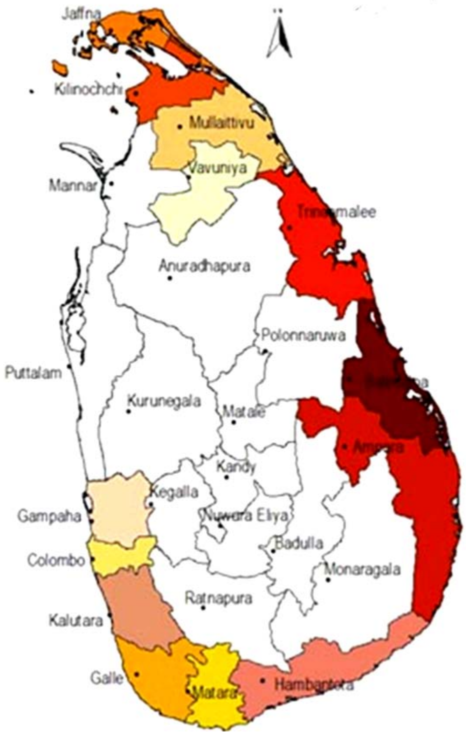


Figure 4-4 Intensity of affection of the 2004 Tsunami

In case a tsunami reaches the Jaffna region, the Pooneryn peninsula would be greatly exposed. Its low altitude and long and narrow profile suggest that the whole peninsula could be swept by waves. This is a type of risk for which might be better dealt via insurance, as building protection structures might be inordinately expensive and environmental inconvenient.

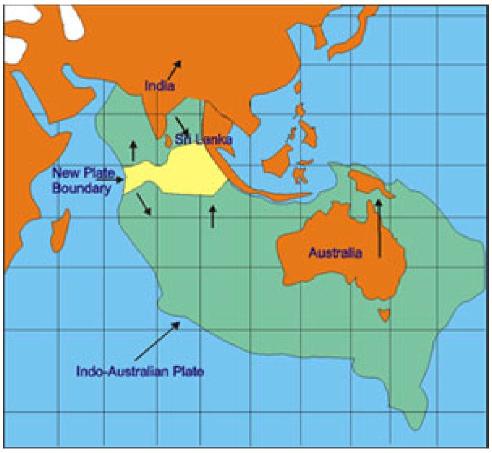


Figure 4-5 Potential location of a new tectonic plate near Sri Lanka

The peninsula, as of today, presents a distinct topographic feature. Almost all along the peninsula it is easy to find substantial sand dunes. Some of these dunes reach several meters high. They are entrenched with bushes and grown-up vegetation. During the rainy season, small water bodies can be found within the dune area. Most of these sand dunes are grouped in the central part of the peninsula. The figure below provides a representation of the sand dunes field (kindly provided by SEA)

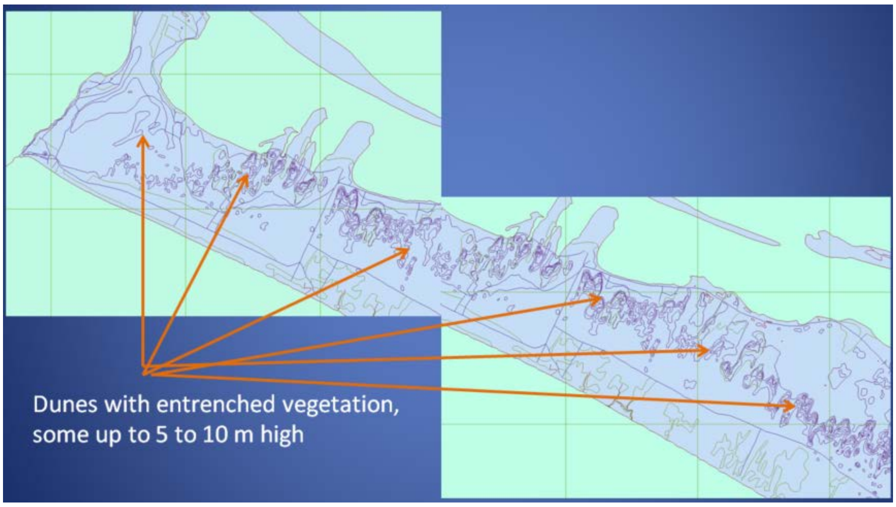


Figure 4-6 Topographic representation of the dune field (kindly provided by SEA)

A circular dirt road almost entirely circles the peninsula (see picture 4-7). On the southern rim of the peninsula and on the south side of the circling dirt road the terrain appears to be sand beach, where sand, pebbles and some seashells can be observed. The southern beach varies in width, from being just tens of meters to some 400 meters at this widest point. At the very tip of the peninsula, one can find the Kai Munai Naval facility. The northern rim of the peninsula differs from the southern rim. The circular dirt road is, in general terms, closer to the shore in the northern rim and the beaches tend to be smaller in width. At the northern rim road comes closer to Pooneryn, the terrain flattens showing some wetlands (in the rainy season) free of higher vegetation. The pictures below, obtained by the Typsa team while traversing the peninsula, illustrate some of the described features.

Figure 4-7 Ring road around the peninsula, showing location of the Navy facility


Figure 4-8 Views to the north of the southern rim road

Figure 4-9 Three views to the south of the southern rim road

Figure 4-10 Views to the north of the northern rim road

As indicated above, SEA has acquired some relevant information about the dune profiles in the peninsula. In addition, generally accessible tools, like Google Earth allow us to get a complementary idea of how relevant this phenomenon is in the peninsula. The pictures that follow show profiles and images that should be self-explanatory.

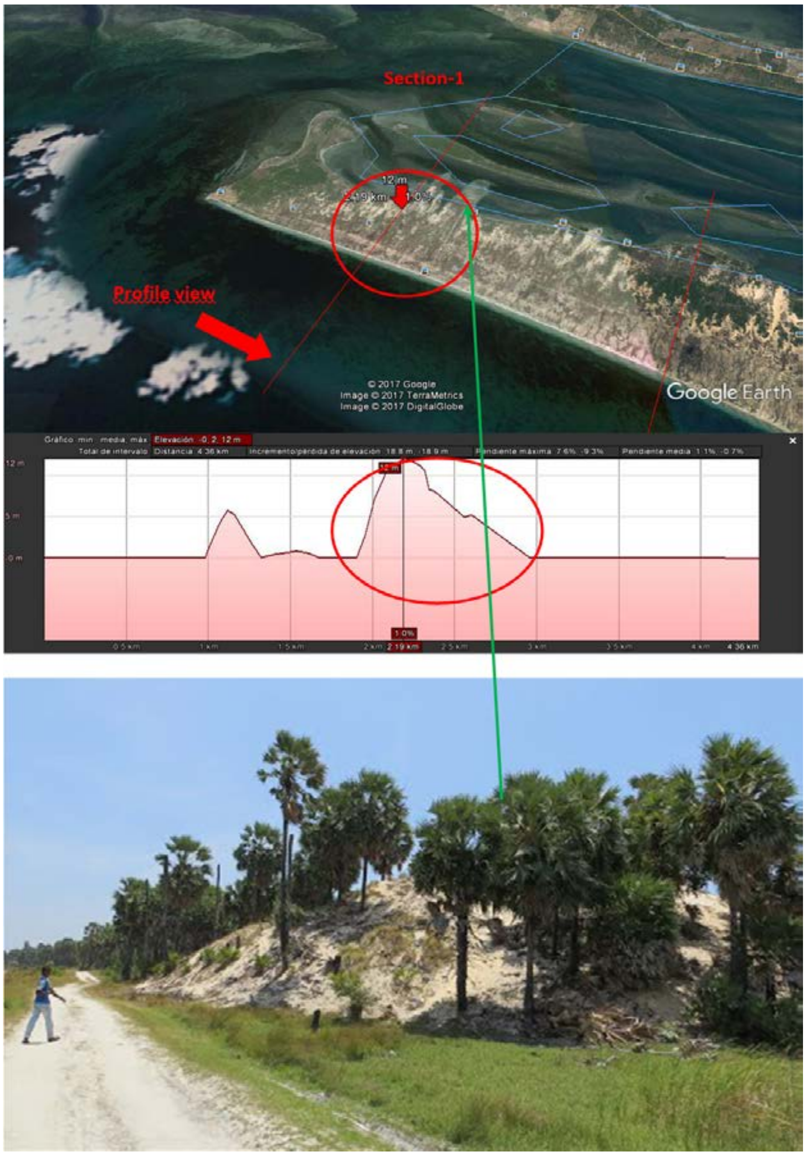


Figure 4-11 Section 1 profiles obtained from Google Earth

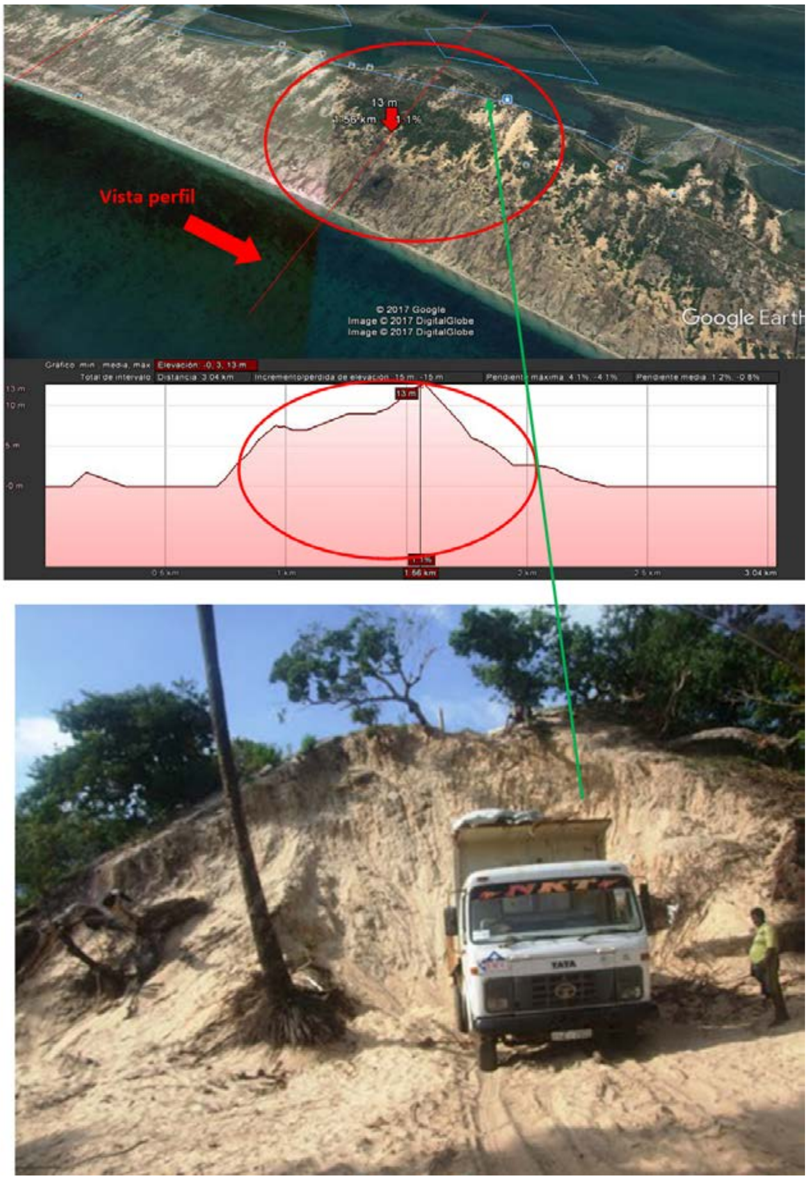


Figure 4-12 Section 2 profiles obtained from Google Earth

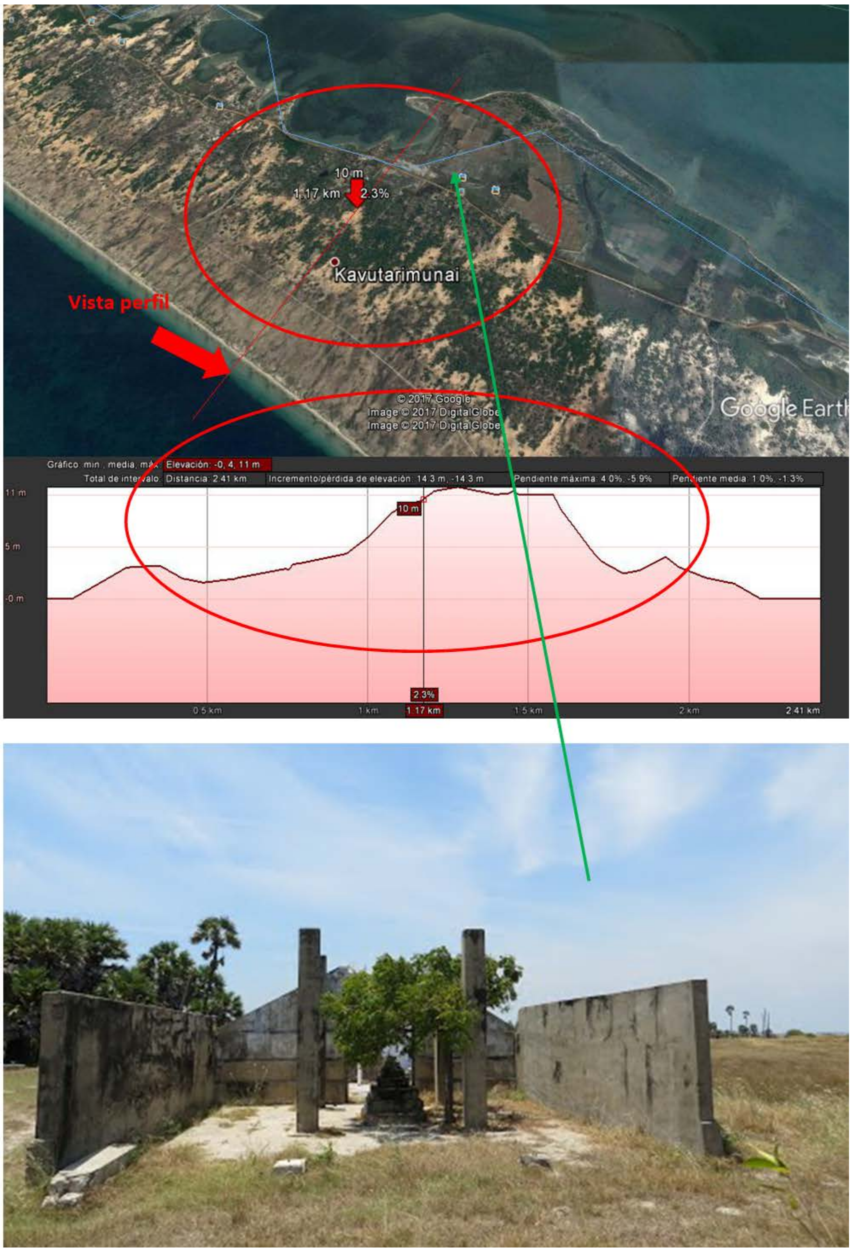


Figure 4-13 Section 3 profiles obtained from Google Earth and example of constructions in the peninsula

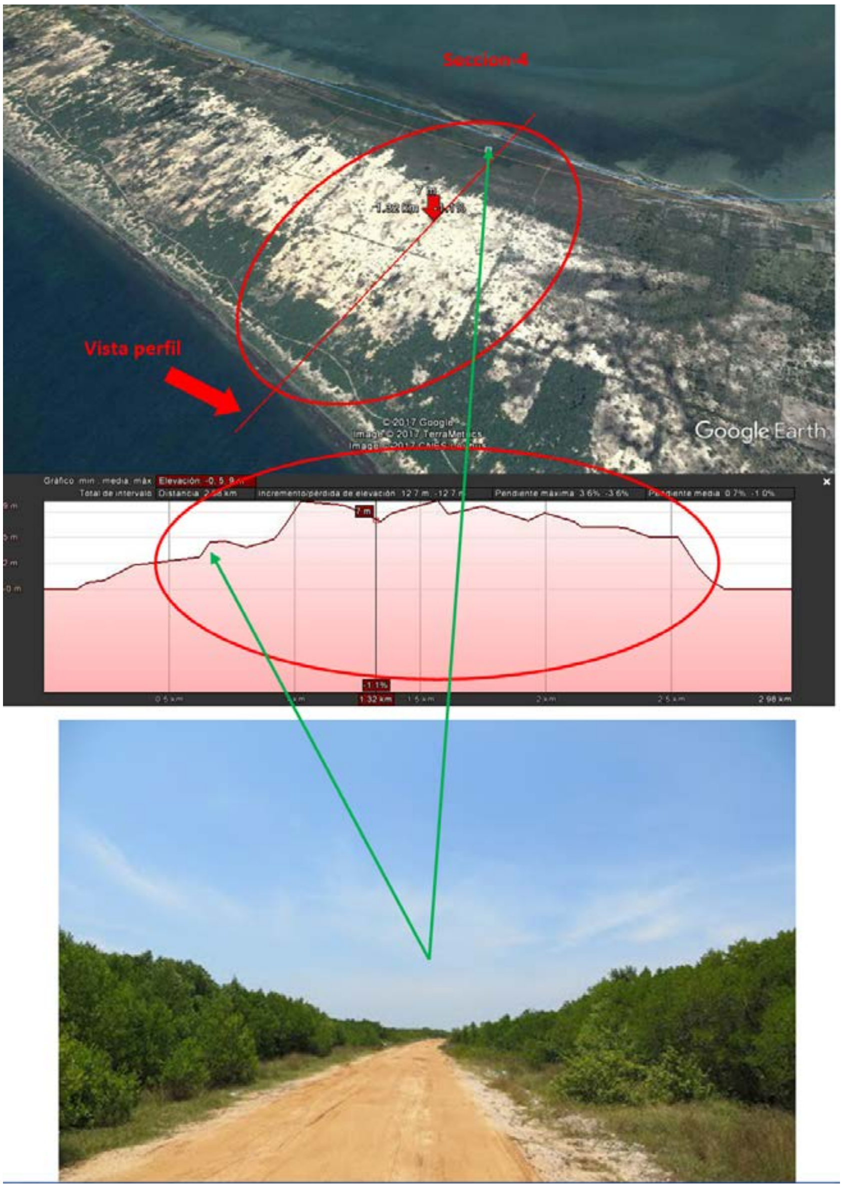


Figure 4-14 Section 4 profiles obtained from Google Earth and view of ring road

The information gathered during our visit to the site and the information received from other sources clearly confirm that dunes are a very relevant widespread phenomenon in the Pooneryn peninsula and that they need to be taken into account when planning the facility on the area. The significance of dunes from the environmental perspective will be discussed later in this document.

4.2. SITE ACCESS

Access to the Pooneryn peninsula is easy. The town of Pooneryn is traversed by the A32 coming from the south and reaching the Jaffna peninsula. From the west, Pooneryn can be reached via the B357 road. All these road are asphalt roads in good condition

Figure 4-15 View of the A32 road at the south of Pooneryn (looking north)

From the town of Pooneryn, the peninsula can be entered by different routes. These are dirt roads in reasonable condition[2]. As described above, ultimately a dirt road circulates the peninsula. There are some additional dirt roads that allow crossing the peninsula at various points, thereby connecting the southern and northern borders of the peninsula. The pictures above and below illustrate some of the relevant features

Figure 4-16 Access to the peninsula from Pooneryn town. Inset shows status of circular dirt road at the indicated point

[2] For transporting large components, such as wind blades, some of the roads might need reconditioning. This should be a future specific study to be conducted in anticipation of the wind farm component of this project.

4.3. GENERAL ENVIRONMENTAL ASPECTS

As mentioned, the landscape of Pooneryn Region is characterized by sandy flat areas close to the beach side, sand dunes built up to the height of several meters predominantly located in the middle section and the lagoon side which are created due to strong incoming Southwest monsoonal winds. Further, scrub forest, stunted dry forest, Palmyra covered areas, coconut plantations, mangroves and salt marshes are the other land uses types that can be seen in this site.

The site can be described as a relatively undisturbed area due to low human density. Most of the landscape is covered with natural habitats. A brief description of the major habitat types present in the area is given below.

- **Sand dunes**: Middle portion of the sub-continent comprise of sand dunes. The vegetation in such sand dunes is dominated by Borassus flabellifer and other thorny scrubs, which are sparsely distributed. During rainy season, many herbaceous species appear on the sand. The ground orchid, Habenaria viridiflora Tacca chantrieri, Heliotropium zeylanicum are some of the noteworthy species observed during the preliminary survey. Depressions located at the base of dunes collects fresh water during the rainy season, which provide habitats for birds.

- **Sand bar**: A small portion of the southern part at the very tip of the sub-continent comprise of this habitat. There are no trees or shrubs in this habitat which is dominated by grasses and sedges. Ground level is almost at the sea level. Hydrophylax maritima, Fimbristylis triflora, Fuirena uncinata, Cyperus arenarius, Cyperus bulbosus, Sesuvium portulacastrum, Trianthema portulacastrum are some of the noteworthy species observed.

- **Scrub forest**: Part of the sand dunes and the basal area of the sub-continent support this habitat type. Canthium coromandelicum, Benkara malabarica, Catunaregam spinosa, Carissa spinarum, Ehretia laevis, Gymnosporia emarginata are some of the noteworthy species observed.

- **Stunted dry forest**: Scrub forest at the basal area of the sub-continent gradually changes in to a stunted dry forest towards the mainland. This area consists of scrubs intermixed with some trees species, which are very much shorter than their typical condition. Manilkara hexandra, Drypetes sepiaria, Diospyros montana, Strychnos nux-vomica, Ochna obtusata, Diospyros vera, Canthium coromandelicum are some of the noteworthy species observed.

- **Mangroves**: Most of the coastal belt on the Northern side of the sub-continent contains this habitat type. It expands until it reaches villages towards the mainland. Some trees are reach up to 20 ft. Avicennia marina, Avicennia officinalis, Pemphis acidula, Lumnitzera racemosa, Scyphiphora hydrophylacea, Rhizophora mucronata, Scaevola taccada are some of the noteworthy species observed.

- **Salt marshes**: Salt marshes occur in the low-lying areas among mangroves. Suaeda maritima, Suaeda monoica, Suaeda vermiculata, Halosarcia indica, Cressa cretica are some of the noteworthy species observed. It serves as a good habitat for wading birds.

- **Floral assemblage**: Floral assemblage comprise mostly of common species. Recently, a ‘possibly extinct’ plant species Suriana maritima, has also been recorded in this area. Further, several nationally threatened species including the endangered (EN) Heliotropium zeylanicum and vulnerable (VU) Manilkara hexandra and Strychnos nux-vomica was observed in this site during preliminary studies. In addition several species of nationally near threatened species were recorded in the mangrove and salt marsh habitats.

- **Faunal Assemblage**: The faunal assemblage is dominated by birds. In addition number of butterfly and dragonfly species was recorded in the site. Also the endemic lizard species Sitana devakei was also recorded Pooneryn. Bird species that will trigger critical habitat criteria are presented later below.

4.4. CRITICAL BIRD SPECIES ASSESSMENT FOR THE PROPOSED POONERYN SITE

The project currently under consideration for the Pooneryn peninsula could include the installation of significant new wind capacity (details will be provided later below). One of the usual environmental risks associated with wind projects is the potential affection to bird habitats or bird migration routes.

At present only a preliminary set of data is available on the site since no detailed assessments have been undertaken to date. Based on the available data species that may trigger critical habitat requirement based on IFC guidelines are presented here. For this purpose critical habitat has been defined based on the IFC Guidance Note 6: Biodiversity Conservation and the Sustainable Management of Ecosystem Services and Living Resources (GN6)[3] as follows:

"*Critical habitat is a subset of both natural and modified habitat that deserves particular attention. Critical habitat includes areas with high biodiversity value, including areas with the following criteria:*

(i) Habitat of significant importance to Critically Endangered; and/or Endangered species, endemic; and/or restricted-range species; and globally significant concentrations of migratory species, and/or congregation species;

(ii) Areas with regionally unique and/or highly threatened ecosystems; and

(iii) Areas which are associated with key evolutionary processes."

It should be noted that at this point only identification of species that may trigger critical habitat criteria are flagged. However, this list have to be qualified based on detailed block counts carried out within site in order to determine the habitat usage patterns of these species within the proposed development area to actually determine whether the proposed development will have a direct or indirect impact on critical habitats based on the definition given above.

A list of species that have been observed in the Pooneryn project area based on recent bird studies that may trigger the critical habitat criteria are listed in the table below along with their Global and National conservation status and the reason they are considered critical species.

[3] http://www.ifc.org/wps/wcm/connect/c2815b0049800a9fab72fb336b93d75f/Phase2_GN6_English_clean.pdf?MOD=AJPERES

Scientific Name	Common Name	IUCN Global Red List[4]	SL National Red List[5]	More than 1% of the flyway population
Anas poecilorhyncha	Spot Billed Duck	LC	CR	Nationally important concentration of nationally critically endangered species
Sterna nilotica	Gull-billed Tern	LC	CR	Nationally important concentration of nationally critically endangered species
Pelecanus philippensis	Spot billed pelican	LC	NT	>1% of global population
Anas acuta	Northern pintail	LC	NE	Ramsar Criterion 5
Phoenicopterus roseus	Greater flamingo	LC	NE	Ramsar Criterion 5 and 6
Anas Penelope	Eurasian wigeon	LC	NE	Ramsar Criterion 5 and 6
Anas querquedula	Garganey	LC	NE	>1% flyway Population
Limosa lapponica	Black-tailed godwit	LC	NE	>1% of global population
Mycteria leucocephala	Painted stork	LC	NT	>1% of global population
Platalea leucorodia	Eurasian Spoonbill	LC	LC	>1% flyway Population
Threskiornis melanocephalus	Black-headed Ibis	LC	NT	>1% flyway Population
Charadrius alexandrinus	Kentish plover	VU	LC	>1% flyway Population
Calidris minuta	Little stint	LC	NE	>1% of global population
Tringa stagnatilis	Marsh sandpiper	LC	NE	>1% of global population
Larus brunnicephalus	Brown headed gull	LC	NE	>1% flyway Population
Tringa tetanus	Lesser Crested Tern	LC	NE	>1% flyway Population

Table 4-1 List of species that have been observed in the Pooneryn Peninsula

4.5. SOCIAL ASPECTS

Pooneryn area does not support a large human population or an intensive economic activity. Several isolated fishing villages are located along the northern shoreline. During our exploration, some fishing equipment was also seen at isolated spots on the southern coast of the peninsula. During our visit, some isolated constructions could be seen in the inside of the peninsula. The use of these building did not result become apparent by mere observation from the outside. Our team was told that some of those building could be used for touristic purposes. In the central part of the peninsula, away from both the northern and southern coasts, our team could observer several fenced perimeters. It would seem that, at least part of these plots of land, would be dedicated to tree plantation.

4 IUCN (2016) IUCN list of threatened species. www. Iucnredlist.org

5 MOE (2012) The National Red List 2012 of Sri Lanka; Conservation Status of the Fauna and Flora. Ministry of Environment, Colombo, Sri Lanka. viii + 476pp.

The Pooneryn peninsula host, on its westernmost tip, a Sri Lanka Navy facility. Our team reached the gate of the facility during the visit. The operation of the facility should not be affected by any renewable energy facility.

A detailed inventory of economic activities in the peninsula has not been found and we believe it does not exist. At best, written records about land ownership and economic activity in the peninsula must deficient. The area has not been accessible to the Sri Lanka official institutions until the end of the conflict with the Tamil insurgents (in 2009). Our team was told that some of the historical owners of land in the peninsula might have flown away, making the completion of a proper cadastre difficult.

Our team understand that SEA has been conducting a survey in the peninsula. It would be useful to exploit such a study when completed, as the project eventually moves into a more detailed evaluation phase.

5. INTERCONNECTION OPTIONS FOR POONERYN

5.1. DISCUSSION ON GRID ROBUSTNESS

The amount of new intermittent renewable energy capacity that a node in an electrical grid can typically accept is dependent on the strength of the grid at the point of interconnection.

The strength of the electric power system is defined as the ability of the system to maintain its voltage during the injection of reactive power. In comparison with weaker systems, stronger systems will experience less voltage change following an injection of reactive power. Short Circuit Ratio (SCR), defined as the ratio of the interconnected grid's short circuit MVA (before connecting the generator) to the MW size of the interconnecting generator, has been utilized to quantify the strength of the electric power system with respect to the interconnecting generator. The lower the SCR, the weaker the electric power grid will be. Weak electrical systems become more troublesome when renewable sources with fast controllers are connected to them. This is due to the fact that the voltage/reactive power control loops within these electronic-based generation units are capable of almost instantaneous reactive power injection in response to any voltage change at the point of interconnection[6].

A first approach to estimating how much renewable energy capacity can be connected to a given node can be obtained by using the so called Short Circuit Ratios (SCR), arithmetically defined as follows.

SCR = Short circuit power at the POI (without generator) / Generation capacity

The short-circuit power at the POI naturally depends on the amount of generation and demand at any given moment in time. It is not, therefore, a constant value. The generation capacity also varies along the day. The use of the SCR ratio is then done, by looking for those scenarios where the conditions pose a threat to the grid stability. For a solar project, for example, that would be around the central hours of the day, when the solar generation can be expected to reach a peak. For wind projects, the assessment needs to include the night hours, where possibly both other sources of production and demand are in the low part of their daily profile.

Estimation of the short circuit power at any point in the grid can be done using a grid model. CEB has the Sri Lanka grid modelled using the well know PSS/E software and has information about the generation and demand scenarios typical of the Sri Lanka electricity power system. At our request, CEB has very kindly provided estimates of Short Circuit Level at various points in the electrical grid for two differente scenarios (see table 5-1 and 5-2 below). After reception of these data from CEB, the TYPSA team had also run the grid model obtaining similar values.

[6] Fast reactive power injection/absorption to a weak grid, characterized by high Volt/VAR sensitivity, may translate to un-damped voltage oscillations. Therefore, apart from the system strength, the speed of the voltage controllers associated with the renewable sources has an impact on the dynamic response of the renewable source and the stability of the interconnected grid. While reducing the voltage controller gain will slow down the voltage controller response associated with the renewable sources and could mitigate the voltage oscillations, it will also slow down the post-contingency voltage recovery. The balance between the post-fault transient voltage recovery and a stable response is critical to grid integration studies for renewable sources connecting to weaker portions of the grid.

The SCR values obtained can then be used as a proxy to do an estimate of the renewable energy generation capacity, by setting up some criteria about which are acceptable SCR ranges. The technical literature here does not seem to show unanimous rules about which are acceptable SCR values for solar or wind generation facilities. For example, Kundur (see reference 5) indicate that SCR above 5 denotes high system strength, whereas SCR between 3 and 5 would correspond to moderate strength situations, and values below 3 would signal weak condition. Kundur and others (see, for example 3) also suggests that with modern in the AC and DC control systems, SCR values above 3 could be considered as depicting a high stability scenario.

5.2. KILINOCHCHI SUBSTATION

The closest facility that could serve as a conduit for energy evacuation out of the Pooneryn peninsula would be in the vicinity of the Kilinochchi substation. The Kilinochchi node is relatively far away from the central area in Sri Lanka where most of the electricity generation and consumption happens to be located (the closest generation plants are, as mentioned in Jaffna). This suggests that there could be a limitation in how much renewable energy power (i.e. partly intermittent and non-dispatchable) could be connected to the currently existing 132kV system in the region.

The Kilinochchi substation is fed via a 132kV line that comes from Vavuniya in the South, and from Jaffna's Chunnakam Grid Substation in the North. In the recent past, the Jaffna peninsula was electrically isolated from the rest of the country. But as of 2013, a 67km long line has been erected that connects the Kilinochchi and Chunnakam substations. This new line had allowed integration of Jaffna's power plants (24 MW Uthuru Janani Power Plant owned by CEB and 18 MW privately owned Northern Power Plan) into the broader Sri Lanka grid system. The Kilinochchi substation allow power to be distributed to the region by means of various 33kV feeders

Figure 5-1 Aerial and side view of the Kilinochchi substation

As it might be guessed from the pictures (and confirmed during the site visit), the Kilinochchi substation has no empty space for a new entry bay. An alternative way to interconnect any new renewable energy generation coming from western Pooneryn area would be by means of a new switching substation that would open the existing 132 kV overhead line, at appropriate locations, e.g. North of Kilinochchi.

As indicated, CEB has very kindly provided our team with estimates of Short Circuit Level at various points (see table 6-1) relevant to the analysis done here (after reception of these data from CEB, the TYPSA team had also run the grid model obtaining similar values).

Voltage (kV)	Bus Name	Short Circuit Level (MVA)					
		Thermal Generation Maximum			Hydro Generation Maximum		
		Day Peak Load	Night Peak Load	Off peak Load	Day Peak Load	Night Peak Load	Off peak Load
132	Kilinochchi_132	563	563	526	538	536	519
	Vavuniya 132	909	909	849	884	878	830

Table 5-1 Current short Circuit Levels at various voltage levels and location in northern Sri Lanka

Short term, the connection of any new generation capacity in the Kilinochchi area would have to be done at 132kV. At this voltage level, the available SC power varies in the range [563-519] MVA.

5.3. FUTURE UPGRADE OF THE ELECTRICAL GRID IN THE AREA

CEB has a long-term investment plan which includes the extension of the 220 kV network up from the Vavuniya substation to a new N-Collector substation, to be situated on the northern outskirts of Kilinochchi. This new substation would bring additional resilience to the 132 kV grid. In particular, the SCR ratio should improve, with a positive effect on the ability of the grid to sustain intermittent non dispatchable renewable energy generation. One can imagine that at 132kV the new N-Collector substation (already connected to the 220kV line) could exhibit an SCL similar to the current 132kV at Vavuniya.

CEB shared with our team the document: "*Project Proposal for the Northern Transmission Infrastructure Development for Integration of Renewable Energy*" which describes an important grid upgrade proposal, The upgrade includes bringing a 220kV line from Vavuniya, leading to a significant improvement in the grid resilience.

An estimation of the SCL that would be available at the N-collector substation can be obtained by looking the to the current SCL values at the 220kV level in Vavuniya, or even better by running the grid model for the future N-Collector substation. Again, CEB very kindly has provided us with these estimates (see table 5-2), which were later confirmed by Typsa running the Sri Lanka' electrical grid model.

Voltage (kV)	Bus Name	Short Circuit Level (MVA)					
		Thermal Generation Maximum			Hydro Generation Maximum		
		Day Peak Load	Night Peak Load	Off peak Load	Day Peak Load	Night Peak Load	Off peak Load
220	Vavuniya_220	2083	2116	1950	2037	2030	1821
	N_Collect_220	1391	1406	1330	1370	1367	1269
	Pooneryn	1278	1290	1226	1260	1258	1174

Table 5-2 Future Short Circuit Levels at various voltage levels and locations in northern Sri Lanka

Estimated values at the N-Collector substation suggest that the maximum future renewable energy capacity that could be accepted at the node would be in excess of 300 MW (please refer to section 5.4. *Sizing Pooneryn solar and wind projects*, for further details). These estimates need to be confirmed by specific dynamic studies, that should take into account the possible interaction between the solar and the wind fields. The studies should explore the behaviour of the grid vis a vis a number of scenarios. The scenarios should be able to capture a variety of transient events; both originated in the grid itself or in the solar and wind fields.

5.4. SIZING POONERYN SOLAR AND WIND PROJECTS

The discussion above indicates that the Kilinochchi node would move from the current short circuit power values around 500 MVA to values around 1200 MVA once the 220kV link is completed. Assuming that 3 is desirable minimum value for the SCR metric (see discussion in section 5.1. above), one can derive the following tentative capacity scenarios:

- Phase I, using the current 132kV infrastructure
    - Short Circuit Level ~ 500 MVA
    - Maximum renewable energy capacity ~ 500/3 = 166 MW

- Phase II, using the future 220kV infrastructure
    - Short Circuit Level ~ 1200 MVA
    - Maximum renewable energy capacity ~ 1200/3 = 400 MW

So, our proposal would be to set an objective for phase I up to 150MW, with the potential addition of 250 MW during the second phase to reach the estimated maximum of 400MW.

Because the 132kV infrastructure is already in place, <u>the first phase could be initiated right away</u>. Should this first lot be solar or wind? We posit that this first stretch should be using solar PV technology for several reasons:

i. First, the solar plant can be quickly deployed with minimal environmental impact, implying no affection to the dune areas, neither requiring significant modification of the access roads and, quite notably, not impacting the bird population, and thereby not requiring a previous long term bird study.

ii. Second, there is an opinion among many experts[7], that solar plants when compared with wind farms can be integrated into weak electrical grid in an easier way. In other words, solar plants could work with lower SCR values. In the Pooneryn case, this general idea is reinforced because one can anticipate that a solar plant in the Pooneryn peninsula could lead to less abrupt

[7] PV projects can potentially mitigate voltage stability problems that are reported for that area and consequently increase the reliability of the transmission system. As short circuit levels are low, which means that the voltage in these areas is extremely sensitive to active and reactive power variations. Therefore, the ability of the PV project to control the voltage and to provide reactive power will be key to a successful integration of the PV project. Certain modern PV inverters have excellent reactive power control capability, which can greatly be used for voltage control. However, an increased reactive power capability is only available at additional costs (which is moderate) and therefore, corresponding requirements must be specified very carefully and implemented and monitored properly to ensure that the PV farm will actually deliver what was expected. PV inverters are even able to provide reactive power during night time.

fluctuations in the energy output than an equivalente wind farm, i.e. introducing smaller deviations from the forecasted active energy output.

Therefore, our proposal is to have a Phase I project involving some 150MW of solar PV and subsequent wind phase (Phase II) of 250 MW.

5.5. SRI LANKA GRID CODE

In March 2015, CEB has published a draft of a new Sri Lanka Grid Code. The latest revised version of this code is dated August 2016. The document is in a line with other modern grid codes found elsewhere in the world. A complete review of the document will be done within the current asingment and presented as a separate document (task ii within Phase 1A, according the ToR). In this section, we provide a summary of the grid access rules described in the latest version of the Grid Code document.

Section 3.17 of the code deals with the so called “Special connection requirements for intermittent resource based generating units”. The section would then apply to generating facilities based on both solar resources.

The code requires this type of generation facilities to comply with the Power Factor ranges given in the figure below

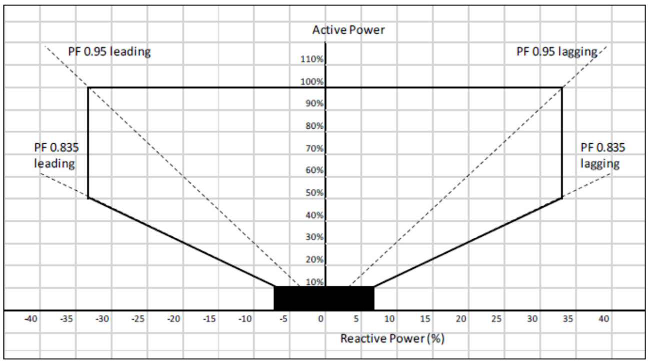


Figure 5-2 Power Factor Variation and Reactive Power Capability

These requirements are in line with requirements found elsewhere and can be dealt with by modern inverters.

The document indicates that f it may be necessary for intermittent generators to limit the maximum rate at which the power output changes in relation to changes in the intermittent resource. Therefore, power ramp up rate shall be able to be limited. But the document does not seem to pose a comparable ramp down control requirements on generators.

Curtailment request are described as possible, but there are not specific numbers to assess the possible impact of this procedure.

In summary, the current grid code does not seem to pose specially demanding burden on future solar or wind generators.

6. SOLAR PV AND WIND PROJECT AT THE POONERYN PENINSULA

6.1. CHARACTERISTICS OF THE POONERYN PENINSULA: A RENEWABLE ENERGY VISION

The Pooneryn peninsula is an especially attractive location for renewable energy projects. It presents a convenient road access; it has specific areas of flat and relatively clear terrain; it has (as it will be shown later) excellent wind resources, while at the same time, is located in the region where solar irradiation reaches some of the highest values in Sri Lanka. These attractive features need to be considered in conjunction with the significant environmental values of the peninsula, which should be preserved.

The combined solar and wind capacity potential of the peninsula is quite relevant (see the sections on solar and wind resource assement). However, as it is always the case, renewable energy capacity needs to be checked against the electrical grid capacity to absorb the energy output, and the ability of the grid to manage intermittency episodes.

Typsa has explored what would be the most effective and efficient way to exploit the renewable energy resources of the Pooneryn peninsula, in a way which would be compatible with the current status of the electrical grid in the north of Sri Lanka (see sections above). Our group as also explore, how the potential of the peninsula could be maximized in case the electrical grid in the north of Sri Lanka gets reinforced.

This exploration has to lead us to propose a combined solar and wind project, that would be deployed in phases, in sync with the upgrade of the grid in the region, and that would try to minimize the footprint and the overall environmental impact. Within this phased approach, <u>the solar project would be delivered first, as it is compatible with the current status of the electrical grid in the area</u>. <u>The wind project would follow, once the grid upgrades are in place and the corresponding environmental studies would be completed</u>.

6.2. TENTATIVE LAYOUTS OF THE SOLAR AND WIND PROJECTS

This section provides tentative solar and wind layouts. This proposal is not to be taken as describing the sole possible alternative on the Pooneryn peninsula, but one option that leads to good energy production values, while tries to minimize environmental impact.

In fact, as described elsewhere in this document, the central part of the Pooneryn peninsula presents distinct dune formations which have considered of environmental value. Our approach to producing tentative layouts has been to stay as far away from these dunes formation. As a result, for the solar fields we propose to use specific areas near the southern and northern beaches of the peninsula. Areas, that are in both cases away from the dunes and clear of the most valuable vegetation.

The sitting criteria for the wind turbines have been to ensure adequate production of the wind turbines, by avoiding wake effects. Also, the tentative selection of a 3.5MW Vestas turbine allows minimizing the number of turbines to locate for a given capacity objective. Finally, the sitting of the wind turbines has been produced so as to make the construction of operation of the wind park fully compatible with potentially pre-existing solar fields.

Our proposal for the solar fields can be easily grasped from the picture in figures below. The picture shows the allocation of a quite sizeable solar project, that complete avoids the dune fields. The capacity shown in the pictures corresponds to plants using fix tilt structures. The possibility to use tracking structure is left open until a more detailed account of the geotechnical conditions of the site is obtained.

Tracker structures would need more solid foundations, especially in a location like Pooneryn where high wind regimes are known to exist.

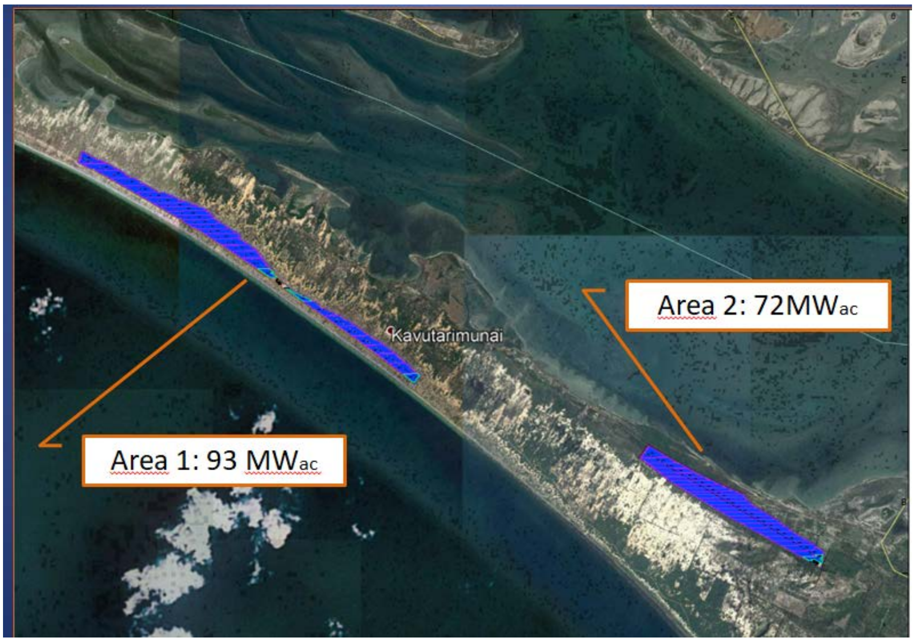


Figure 6-1 Overall view of the proposed solar layout. Fix tilt option

These layouts have been built using a conventional fix tilt structure. This type of structure can be set up with a variety of foundation options, something we suspect might be convenient given the apparent sandy soils in the peninsula. Each of the proposed production areas would be equipped with a step up substation that would produce output in either 132kV or 220kV. The picture that follows provides additional insight into the proposed approach

Figure 6-2 Close up of the fix tilt of the southern field and the corresponding substation

Please note that on the southern field all the field is placed south of the ring road, away from the dune area, and making use of the flatter and more clear terrain available in that part of the peninsula.

Figure 6-3 Close up of the fix tilt of the northern field and the corresponding substation

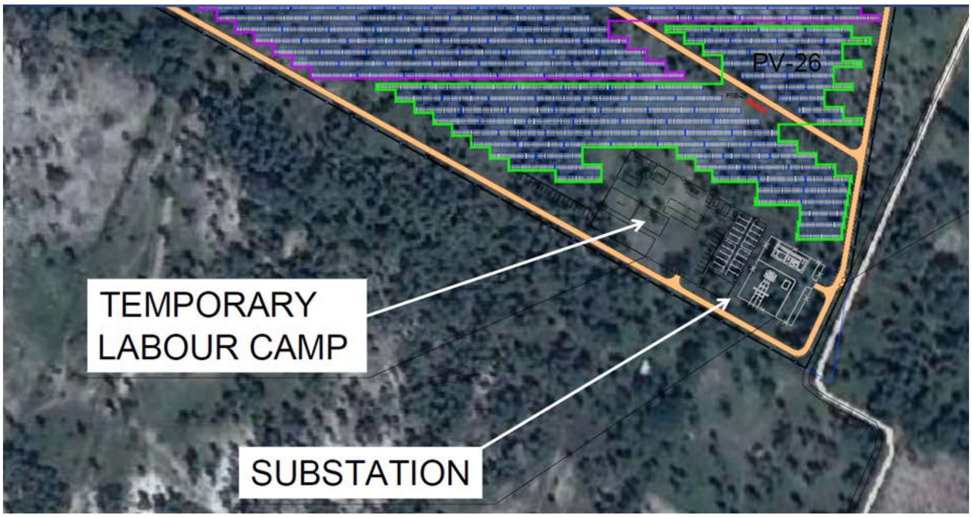


Figure 6-4 Close up of the fixed tilt of the northern field and the corresponding substation

Again, the layouts proposed should not be considered as the only option available, and they would not to be revisited in later phases of the project. Yet, they provide a good indication that a very sizeable solar capacity can be deployed in the Pooneryn peninsula without invading the central dune areas.

The summary of the proposed X-Si Fixed Tilt layouts can be presented as follows.

Southern solar field	Northern field
Total Peak Power: 92.862 MWp Total Inverter Capacity: 77.55 MVA DC/AC Ratio in POI: 1.29 No. Power Stations: 29 No. inverters: 55 Blocks: 26@2.82 MVA + 3@1.41 MVA Total fenced area: 114.62 ha	Total Peak Power: 86.108 MWp Total Inverter Capacity: 71.91 MVA DC/AC Ratio in POI: 1.29 No. Power Stations: 26 No. inverters: 51 Blocks: 25@2.82 MVA + 1@1.41 MVA Total fenced area: 118.75 ha
Common to both fields	
- PV Modules: 335 Wp - Fixed Structure - Tilt 15º	- 30 modules per string - 2 modules in portrait position - Pitch 7.50 m

Table 6-1 Tentative definition of south and north PV fields in Pooneryn

The siting of the wind turbines has been done with several criteria in mind: (i) minimization of the number of turbines (ii) avoidance of wake effects (iii) compatibility with the solar field, both during construction and operation. The overall approach can be envisioned paying attention to Figure 6-5.

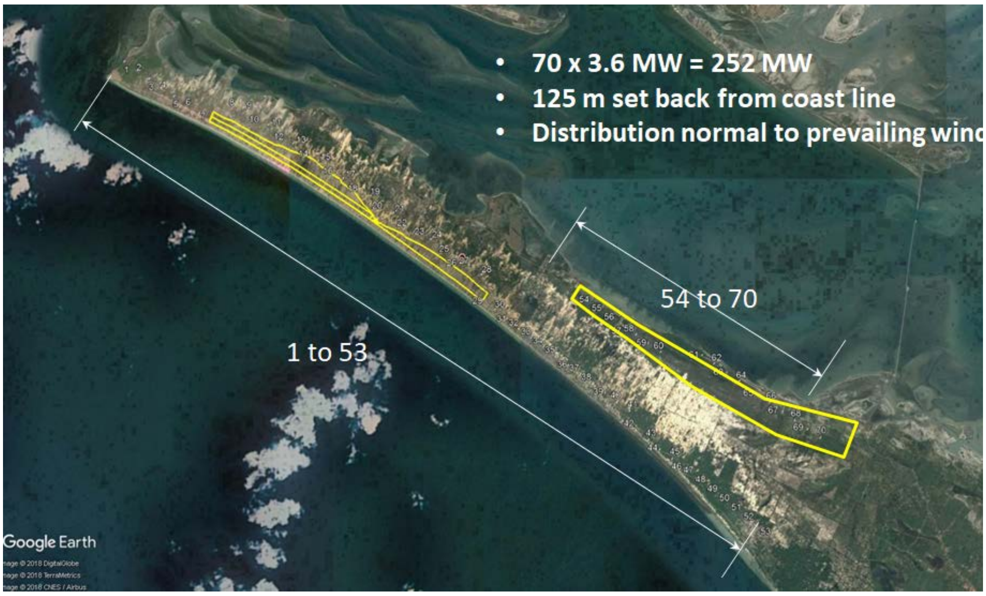


Figure 6-5 Overall view of the wind sitting strategy

The pictures below provides a panoramic view of the proposed combined solar and wind fields.

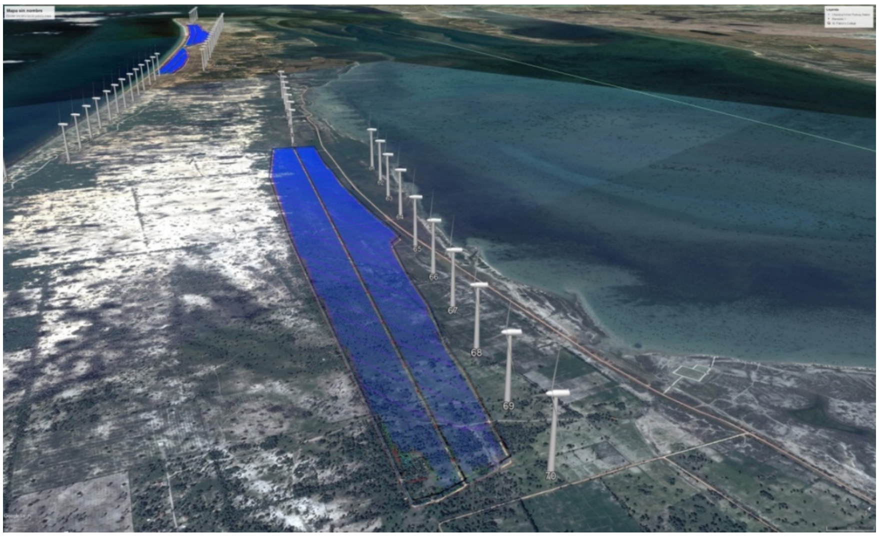


Figure 6-6 Overall view of the wind sitting strategy

It is important to note that the proposed layout should allow the erection of the wind turbines, even after the solar field is operational. The turbines are separated enough from the solar field to enable moving around the cranes. In fact, the Pooneryn situation is relatively simple when compared to other wind locations, where there is a much-reduced space to set up the platform (see Figure 6-7)

Figure 6-7 Turbines are sufficiently set apart from the solar field

6.3. INTERCONNECTION LAYOUT

6.3.1. Phase I at Pooneryn, the solar phase

A way to interconnect the PV generation (both the northern and southern sectors) to the current Sri Lanka electrical grid, would be by setting up a new switching substation that would open the existing 132 kV overhead line, at an appropriate connection North of Kilinochchi (in principle a location just north of Kilinochchi has been suggested by CEB)..

Under these conditions, the minimum interconnection infrastructures for the energy evacuation for Phase I, i.e. the solar phase, out of the Pooneryn project should include the following:

- Two step up substations (one per sector, the northern and southern rim of the Pooneryn peninsula) including the MV switchgear, one power transformer per substation, one transformer bay and 2 line bays 132 kV per substation, protection and control, auxiliary systems in AC and DC and telecom facilities.
- One 132 kV overhead line, 10 km estimated length, two circuits, on lattice towers, 2 x Zebra conductor and OPGW for fibre optics communications from sector A to sector B.
- One 132 kV overhead line, 35 km estimated length, double circuit, on lattice towers, 2 x Zebra conductors and OPGW for fibre optics communications from sector B to the new switching substation. This OHL should be designed for 220 kV (working at 132 kV in phase I) to allow the connection in phase 2 at the 220kV voltage level.
- One switching substation, to be located near Kilinochchi, 132 kV, with 4 line bays, including protection and control, auxiliary services in AC and DC and telecom facilities.

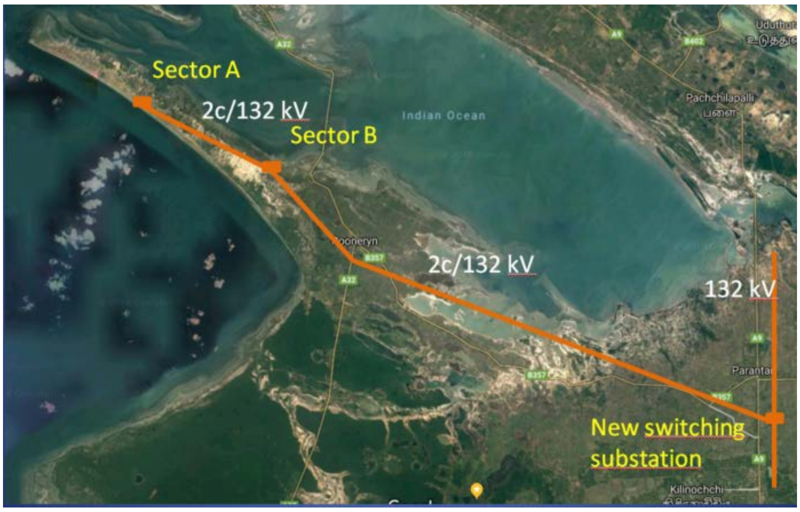


Figure 6-8 Potential evacuation route of Phase I (solar) project at Pooneryn peninsula

The topography between Pooneryn to Kilinochchi is mildly flat. From that perspective, no significant difficulties for the construction should be found. The issue of gaining rights to set up to tower and the service routes need to be explored in a subsequent phase of the project, as no information about land ownership in the area has been acquired to date. We suspect that a double circuit OHL from sector B to the switching substation embodies the option with a lower cost and environmental impact, but this should be confirmed by detailed calculation..

These tentative interconnection infrastructures may be modified or adapted in a further design step due to specific technical requirements of CEB or additional interconnection needs.

A simplified single line diagram corresponding to this first phase could possibly clarify the proposed conceptual scheme:

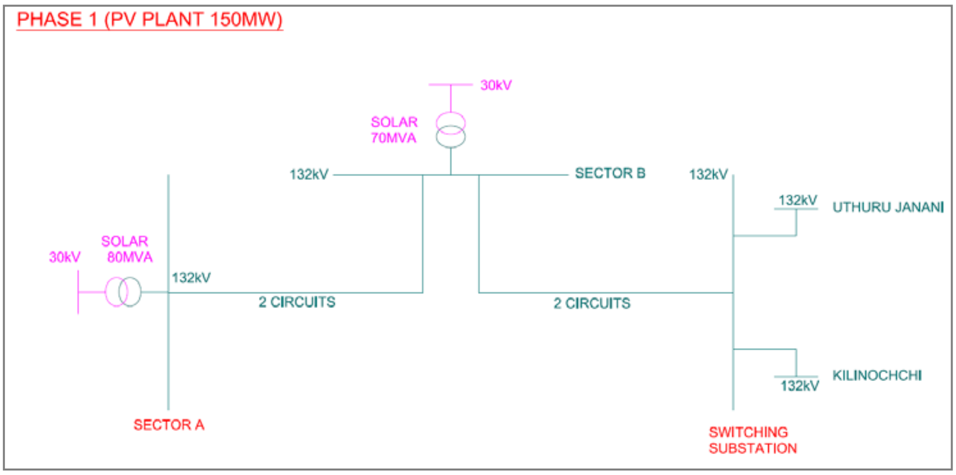


Figure 6-9 Simplified SLD showing connection of the first phase solar field

Note that the connection from the second solar step-up substation (the northern field substation) has been indicated to use either a 220kV or 132 kV infrastructure. Choosing one over the other is a matter of deciding how probable the wind farm phase is seen at this stage, and deciding how the balance between upfront CAPEX investment and reduced electrical losses play in the future. A 132kV line would be the less costly option now but could lead to higher electrical losses during the second phase of the project (the wind phase). This discussion is better addressed during the debate on the second phase scenario, where the wind capacity would be added.

6.3.2. Phase II at Pooneryn, the combined solar & wind phase

The overall proposed connection process moving for Phase I into Phase II would look something like

- The first phase with the solar PV plants in 2 sectors, as described, connected in 132 kV to the new switching substation as described above in section 0
- A second phase with the wind generation also in 2 sectors connected through extensions of the solar generation substations in 132 kV
- Construction of a new step up substation 132/220 kV and connection to the new N-Collector substation. This could be done in, at least, two different ways
    - o Option one would be set the 132/220 kV substation at the last step up substation in the Pooneryn peninsula site (Figure 6-10)

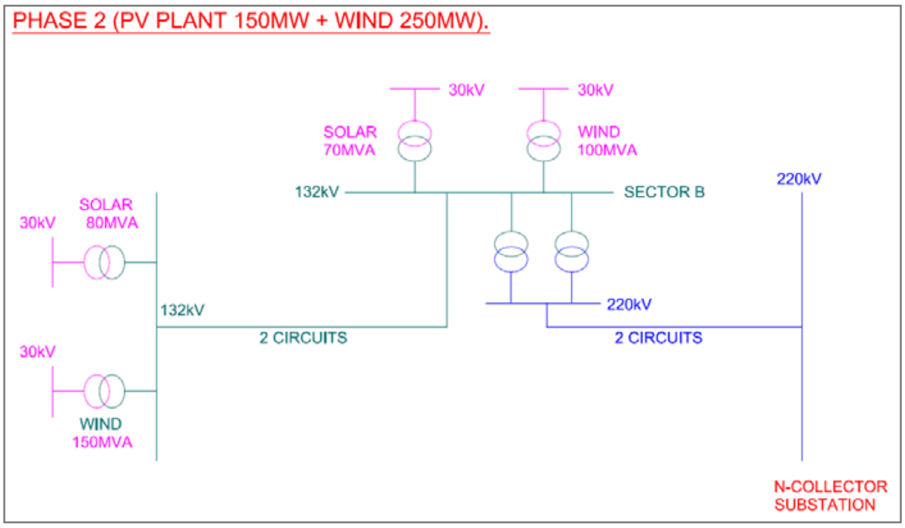


Figure 6-10 Simplified SLD showing connection a new 132/220 kV set up a substation to be located near the generation fields

- <u>Option 2</u> would be to do the export for both solar and wind in 132 kV and <u>do the step up at new N-Collector substation</u>. In this case, the first Gen-Tie line for solar would be done using less costly 132 kV circuits. <u>This option would lead to less investment in the first phase but more electrical losses in the second phase</u>. At the same time, this option represents a less risky approach as it will minimize upfront cost, being less sensitive to a potential delay or cancellation of the second wind phase project.

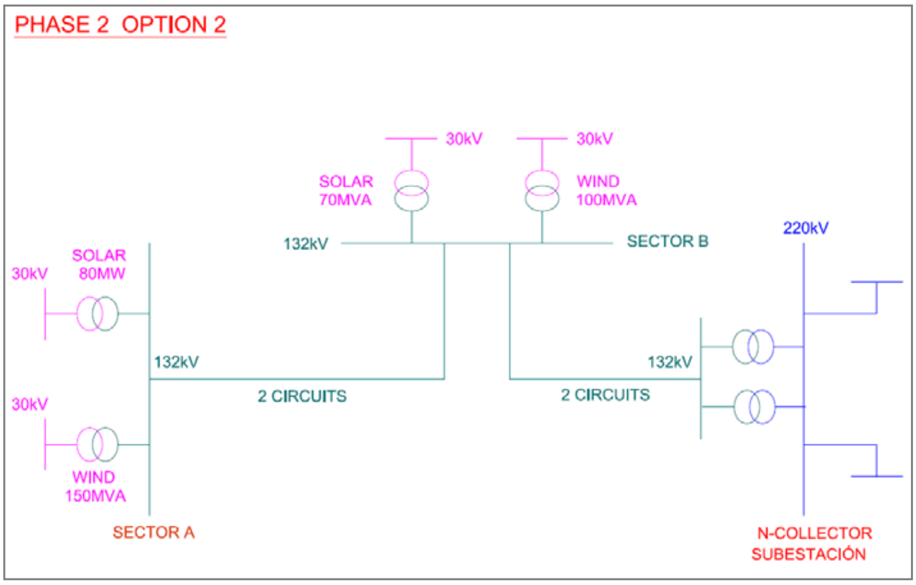


Figure 6-11 Simplified SLD showing connection a new 132/220 kV set up substation to be located at N-collecto substation at Kilinochchi

- To make a decision about which is more adequate <u>scenario, a grid impact study and an evaluation of the CAPEX / OPEX involved in each of the options need to be done. We propose to further develop this point, during the next project phase, in close collaboration with CEB</u>.

Considering the design leading to less electrical losses during Phase II, (connection in 220 kV to N-Collector substation and 132/220 kV step-up transformers in sector B), it would make sense to design the OHL in 220 kV from the very beginning but using the 220kV line in 132 kV during phase 1 (the solar phase).The additional infrastructures to be considered for this second phase shall be as follows:

Option 1 for Phase II interconnection	Option 2 for Phase II interconnection
Extension of Sector A substation with the wind connection infrastructures (one 132 kV transformer bay, one 132/30 step-up power transformer, medium voltage system, auxiliary services and protection and control)	**THE SAME**
Extension of sector B substation with the wind infrastructures and step up to 220 kV (two power transformers, two 220 kV line bays, auxiliary services and protection and control)	Extension of sector B substation with the wind infrastructures
Extension of N-Collector substation (two line bays, auxiliary services and protection and control).	Extension of N-Collector substation (two line bays). step up to 220 kV (two power transformers 132/220 kV, 132 kV transformer bays) auxiliary services and protection and control)
Displacement of the OHL connection in the 132 kV switching substation to the new 220 kV N-Collector substation.	**THE SAME**

Table 6-2 Interconnection infrastructures to be considered for second phase fields in Pooneryn

An upfront consideration of the future phase 2 (solar & wind project) should lead to including the following aspects:.

- Sector B substation must consider the changes related to the new step-up power transformers and connection in 220 kV.
- OHL from sector B to the switching substation should be designed for 220 kV from the beginning.

In this way, most of the infrastructures will be valid for phase 2 (solar & wind projects). Only the 132 kV switching substation will remain disconnected but operational for CEB future needs (i.e. integration into the new N-Collector substation).

6.3.3. Interconnection overview and complementary interconnection discussion

As indicated, there are some elements of the proposed interconnection scheme that ought to be refined. Such a process needs to be undertaken in conversation with CEB and should take into consideration the following criteria:

a) Investment done during Phase I (the solar phase) of the project should be usable during Phase II (the wind phase). The tentative approach proposed in this document already takes this criteria into account. The following table might help in making this feature of the proposed solution clearly visible

Interconnection infrastructure plan	
Phase I Solar	**Phase II Solar + Wind**
Two step up substations (one per sector, the northern and southern rim of the Pooneryn peninsula) including the MV switchgear, one power transformer, one transformer bay and 2 line bays 132 kV, protection and control, auxiliary systems in AC and DC and telecom facilities.	**RETAINED**
One 132 kV overhead line, 10 km estimated length, two circuits, on lattice towers, zebra conductor and OPGW for fibre optics communications from sector A to sector B	**RETAINED**
One 132 or 220 kV overhead line, 35 km estimated length, double circuit, on lattice towers, zebra conductors and OPGW for fibre optics communications from sector B to the new switching substation. This OHL should work at 132 kV in phase 1. In Phase II Option 1 it will work in 220kV- Phase II Option 2 it will continue work in 132kV.	**RETAINED**
One switching substation, 132 kV, with 4 line bays, including protection and control, auxiliary services in AC and DC and telecom facilities.	*Not retained, to be potentially used for distribution purposes*
	Extension of Sector A substation with the wind connection infrastructures (one 132 kV transformer bay, one 132/30 step-up power transformer, medium voltage system, auxiliary services and protection and control).
	Extension of sector B substation with the wind infrastructures as said before,
	Step up extension 132/220 kV (in sector B or at the N-collector substation depending on the chosen option) and connection to the new N-Collector substation
	Extension of N-Collector substation (two line bays, auxiliary services and protection and control).
	Displacement of the OHL connection in the 132 kV switching substation to the new 220 kV N-Collector substation

Table 6-3 Overall view of the interconnection infrastructure deployment

b) Phase I's investment in interconnection infrastructure, should take into account the expected development time for Phase II, so as not to penalize Phase I with cost pertaining to infrastructure that would be mostly serving Phase II.

c) The final configuration should be compliant with CEB standards and best practices. Potentially the following specification might be considered:

- Substations must be designed following a N-1 criteria (1 ½ circuit breaker, ring arrangement).
- Aggressive climatic conditions need to be noted:
    - 40 mm/kV creepage distance for insulators.
    - Indoor gas insulated substations, GIS type, to be considered
- Double circuit OHL from sector A to sector B (already discussed in the design as per above)
- Switching function in sector B substation

6.4. WIND OVER SOLAR FIELD SHADOWS STUDY

A potential concern that has been considered is the potential shadow casting that the wind turbines could produce over the solar area. As the pictures above show, the turbines are in all cases located to the north of the solar fields. Therefore, no shadows could be produced, but the orientation of the Pooneryn peninsula is not an eact East-West one and one could expect some shadows in the early or late hours of the day.

Typsa had used an internal software tool (T3) to produce the scene accurately and then insert the scene in PVSyst (see Figure 6-12 for illustration)

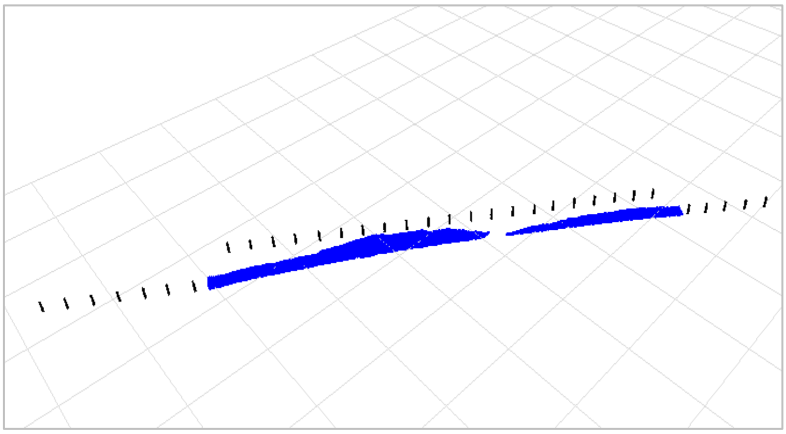
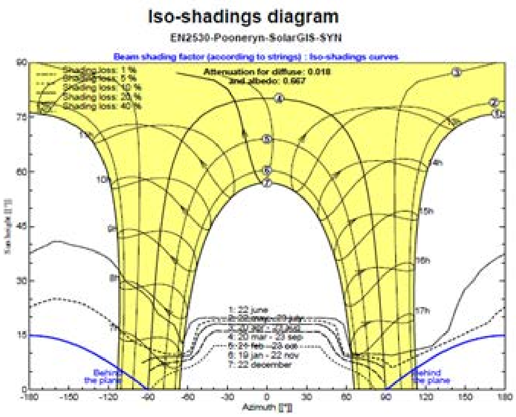


Figure 6-12 Southern field shadow scene

The result of our study shows that the impact of the impact of the wind turbines on the annual energy production is very low, approximately 0,6%. The direct beam shadows would occurr in the early morning or later afternoon due to wind turbine situated in the east or west end of the PV fields. It is at that time that the solar production is less important. Another way to look at this, is to notice that Sri Lanka being close to the equator (10º latitude) sees the sun move up in the sky very rapidly in the day, so the sun is up and to the south most of the day and in that situation the turbines situated to the north of the solar fields cast no shadows. These effect can be visualized using the Iso-shading diagram and hourly global shading factor, displayed in Figure 6-13.



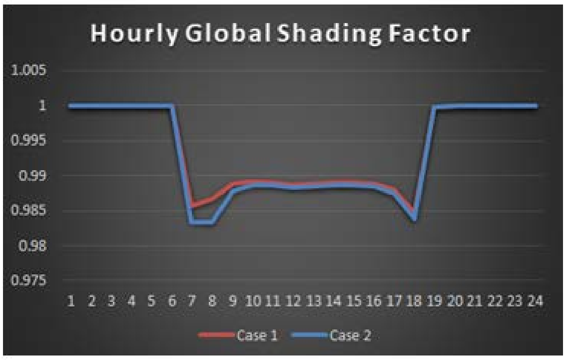


Figure 6-13 Iso-shading diagram, and hourly global shading factor showing that shadows from wind turbines are not important

6.5. COMPATIBILITY OF CONSTRUCTION

Another potential area of concern that has been reviewed by the Typsa team refers to the following question: Could the transportation and erection of solar turbines be impeded by the pre-existing solar fields?

The layouts show above show that there is nice set back from the northern border of the solar fields to the row of wind turbines, both tin the southern and northern fields. In addition, wind turbines are erected in much more complicated situations (see Figure 6-14 for illustration)

Figure 6-14 Illustration of narrow platforms and roads in existing wind farms

These days, turbine manufactures, such as Vestas, and other, provide minimal platform designs that are compatible with the situation anticipated in Pooneryn. Cranes can be mounted and transported from turbine location to turbine location and do not need to be mount ex novo at each turbine site (see figure 5-X for an illustration)

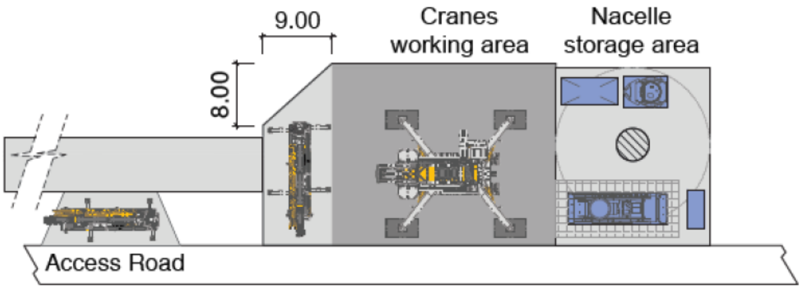


Figure 6-15 Just in time arrangement for turbine mounting operation(from Vestas)

6.6. AREAS OF POTENTIAL ENVIRONMENTAL CONCERN

The potential environmental impact of a renewable energy project at the Pooneryn peninsula would depend on the size and layouts of the solar facilities, wind turbines, step up substations and Gen-Tie lines. None of these aspects are firmly set up yet. This document has presented (see preceding sections) only one potential layout that looks technically viable and environmentally plausible. It is based on this scenario and on account of the environmental values of the Pooneryn peninsula that this section presents a preliminary discussion of the environmental concerns associated to the project. A more detailed evaluation will have to take place one the project moves into firmer ground. Such an assessment will have to be compliant with local Sri Lanka regulations and with IFC standards.

Impact on Habitats: The proposed combine solar and wind could have a significant impact on natural habitats. The effect could be most significant on the northern shore. If the inwards section of the peninsula were to be used, that could compromise habitats such as sand dunes, mangroves and salt marshes. The design should be reassessed and adjusted, in case of need, once a more detailed environmental inventory is completed and a decision is made about the objective new generation capacity.

Impact on Wildlife. Two main effects could be produced depending on the final layout and the split between new solar and new wind capacity. First, loss of sensitive wildlife habitats, especially habitats such as mangroves, salt marshes, dune vegetation and mud flats that serve as essential habitats for aquatic birds including migratory birds. Second, the wind component of the project could lead to increased collision risk to birds due to the establishment of wind farms since Pooneryn area supports large number of bird species of which some will trigger the critical habitat criteria of IFS. At this state, it is not possible to provide a detailed analysis of the essential habitats of the proposed project area (a preliminary account has been done in section 4.4. above). A complete review should be made after a detailed survey of the entire project affected area.

Impact on the protected areas Declared under National/ International laws: The proposed site does not have any protected status at present. There are a number of forest reserves immediately south of Pooneryn, which will not be directly or indirectly affected by the proposed development

Possible mitigation measures required: Due to the sensitivity of the site it is strongly recommended that detailed surveys that should inform a critical habitat assessment. Further, Seasonal variation in animals, as well as plants, is very high due to its rainfall pattern and migratory patterns of the animals, which also justifies the need for detailed assessments. Critical habitats identified based on a comprehensive assessment should not be disturbed as it will have a significant impact on the overall biodiversity of the area. Therefore, micro-siting of the project components should be done very carefully and possibly project should be downsized considerably from its present design to ensure that this development is sustainable. Also detailed avifaunal collision impact assessment should be done before delineating sites for locating wind turbines.

7. PRODUCTION STUDY

7.1. SOLAR RESOURCE AND PRODUCTION ESTIMATE

The Pooneryn peninsula appears to be among the areas in Sri Lanka with greater irradiation values (see figure).

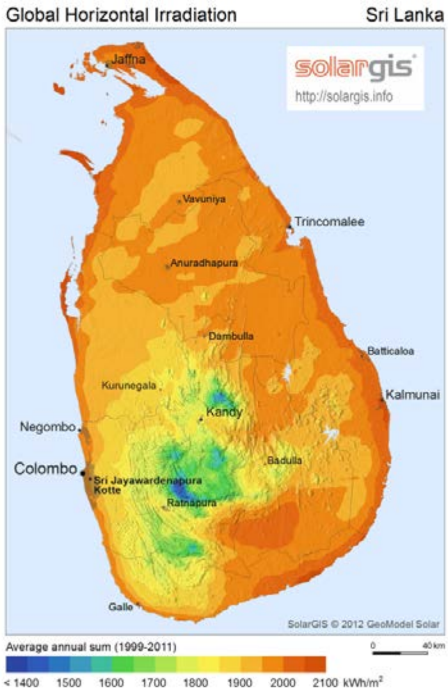


Figure 7-1 Irradiation map of Sri Lanka

Our team have used SolarGis monthly data as a source for the typical meteorological year

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²
January	153.0	70.00	26.00	169.4
February	167.0	63.00	26.80	180.7
March	207.0	73.00	28.20	212.2
April	186.0	72.00	29.70	180.1
May	188.0	87.00	30.00	173.8
June	178.0	81.00	29.40	161.3
July	182.0	86.00	29.00	166.8
August	184.0	86.00	28.90	175.3
September	181.0	77.00	28.80	180.6
October	164.0	74.00	28.10	172.2
November	129.0	68.00	27.10	140.9
December	129.0	69.00	26.30	143.8
Year	2048.0	905.99	28.20	2057.1

Table 7-1 Typical meteorological year at Pooneryn Peninsula

The yearly Global Horizontal Irradiation is around 2048 kWh/m2/year. This can be considered like a good value. The Irradiation has a significant diffuse component (45%), which would rule out the use of Concentrated Solar Power (CSP) technology. As it can be seen, temperature values reach high values during the summer. This aspect combined with the high diffuse component of the radiation suggest that the use of non-crystalline modules, such Si thin film or CdTe panels should be explored as an alternative to the more traditional crystalline Si modules. Another feature of the radiation profile is that the Global Irradiation is relatively alto along the year,

To estimate the energy production that could be derived from this meteorological scenario, our team have run several plant models using the well-known PVsyst software (6.70 Version), The estimate has been done using a single 1.41 MW blocks, arranged in four different configurations.(fix tilt and tracker, with crystalline-Si and non-crystalline modules) as shown in the following table. The number of h_{eq} in a year is provided as a convenient indicator of the productivity of each configuration:

Concept		Polycrystalline Si module	CdTe module
Fix Tilt structure at 15C	**Total Wdc**	92,962,500	92,957,760
	Total Wac	77,550	77,550
	Module	277,500	221,328
	MWh/year	155,092	157,502
	h_{eq}/year	1,668	1,694
	PR	81.10%	82.36%
Single axis tracking with 7.5m pitch	**Total Wdc**	92,962,500	92,950,200
	Total Wac	77,550	77,550
	Module	277,500	221,310
	MWh/year	181,308	185,933
	h_{eq}/year	1,950	2,000
	PR	78.83%	77.45%

Table 7-2 Energy output of various solar configurations at Pooneryn

The PVSyst outputs corresponding to these four scenarios are provided as an attachment to the present document.

The results indicate that there would be little gain by using non-crystalline panels. This is a somewhat surprising result, given the relatively high average temperatures and high averaged diffuse component of the radiation. Perhaps, this result could be due to an uneven distribution of the diffuse radiation. In other words, at Pooneryn there seems to be some days with a very high component of diffuse radiation at which the non-crystalline module would produce relatively more than X-Si modules; but a significant share of the production would be coming from other days, with mostly clear skies where the crystalline modules would do very well. The result is otherwise a convenient one for a practical standpoint, as crystalline modules is much more accessible in the market than amorphous modules.

Another interesting, less surprising result is that tracker projects offer a better yield, close to 17% higher for each type of module. This better yield has to be the weighted cost of tracker structures and, in the Pooneryn case, the potential complication associated with tracker foundations in the apparently sandy soils of the Pooneryn peninsula; and in the relative lack of large regular plots of land that are normally to be associated with tracker projects. Wind resource and production estimate

7.2. WIND RESOURCE AND PRODUCTION ESTIMATE

The best wind resources in Sri Lanka are concentrated in specific locations in the central part of the island and in the Western (Puttalam, Mannar Ma and Jaffna) and, to a lesser extent, the Northern coasts (see figure 5-20)

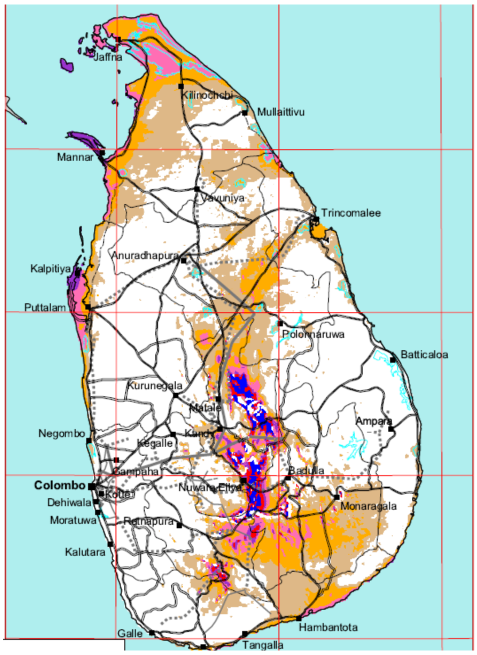


Figure 7-2 Wind resources map of Sri Lanka

It is well know that, while solar resources can be quite accurately estimated using satellite data, proper estimation of wind resources need on-site measurements. Likely, SEA has been exploiting a met mast station in the Pooneryn (coded by sea as PO1_mast) peninsula and kindly shared the data with our team.

Table 4-6 provides relevant data about the met mast.

Property	Value
Met mast name	PO1_mast
Coordinate X	403.645
Coordinate Y	1.056.659
Reference system	UTM WGS84
UTM zone	T44N
Elevation	3.1 m
Measurement level	40-60-78.6 (double)
Reference period data availability	98.78%
Start measurement	23/02/2015
End measurement	24/02/2016

Table 7-3 Main met mast characteristics

The following information from Pooneryn wind farm has been received: (i) Decoded data from PO1_mast (ii) Meteorological mast installation scheme. Our team has thoroughly analysed the wind data provided by SEA. In the body of this document, we only present a summary of the key findings, but the complete analysis can be found as an attachment to this document.

The data provided by SEA was subjected to Merra2 analysis in order to make the obtained results representative of the long-term wind regime. Calibration certificates of all the anemometers at PO1_mast supposedly comply with the MEASNET standard since they are Thies First Class sensors. Already decoded data has been received and therefore it has not been possible to verify whether the correct calibration equations have been applied to the data registered by the logger.

There is no indication to whether the boom orientations are referred to the geographic north (true north) or the magnetic north. Since the magnetic site declination is 1.88ºW, the expected uncertainty due to this issue is kept under control. The top wind vane has been selected as the correct one. However, the data shows good correlation values between the top wind vanes.

The resulting long-term wind speed at hub height for the reference period is taken to be 8.2223 m/s, at 112 m height. The figures below provide insight into the statistical distribution of the wind regime at the mast location.

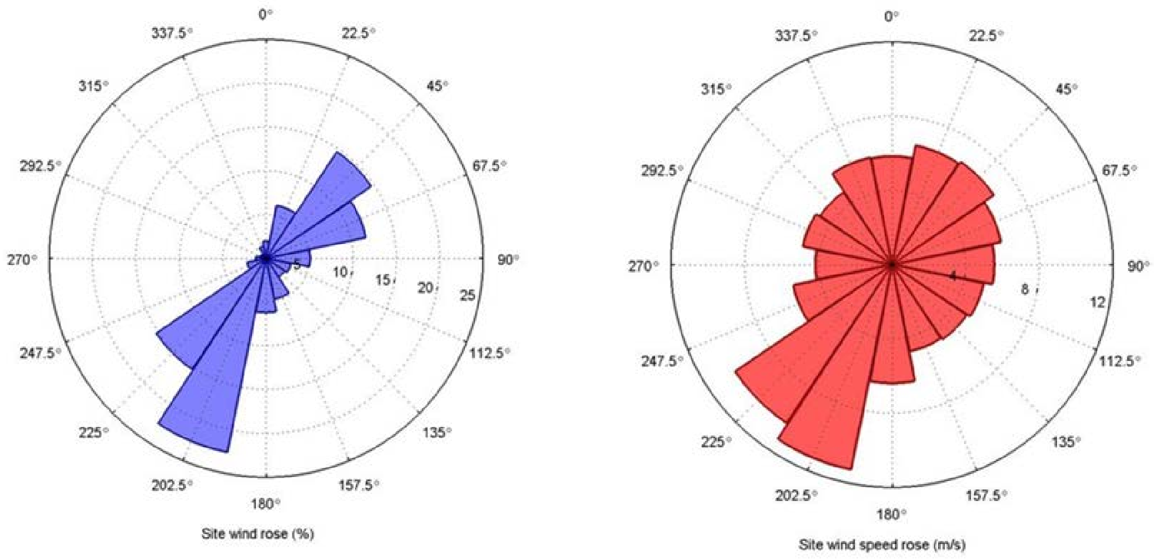


Figure 7-3 Pooneryn mast wind rose (%) and wind speed rose (m/s)

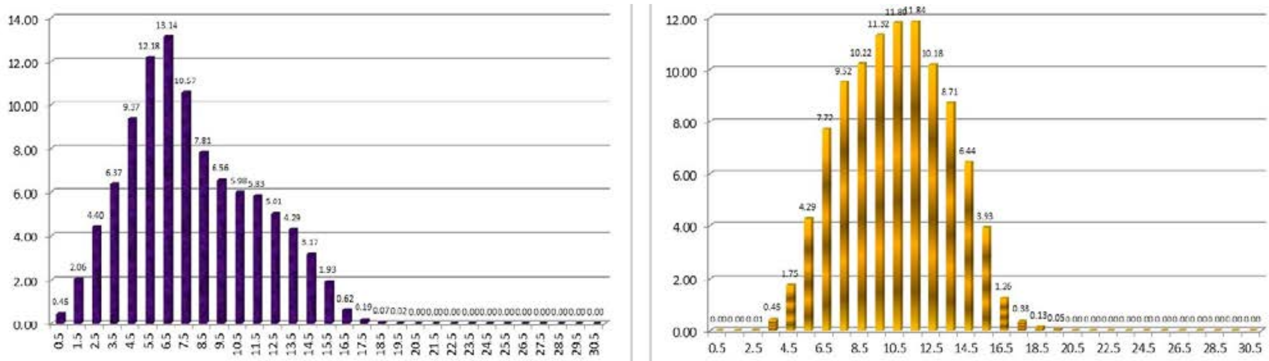


Figure 7-4 Figure 7-1 Wind histogram (left) and energy histogram (right)

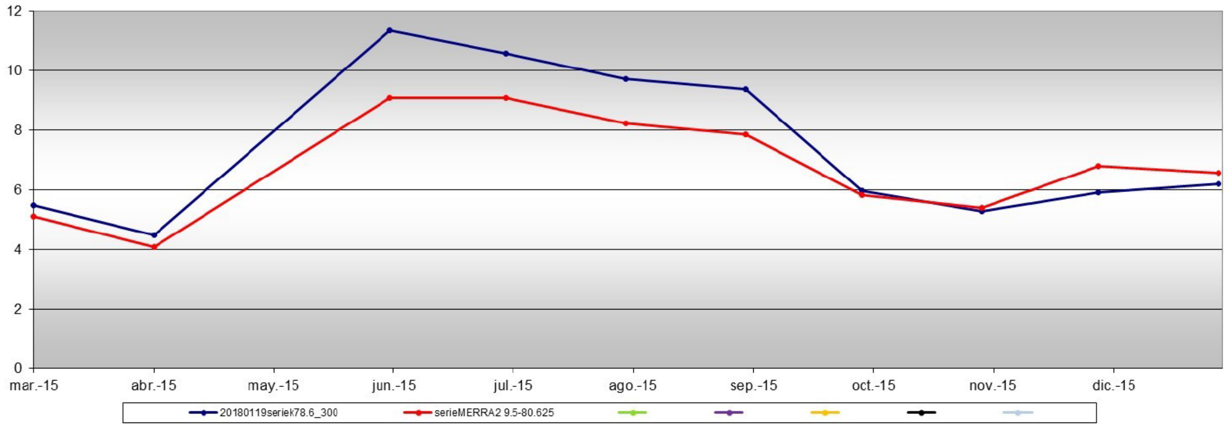


Figure 7-5 Monthly wind speed from PO1_mast and Merra2 data

It can be seen that the highest average monthly wind velocities are in the summer months.

In terms of hourly distribution, the analysis shows that the daily production of energy shows different profiles for different months in a year. However, for the most productive months, the output tends to pick in the late hours of the day (around 18:00) and keep high in the early hours of the morning. This is a nice feature as it would make the solar and wind production at Pooneryn somewhat complementary. Figure 5-25 below provides a graphical representation of the hourly energy production estimate.

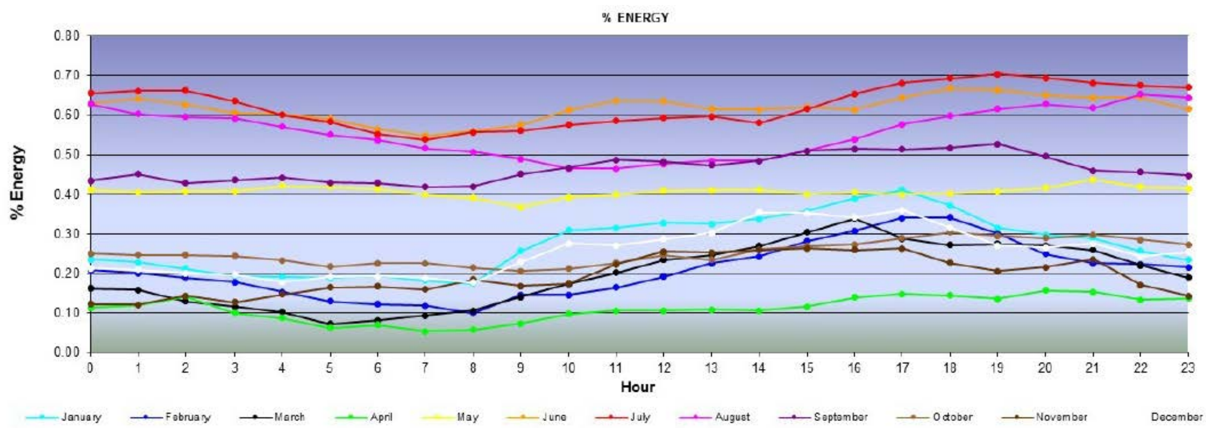


Figure 7-6 Hourly energy production distribution. Each line represents a month in a year

In order to evaluation the potential productivity of the Pooneryn site, a production estimate has been done for a tentative wind layout (shown and discussed later) using 70 Vestas V136-3600 turbines. at a hub height of 112 meters, with rotor diameter of 136 m and 3600 kW rated power each. The table shows the main results of the production simulation:

ENERGY YIELD	
GROSS ENERGY YIELD MWh/YEAR	1,175,334
WAKE EFFECTS %	4.31
UNAVAILABILITY %	3.00
ELECTRICAL LOSS %	3.00
TURBINE PERFORMANCE %	3.00
ENVIRONMENTAL %	2.00
CURTAILMENT LOSS (NOISE, POWER LIMITATION, WSM ...) %	0.00
OTHER LOSSES %	0.00
TOTAL LOSS %	**15.31**
NET ENERGY YIELD P50 MWh/YEAR	**1,005,234**
P50 NET CAPACITY FACTOR %	**45.51**
P50 EQUIVALENT HOURS	**3989**
NET ENERGY YIELD P75 MWh/YEAR	946,109
P75 NET CAPACITY FACTOR %	42.83
P75 EQUIVALENT HOURS	3754
NET ENERGY YIELD P90 MWh/YEAR	892,894
P90 NET CAPACITY FACTOR %	40.42
P90 EQUIVALENT HOURS	3543

Table 7-4 Estimate Energy Yield for reference wind farm Tentative layout Solar PV project

The results show good yield values with 3,543 P90 and 3,989 P50 equivalent yearly hours. These values confirm the Pooneryn peninsula as a desirable location for a wind project, from the perspective or resource availability.

8. FINANCIAL ANALYSIS

8.1. CAPEX

This section provides an approximation to the CAPEX and LCOE for both Phase I (Solar) and Phase II (Solar & Wind) projects at the Pooneryn peninsula. The estimates have been derived using ratios observed in similarly large international projects in which Typsa has been involved[8]. The estimate does not capture possible specificities derived from the Sri Lanka supply conditions, except in what refers to interconnection infrastructure where indicative numbers provided by CEB have been used as a guidance.

Estimated CAPEX USD Million			
Phase I Solar		**Phase II Solar + Wind**	
150 MW PV capacity mounted on fix tilt	$107		
Two step up substations (one per sector, northern and southern rim of the Pooneryn peninsula) including the MV switchgear, one power transformer, one transformer bay and 2 line bays 132 kV, protection and control, auxiliary systems in AC and DC and telecom facilities.	$ 6.2	**RETAINED**	
One 132 kV overhead line, 10 km estimated length, two circuits, on lattice towers, zebra conductor and OPGW for fibre optics communications from sector A to sector B	$ 2.6	**RETAINED**	
One 132 or 220 kV overhead line, 35 km estimated length, double circuit, on lattice towers, zebra conductors and OPGW for fibre optics communications from sector B to the new switching substation. This OHL should working at 132 kV in phase 1. In Phase II Option 1 it will work in 220kV-Phase II Option 2 it will continue work in 132kV.	@132 kV Option $ 9.3 @220 kV Option $ 13	**RETAINED**	
One switching substation, 132 kV, with 4 line bays, including protection and control, auxiliary services in AC and DC and telecom facilities.	$ 4.5	*Not retained, to be potentially used for distribution purposes*	
		252 MW of wind capacity	$226

[8] For the PV estimates, we have used four recent projects in which Typsa has been involved and has got access to the corresponding CAPEX break down. In particular, (i) a 33 MW PV plant in Burkina Faso (2017) (ii) a 10 MW PV plant in Saudi Arabia (2018) (iii) a 18 MW PV plant in Mexico (2018) and (iv) a 80 MW PV plant in Argentina (2018).

Estimated CAPEX USD Million		
Phase I Solar	**Phase II Solar + Wind**	
	Extension of Sector A & B substations with the wind connection infrastructures (132 kV transformer bays, two 132/30 step up power transformer, medium voltage system, auxiliary services and protection and control).	$ 6.5
	Step up extension 132/220 kV (in sector B or at the N-collector substation depending on the chosen option) and connection to the new N-Collector substation	$ 9.5
	Extension of N-Collector substation (two line bays, auxiliary services and protection and control).	$ 2.0
	Displacement of the OHL connection in the 132 kV switching substation to the new 220 kV N-Collector substation	$ 1
TOTAL Option 1 Phase I ……………………… $126.6 TOTAL Option 2 Phase I ……………………… $130.3	TOTAL Phase II ……………………………………… $245	

Table 8-1 Overall estimated CAPEX for Phase I and Phase II

8.2. LCOE ESTIMATES

To get a first order of magnitude of the LCOE that could be derived for each of the two Phases of the project at the Pooneryn Peninsula, a simplified financial model has been constructed. In computing LCOEs, parameters such as the percentage of project financial leverage and the cost of borrowed capital usually have a significant impact. For Typsa, it would be premature to speculate about the values that these parameters could take for the Pooneryn project, as they would be dependent on the way the projects are structured and the roles that IFC and other lenders and investors could take in the project. Consequently, our financial calculation has assumed that both Phase I and II investment are all done upfront at the beginning of each phase; and that there is no financial leverage. As a result, the only running expense is the OPEX cost, as there would be no principal or interest payments. The OPEX cost estimates have been obtained using ratios derived from previous Typsa experience elsewhere and are not based on probing the local market (note: the cost of land has not been included).

With these considerations in mind, the following indicative figures have been obtained:

- The first phase (included wind & solar HV export line from Pooneryn to Kilinochchi):
  - LCOE in the range of $38.5 / MWh
- The second phase, combined solar and wind, including additional HV upgrades
  - LCOE in the range of $33.2 / MWh

It is worth noticing that the LCOE for Phase I is burdened with the cost of the common Gen-Tie line. The indicative figures provided are in line with some of the prices seen in the international arena for similarly large projects.

9. SITE EVALUATION SUMMARY

A site evaluation effort of the sort addressed in this report seeks several results:

- A preliminary evaluation of the feasibility of the sites under consideration
- Identification of potentially fatal flaws that jeopardize the project development
- An indication of approaches and mitigation measures that could be implemented to facilitate the project development.
- In case of multiples sites are being considered, a process whereby the sites can be ranked from most to less convenient

And, such an evaluation process needs and will involve technical considerations as well as environmental and social considerations.

When several competing sites are involved, an approach sometimes undertaken is to use a numerical evaluation method, i.e. a matrix of weighted aspects. Because the present edition of the document, just refers to the Pooneryn site, we will only use a qualitative approach in our evaluation.

In a following, upcoming, edition of this document, the Monaragala sites will be included and the method used will be expanded to include the weighting procedure as it would facilitates comparison among the sites, communication and presentation of the results. Nevertheless, it might be already worth noticing that using the weighted evaluation matrix does not void out the valuable subjective opinion, it simply makes the site comparison easier.

9.1. POONERYN SITE EVALUATION MATRIX

The Pooneryn evaluation matrix is shown below. Each of the aspects considered is commented, and three step scale has been created to facilitate identification of potentially fatal flaws or critical elements. The proposed evaluation steps are D for *Difficult*, A for *Acceptable* and G for *Good*

Aspect	Comment	D	A	G
General site condition. This refers to some general features of the site, such as the existence of vegetation that would need to be removed, or buildings or any sort of construction, and the potential existence of mandatory setbacks. These aspects include a consideration of the available surface at the site.	The general area where the project is to be located present a complex landscape. The project should avoid the central part of the peninsula and seek locations away from the dune area and clear from vegetation. No major construction are present and the existing one should not pose a significant problem		**A**	
Land ownership. Is the land ownership clear? Does transfer of the property rights look feasible within reasonable cost and time?	This an element about which very little information exists. The report explains some of the reasons for the lack of a proper cadastre. SEA might have ownership information that needs to be revised. It seems reasonable to assume that this should not be a critical aspect		**A**	
Topographic features. This refers to the topographic features of the site. A flat site is ideal for a solar plant. A non-flat site might require grading works.	Complex. The dunes in the central part of the peninsula are valuable from an environmental perspective, but also inconvenient from a mere technical one. They should be avoided, which should be possible along the lines proposed in this report		**A**	
Hydrological aspects. Hydrological aspects of the sites, such as the existence of water courses, water bodies, and the potential need for water-related works.	This aspect need further study, especially in relation to the northern coast solar field, which appeared to be partly wetland at the time of the visit. In addition, the flooding risk derived from high tides or other phenomena needs to be assessed.		**A**	
Geotechnical aspects. This aspect tries to capture a fairly prelaminar evaluation of the site in relation to the potential ease or difficulty in using conventional foundation.	This could be an area of significant complexity. A proper geotechnical survey needs to be completed. The solar project is less sensitive to geotechnical conditions, but the design of the solar foundations will depend on the survey findings. The wind project cost will be significantly affected by the type of foundation needed. This is a point that will certainly have to be studied in much detail in the next phase. We consider this aspect as critical and potentially difficult	**D**		
Meteorological aspects of the site. The electricity production of the sites is totally dependent, among other meteorological aspects, on the	The site shows excellent wind conditions and good solar resources (among the best in			**G**

Aspect	Comment	D	A	G
amount of irradiance received, the % of this irradiance being direct and the temperature. This aspect evaluates the quality of these data and assess the potential productivity of the site.	the country)			
Water supply issues. Is water available for maintenance operations?	No specific information about this has been gathered. At this point it is unknown if municipal water supply would be accessible But it is reasonable to assume that given the rain intensity in the area, and seawater resources, plus the easy road access, one or several acceptable solutions will be found for the water supply.		**A**	
Shadowcasting. This aspect evaluates whether production losses can be expected from existing of future objects.	As explained in the report, this not an area of concern at all			**G**
Road access. Road access is an essential aspect of construction. This aspect evaluates the adequacy of this aspect.	Excellent road access up to the entry to the peninsula. The ring road might need to be improved at specific locations, to allow the transport of wind turbine components. It is not considered a critical issues		**A**	
Existing utilities. If utility infrastructure is present, this can affect the design and the available surface.	No public utilities water or electricity should be significantly affected by the project. I the area there are some low voltage electrical lines. In some cases, it might be necessary to relocate some electricity poles. This is not considered a critical element.			**G**
Interconnection infrastructure. This critical aspect tries to evaluate the ease or difficulty of the export interconnection. It involves evaluation of the potential Gen-Tie line and the receiving substation. It might also involve the consideration of grid stability issues.	This aspect has been discussed at length in the report and in meetings with CEB. A proposal exists what seems doable and cost-effective.		**A**	
Environmental protection. Is the site affected by any sort of protective figure, such national or regional park, or declared like a	There are not protection figures at play in the area			**G**

Aspect	Comment	D	A	G
valuable international resource?				
Environmental vegetation aspects. Does the site has unique or special vegetation that would be destroyed and that cannot be easy compensated? Is the site populated with native vegetation, and would its removal entail a significant loss?	The project should be conceived to keep vegetation removal to a minimum, and if occurring limit this to non-critical species		**A**	
Wildlife aspects. Does the site host species either on a permanent or transitory basis that would be negatively affected by the development of the project? Can mitigation or compensatory measures be envisioned at this stage?	The primary concern is the potential affection to the bird population by the wind component of the project. This is an aspect that needs careful evaluation and, eventually, a sensible design that will minimize the impact and deliver mitigation measures	**D**		
Social aspects. Are there any local dwellers on site? Are these legally established? Have they been there for long? Have they acquired a “de facto” right of us? Is it possible to imagine compensatory measure in case of displacement, within reasonable cost and time margins? Could potential conflicts occur with local dwellers if a displacement has to take place?	This is an aspect that needs to be re-assessed as the project moves into the next phase, but no significant difficulties are expected, as the peninsula has very low population density. The potential impact on plantations and other legal or illegal economic activities needs to be assessed.		**A**	
TOTAL		**2**	**9**	**4**

9.2. POONERYN EVALUATION SUMMARY

The Pooneryn site is situated just west of the village of Pooneryn in the northern tip of the Island. The site offers attractive solar and wind resources for renewable energy generation. The site also exhibits distinct environmental values, mainly a rich dune landscape and several seasonal water bodies that interacting with the northern bordering lagoon to host a varied bird species population.

Typsa thinks that it is possible to find ways to develop the Pooneryn peninsula for renewable energy in economically attractive terms while reducing the environmental impacts to acceptable levels. Any such development needs to do the utmost to preserve the valuable dune environment in the Pooneryn peninsula and minimize the effect on the incumbent bird population.

These project development constraints need to be supplemented by considerations relative to available options to export the large quantities of electricity that would be generated in the Pooneryn peninsula.

As seen in this report, the 132kV line that joins the Kilinochchi and the Chunnakam substations offers, in the short term and at relatively low cost, a viable option to interconnect a future Gen-Tie line coming from the Pooneryn peninsula. This report proposes to do this by opening the existing 132kV line and setting up a new switching substation north of Kilinochchi, as a point of interconnection. Under this arrangement, in a relatively simple way, the Pooneryn peninsula should be able to significantly contribute to the energy availability in the northern part of Sri Lanka’s grid.

The discussion about the export capacity of a new Gen-Tie line and the carry away capacity of the grid, needs to be completed with an analysis of the robustness of the grid at the point of interconnection. In other words, with a consideration of the ability of the grid to cope with intermittent, non-dispatchable power electronic converter base energy generation systems (such as solar and wind systems).

Short Circuit Power values at the point of interconnection can be used as a proxy to estimate the electrical grid strength, Short Circuit Power available at the Kilinochchi substation, is currently in the range of 500 MVA. This leads us to suggest that solar a plant of some 100MW to 150MW could be taken in by Sri Lanka’s grid as of now, without any significant reinforcements.
As a result of the interconnection and environmental circumstances relevant to the Pooneryn project, Typsa has proposed, and discussed with a variety of local stakeholders in Sri Lanka, a phased approach, by which there would be a first phase consisting of a large-scale solar PV plant at Pooneryn (up to 150MW) that would connect to the existing grid. And, second wind phase (up to 250MW), to be implemented once the Kilinochchi substation is linked via a new 220 kV line with the Vavuniya and Anuradhapura substations.

From a technical point of view, this phased approach can be made in a way by which almost all the equipment and infrastructure build for Phase I, will be kept and used during Phase II, thereby leading to an economically efficient project.

But, for the project to move forward in its entirety, the proposed approach needs to be made compatible with the environmental values of the Pooneryn peninsula. In this context, the first solar part of the project can be anticipated to have a reduced and manageable ecological impact. While, the second phase, the wind phase can only be undertaken once a proper detailed evaluation of the effects that a substantial wind turbine field would have on the bird communities in the area.

<u>As a result, both interconnection and environmental criteria suggest that a sensible way to exploit the excellent energy resources in the Pooneryn peninsula would be to launch a solar project first and do so in a way that would allow starting later a large-scale wind project</u>.

As a summary, our team thinks that it is possible to develop a large utility-scale renewable energy project in the Pooneryn peninsula, with both a solar and a wind component, that would improve the energy supply in the area, in an economically attractive way; and to deploy the assets in the ground in a form that would be respectful to the existing valuable environmental elements present in the Pooneryn peninsula and nearby areas

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ANNEXES I: POONERYN WIND FARM RESOURCE ASSESSMENT AND YIELD ESTIMATE

POONERYN WIND FARM - WIND RESOURCE ASSESSMENT REPORT

REVISION CONTROL				
REVISION	DATE	BY		DESCRIPTION
1	25/01/2018	Diana Calero		First draft, Vestas V136-3600 T112 model

PREPARED		REVISED
Diana Calero		José Miguel Jáuregui

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Notwithstanding anything to the contrary herein: This document should not be disclosed to any party who provides wind resource assessment services (hereinafter a "Competitor") or any party who owns or controls a Competitor or is owned or controlled by a Competitor.

While this document has been elaborated according to main sector guidelines [1], 2], Nayxa does not make any warranty, either expressed or implied, or assumes any legal liability or responsibility derived from the accuracy of any results or any information disclosed.

When performing the analysis summarised herein, Nayxa assumes that the site data and other supplied information accurately represent the conditions present at the wind farm location. It is also assumed that all relevant and available information has been supplied to Nayxa.

All site data was obtained, measured and provided by the Customer. Nayxa has not participated in obtaining or measuring the site data. The Customer has decided upon the number, location, height and type of meteorological masts. The Customer has decided the length of the measuring period.

Nayxa has not performed any verification of the site data beyond standard data filtering (i.e., ice accretion on sensors, meteorological tower shading, sensor failures, location of the mast in Google Earth, etc.). A site visit has not been performed.

Wind data from 1 measurement mast has been processed in order to obtain the results and calculations presented in this report; should the measurement period or any data change, Nayxa informs that the results obtained might differ from those presented in this report.

The main scope of this report is to assess the expected production of Pooneryn wind farm. Pooneryn wind farm consists of 70 wind turbines totalling an installed power of 252.0 MWs. Nayxa has designed the layout of the project in agreement with the client.

0. EXECUTIVE SUMMARY

The main target of this report is to calculate the expected energy yield of Pooneryn wind farm, using the wind turbine model Vestas V136-3600 IEC S class, at a hub height of 112 meters. In particular the following objectives have been pursued:

- To design the most optimal configuration for the project.
- To calculate the long term wind speed at each wind turbine position.
- To analyse the vertical wind profile at each mast.
- To conduct an assessment of the annual energy production of the wind farm.
- To calculate the expected losses of Pooneryn wind farm.
- To assess the expected uncertainty associated with the production results.

The inputs specified in the next table have been used in the Wind Resource Assessment (WRA) of Pooneryn wind farm. The provenance of each source is also given.

PROJECT NAME		INSTALLED POWER MW
POONERYN WIND FARM		252.00
INPUT DATA		
WIND DATA DECODING	Client	
WIND DATA FILTERING		Nayxa
ELEVATION & CONTOUR MAP		Nayxa
ROUGHNESS MAP		Nayxa
LAYOUT OF THE WIND FARM		Nayxa
LONG TERM DATA		Nayxa

Table 1. Input data used in the WRA of Pooneryn wind farm.

Pooneryn wind farm is located within the limits of Kilinochchi District in Sri Lanka. In order to perform this WRA, a meteorological mast known as PO1_mast has been analysed. Merra2 reanalysis data [3] has been used in order to make the obtained results representative of the long term wind regime.

PO1_mast is located within the limits of the project as it can be seen on the maps presented in annex B and has been used to estimate the energy yield at the wind turbines of Pooneryn wind farm. PO1_mast has also been used to calculate the mean air density of the project along with long term databases. Since the extension of the proposed wind farm is over 15 kilometers, it would be advisable to install extra met masts.

Pooneryn wind farm consists of 70 wind turbines totalling an installed power of 252.0 MWs. Nayxa has designed the layout of the project in agreement with the client. The selected wind turbine model is the Vestas V136-3600 at a hub height of 112 meters. The main characteristics of the project are shown in the next table.

PROJECT NAME	INSTALLED POWER MW
POONERYN WIND FARM	252.00
PROJECT SUMMARY	
WIND TURBINE MODEL	VESTAS V136-3600
HUB HEIGHT (m)	112.00
ROTOR DIAMETER (m)	136.00
NUMBER OF TURBINES	70
WIND TURBINE RATED POWER (Kw)	3600
PROJECT LOCATION	POONERYN - SRI LANKA

Table 2. Pooneryn wind project details.

Maps within annex B show the location of the provided masts along with all the wind turbines of the project and the neighbour wind farms, if any, taken into account to model the wind field and wake losses at Pooneryn wind farm.

In this assessment no adjacent wind farms have been taken into account to model the wake losses of the wind turbines at Pooneryn wind farm. All the results presented have been estimated with the help of commercial software such as WAsP [4], [5], WindFarmer [6], [7] and in-house developed software at Nayxa.

In the next tables, a summary of the results obtained in the WRA of Pooneryn wind farm, for the wind turbine model Vestas V136-3600 at a hub height of 112 meters, is presented.

The free flow wind speed corresponds to the wind speed obtained from the wind modelling (terrain speed-up factors) and no wake affection. The wind farm speed refers to the wind speed obtained from the wind modelling (terrain speed-up factors) and taking into account the wake affection. This is the expected and real wind speed each wind turbine will face during operation.

These results are corrected to be representative of the long term period whenever an onsite wind index time series, reanalysis data or a reference meteorological mast are available and show good correlation properties with onsite measurement masts.

Turbine	Hub m	Rotor m	Power Kw	COORD. X	COORD. Y	DIST. CLOSER WTG	Density Kg/m^3	Height m	RIX %	Free Flow Wind Speed m/s	Wind Farm Speed m/s	A Weibull	K Weibull
POONERYN WIND FARM / SITE CONDITION ASSESSMENT RESULTS													
WT-1	112	136	3600	396412	1061479	2.22	1.1579	9	0.0	8.29	8.21	9.30	2.32
WT-2	112	136	3600	396659	1061306	2.21	1.1578	10	0.0	8.29	8.18	9.30	2.32
WT-3	112	136	3600	396905	1061133	2.21	1.1578	10	0.0	8.34	8.24	9.40	2.31
WT-4	112	136	3600	397153	1060961	2.22	1.1578	10	0.0	8.34	8.23	9.40	2.31
WT-5	112	136	3600	397399	1060787	2.22	1.1582	6	0.0	8.24	8.14	9.30	2.31
WT-6	112	136	3600	397646	1060614	2.22	1.1584	4	0.0	8.23	8.07	9.30	2.31
WT-7	112	136	3600	397894	1060442	2.22	1.1582	6	0.0	8.25	8.06	9.30	2.31
WT-8	112	136	3600	398518	1060715	2.20	1.1572	15	0.0	8.46	8.34	9.50	2.30
WT-9	112	136	3600	398763	1060544	2.20	1.1576	11	0.0	8.39	8.28	9.40	2.31
WT-10	112	136	3600	399010	1060373	2.21	1.1579	9	0.0	8.34	8.24	9.40	2.31
WT-11	112	136	3600	399255	1060200	2.21	1.1578	10	0.0	8.34	8.24	9.40	2.32
WT-12	112	136	3600	399500	1060027	2.21	1.1579	9	0.0	8.33	8.23	9.40	2.31
WT-13	112	136	3600	399746	1059855	2.20	1.1578	10	0.0	8.32	8.21	9.40	2.31
WT-14	112	136	3600	399992	1059684	2.20	1.1580	8	0.0	8.28	8.19	9.30	2.33
WT-15	112	136	3600	400238	1059511	2.21	1.1583	5	0.0	8.23	8.13	9.30	2.33
WT-16	112	136	3600	400485	1059338	2.21	1.1582	6	0.0	8.27	8.17	9.30	2.33
WT-17	112	136	3600	400731	1059165	2.21	1.1582	6	0.0	8.26	8.16	9.30	2.34
WT-18	112	136	3600	400976	1058991	2.21	1.1583	5	0.0	8.24	8.14	9.30	2.34
WT-19	112	136	3600	401222	1058819	2.21	1.1579	9	0.0	8.33	8.23	9.40	2.33
WT-20	112	136	3600	401470	1058647	2.21	1.1580	8	0.0	8.33	8.24	9.40	2.33
WT-21	112	136	3600	401718	1058476	2.21	1.1582	6	0.0	8.33	8.23	9.40	2.33
WT-22	112	136	3600	401963	1058303	2.21	1.1581	7	0.0	8.35	8.26	9.40	2.33
WT-23	112	136	3600	402210	1058131	2.21	1.1578	10	0.0	8.38	8.28	9.40	2.33
WT-24	112	136	3600	402457	1057959	2.21	1.1582	6	0.0	8.33	8.23	9.30	2.34
WT-25	112	136	3600	402701	1057782	2.22	1.1582	6	0.0	8.31	8.21	9.30	2.33
WT-26	112	136	3600	402950	1057612	2.22	1.1579	9	0.0	8.32	8.22	9.40	2.33
WT-27	112	136	3600	403198	1057438	2.22	1.1578	10	0.0	8.32	8.19	9.40	2.34
WT-28	112	136	3600	403444	1057263	2.22	1.1581	7	0.0	8.29	8.14	9.30	2.34
WT-29	112	136	3600	403464	1056748	2.21	1.1588	1	0.0	8.21	8.08	9.20	2.35
WT-30	112	136	3600	403705	1056569	2.21	1.1585	3	0.0	8.23	8.10	9.30	2.35
WT-31	112	136	3600	403943	1056385	2.21	1.1585	3	0.0	8.25	8.12	9.30	2.35
WT-32	112	136	3600	404184	1056205	2.21	1.1583	5	0.0	8.30	8.13	9.30	2.35
WT-33	112	136	3600	404425	1056024	2.21	1.1584	4	0.0	8.28	8.06	9.30	2.35
WT-34	112	136	3600	404666	1055844	2.21	1.1584	4	0.0	8.28	7.99	9.30	2.34
WT-35	112	136	3600	404904	1055661	2.21	1.1584	4	0.0	8.28	7.97	9.30	2.34
WT-36	112	136	3600	405145	1055481	2.21	1.1583	5	0.0	8.29	7.97	9.30	2.34
WT-37	112	136	3600	405385	1055300	2.21	1.1583	5	0.0	8.29	7.97	9.30	2.34
WT-38	112	136	3600	405626	1055118	2.21	1.1582	6	0.0	8.29	7.97	9.30	2.34
WT-39	112	136	3600	405865	1054936	2.21	1.1581	7	0.0	8.30	8.00	9.30	2.35
WT-40	112	136	3600	406105	1054755	2.21	1.1583	5	0.0	8.26	7.96	9.30	2.35
WT-41	112	136	3600	406346	1054576	2.21	1.1582	6	0.0	8.24	7.96	9.30	2.35
WT-42	112	136	3600	406472	1054197	2.22	1.1583	5	0.0	8.25	8.00	9.30	2.34
WT-43	112	136	3600	406706	1054007	2.21	1.1583	5	0.0	8.24	8.00	9.30	2.35
WT-44	112	136	3600	406944	1053823	2.21	1.1583	5	0.0	8.25	8.00	9.30	2.35
WT-45	112	136	3600	407182	1053638	2.22	1.1583	5	0.0	8.25	8.02	9.30	2.35
WT-46	112	136	3600	407419	1053451	2.22	1.1583	5	0.0	8.24	7.99	9.30	2.34
WT-47	112	136	3600	407658	1053267	2.21	1.1582	6	0.0	8.24	8.01	9.30	2.34
WT-48	112	136	3600	407895	1053083	2.20	1.1582	6	0.0	8.20	7.97	9.20	2.35
WT-49	112	136	3600	408132	1052900	2.20	1.1581	7	0.0	8.22	8.01	9.30	2.35
WT-50	112	136	3600	408369	1052714	2.22	1.1581	7	0.0	8.22	8.02	9.20	2.36
WT-51	112	136	3600	408606	1052528	2.22	1.1581	7	0.0	8.19	8.02	9.20	2.37
WT-52	112	136	3600	408848	1052346	2.21	1.1582	6	0.0	8.17	8.01	9.20	2.37
WT-53	112	136	3600	409083	1052158	2.21	1.1582	6	0.0	8.14	8.09	9.20	2.37
WT-54	112	136	3600	405493	1056767	2.21	1.1585	3	0.0	8.24	7.82	9.30	2.38
WT-55	112	136	3600	405740	1056595	2.21	1.1584	4	0.0	8.23	7.78	9.30	2.39
WT-56	112	136	3600	405987	1056420	2.20	1.1582	6	0.0	8.29	7.87	9.30	2.38
WT-57	112	136	3600	406233	1056249	2.20	1.1579	9	0.0	8.30	7.87	9.30	2.39
WT-58	112	136	3600	406482	1056076	2.21	1.1584	4	0.0	8.25	7.83	9.30	2.38
WT-59	112	136	3600	406729	1055904	2.18	1.1583	5	0.0	8.25	7.80	9.30	2.38
WT-60	112	136	3600	406971	1055733	2.18	1.1584	4	0.0	8.22	7.83	9.30	2.39

Turbine	Hub m	Rotor m	Power Kw	COORD. X	COORD. Y	DIST. CLOSER WTG	Density Kg/m^3	Height m	RIX %	Free Flow Wind Speed m/s	Wind Farm Speed m/s	A Weibull	K Weibull
POONERYN WIND FARM / SITE CONDITION ASSESSMENT RESULTS													
WT-61	112	136	3600	407776	1055661	2.21	1.1585	3	0.0	8.19	7.83	9.20	2.42
WT-62	112	136	3600	408024	1055491	2.20	1.1587	2	0.0	8.21	7.85	9.30	2.42
WT-63	112	136	3600	408267	1055317	2.20	1.1587	2	0.0	8.18	7.82	9.20	2.42
WT-64	112	136	3600	408513	1055146	2.20	1.1585	3	0.0	8.23	7.91	9.30	2.43
WT-65	112	136	3600	408858	1054901	2.23	1.1585	3	0.0	8.21	7.87	9.20	2.44
WT-66	112	136	3600	409107	1054729	2.21	1.1584	4	0.0	8.22	7.88	9.30	2.45
WT-67	112	136	3600	409353	1054557	2.21	1.1584	4	0.0	8.22	7.88	9.30	2.46
WT-68	112	136	3600	409600	1054383	2.22	1.1583	5	0.0	8.22	7.90	9.30	2.46
WT-69	112	136	3600	409851	1054213	2.22	1.1583	5	0.0	8.18	7.86	9.20	2.48
WT-70	112	136	3600	410101	1054043	2.22	1.1583	5	0.0	8.14	7.94	9.20	2.50
Wind farm results			252.00			2.21	1.1582	6	0.00	8.27	8.05	9.31	2.36

Table 3. Site condition assessment results of Pooneryn wind farm, UTM WGS84 T44N.

PROJECT NAME	RATED POWER MW
POONERYN WIND FARM	252.00
ENERGY YIELD	
GROSS ENERGY YIELD MWh/YEAR	1,175,334
WAKE EFFECTS %	4.31
UNAVAILABILITY %	3.00
ELECTRICAL LOSS %	3.00
TURBINE PERFORMANCE %	3.00
ENVIRONMENTAL %	2.00
CURTAILMENT LOSS (NOISE, POWER LIMITATION, WSM ...) %	0.00
OTHER LOSSES %	0.00
TOTAL LOSS %	15.31
NET ENERGY YIELD P50 MWh/YEAR	1,005,234
P50 NET CAPACITY FACTOR %	45.51
P50 EQUIVALENT HOURS	3989
NET ENERGY YIELD P75 MWh/YEAR	946,109
P75 NET CAPACITY FACTOR %	42.83
P75 EQUIVALENT HOURS	3754
NET ENERGY YIELD P90 MWh/YEAR	892,894
P90 NET CAPACITY FACTOR %	40.42
P90 EQUIVALENT HOURS	3543

Table 4. Energy yield summary Pooneryn wind farm.

The main conclusions and recommendations obtained from the present assessment are:

- In order to perform this WRA, a meteorological mast known as PO1_mast has been analysed. Merra2 reanalysis data [3] has been used in order to make the obtained results representative of the long term wind regime.

- There is no indication to whether the boom orientations are referred to the geographic north (true north) or the magnetic north. Since the site magnetic declination is 1.88ºW, the expected uncertainty due to this issue is kept under control.

- The layout has been designed and optimized by Nayxa. Distance between wind turbines ranges from 2.18 to 2.21 rotor diameters, RD.

- The mean wind shear meets a value of 0.153 at PO1_mast (78.6/40 m levels). Hellman's potential law of the wind profile with height [18] has been used to calculate this value.

- The height of the met mast, 78.6 meters, agrees with Measnet recommendation [1] on having a met mast with a height of at least 2/3 of the selected hub height, 112 meters in this case. The uncertainty due to the vertical wind speed extrapolation has been calculated on section 10.

- WAsP has been selected as the wind flow model to horizontally extrapolate the climatology registered at the met masts, to the wind turbine locations.

- In this assessment no adjacent wind farms have been taken into account to model the wake losses of the wind turbines at Pooneryn wind farm.

- The annual net energy output of the wind farm is found to be 1005.23 GWh with a capacity factor of 45.51% for the Vestas V136-3600 wind turbine model at a hub height of 112 meters.

- A detailed uncertainty analysis has been performed, focusing on the quality of input data, the calculation procedures, the turbine type parameters as well as the applied losses. The uncertainty analysis is performed considering prediction horizons of 1 and 10 years and P50, P75, P90 and P99 levels [33].

1. INTRODUCTION / SITE ANALYSIS

Pooneryn wind farm is located within the limits of Kilinochchi District in Sri Lanka. In this report a configuration of 70 x V136-3600 wind turbines at a hub height of 112 meters is analysed. The Vestas V136-3600 T112 is an IEC S wind turbine model which is designed to face medium and low wind regimes to exploit the maximum of these conditions.

The project consists of 70 wind turbines which implies a total installed power of 252.0 MWs. Wind field modelling and energy calculation have been estimated with the help of commercial software WAsP and WindFarmer, from Danish Laboratory Riso and DNV GL respectively.

Nayxa has designed the layout in order to maximize the energy yield, minimize the wake loss and the affection in terms of effective turbulence intensity among wind turbines. The following points have been assessed in this evaluation:

- Design of the wind farm (section 2).
- Analysis of raw wind data (section 3).
- Extrapolation of wind data to hub height (section 4).
- Selection of the reference period at each met mast (section 5).
- Long term correction of the wind speed and energy yield (Section 6).
- Wind flow modelling (section 7).

- Calculation of the expected energy yield (section 8).
- Estimation of the losses associated to the project (section 9).
- Calculation of the expected uncertainty (section 10).

Pooneryn wind farm is located in a non-complex area with no accidents on the terrain. On the slope map presented in the annex B it is possible to observe the absence of steep slopes in the surroundings of Pooneryn wind farm. The RIX parameter [5] is calculated by WAsP and meets a mean value of 0.00% with a minimum of 0.00% and a maximum of 0.00%.

Vegetation in the area consists mainly on small shrubs and bushes patched with some bare areas and sporadic woodlands. A high resolution roughness map has been configured by Nayxa with the help of satellite imagery. The following roughness length values have been used in the elaboration of the roughness map.

- Forestry areas: 0.30 to 0.50 m
- Shrub areas: 0.05 to 0.20 m
- Populated areas: 0.40 to 0.80 m
- Agricultural patterns: 0.03 to 0.20 m
- Sparse vegetation: 0.001 to 0.03 m
- Water bodies: 0.000 to 0.0002 m

Nayxa has also built a high resolution orographic map using the STRM version 3 database (30m pixel resolution) to complete an extension of 20 kilometers around the wind farm. Wind turbines are located in sites with an altitude range of 1 to 15 meters with a mean wind farm altitude of 6 meters. In the following pages situation maps and pictures of the wind farm and surroundings are presented.

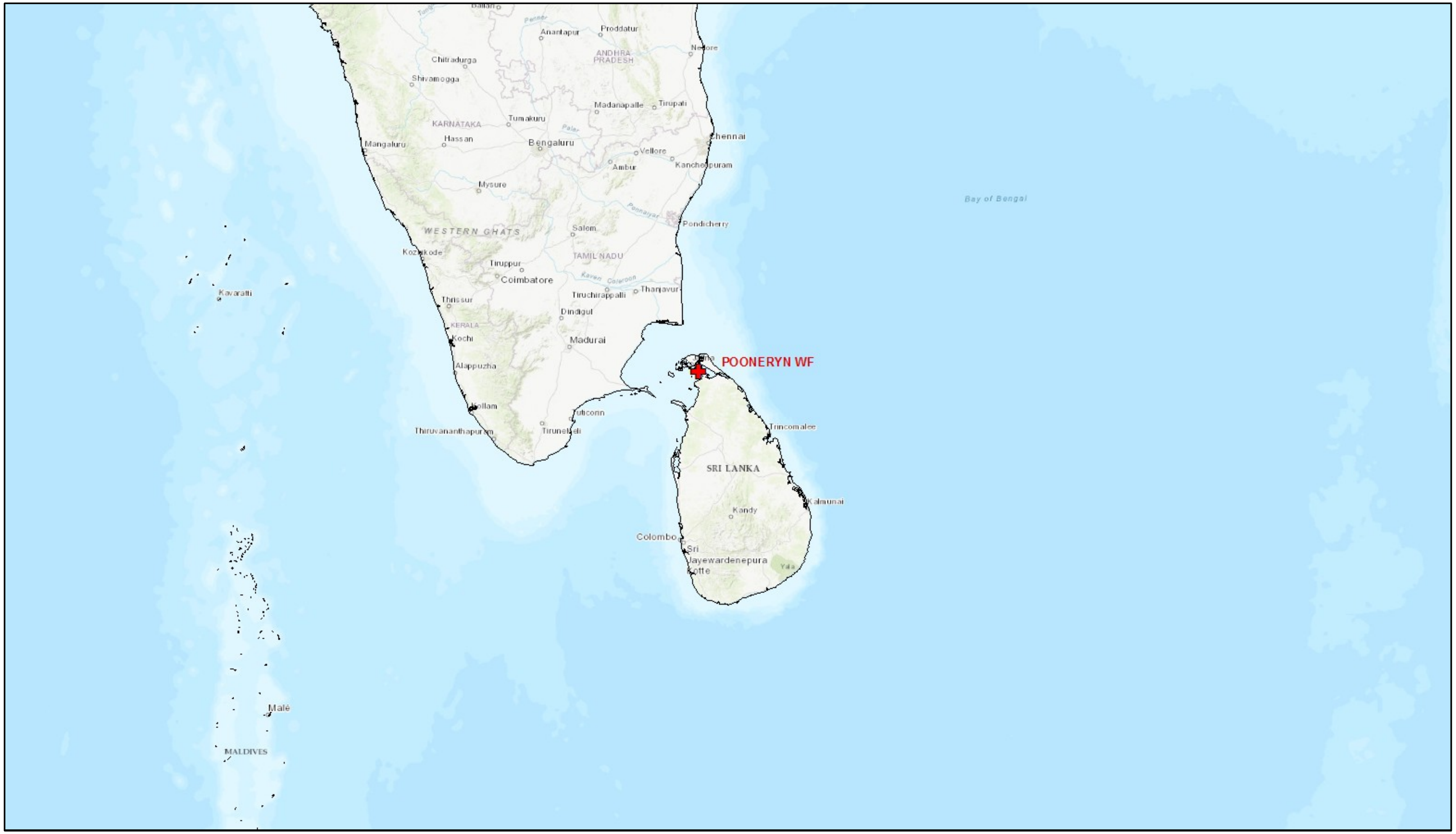


Figure 1. Situation map of Pooneryn wind farm.

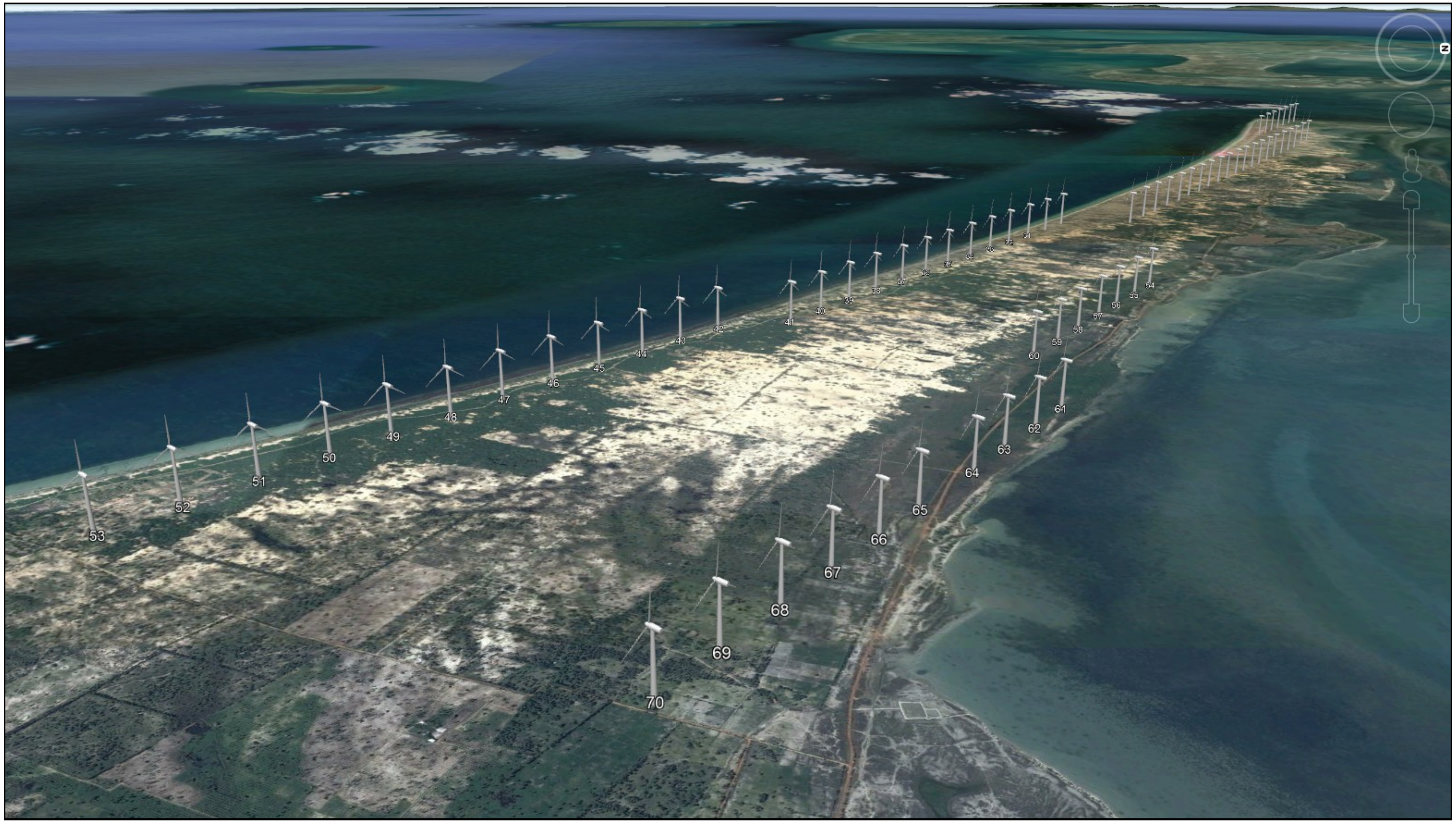


Figure 2. Pooneryn wind farm detail.

2. PROJECT DESCRIPTION

2.1 LAYOUT OF THE WIND FARM

Nayxa has received instructions to design the layout of the project. Several criteria have been managed and analysed in order to select the most optimal locations such as:

- Main wind direction and topography of the site.
- Estimated production.
- Expected wake losses.
- Effective turbulence intensity.
- Restrictions given by the client.

In this assessment no neighbor wind farms have been taken into account to model the wake losses of the wind turbines at Pooneryn wind farm. The layout of Pooneryn wind farm has been presented on section 0. The reference coordinate system used is UTM WGS84 T44N.

The recommended distances among wind turbines depend highly on the wind rose of the site. Highly directives wind roses may allow wind turbines to be placed at a closer distance than open wind roses. In this case the mean distance between the wind turbine positions has resulted to be 2.21 rotor diameters as a consequence of a highly directive wind rose.

2.2 DENSITY CALCULATION

The estimated power output from a wind turbine is given by the following equation shown below.

$$P_{wind} = \frac{1}{2} \times A \times c_p \times v^3 \times \rho$$

Where

A is the rotor swept area: [m^2];
Cp is the power coefficient of the selected wind turbine model;
v is the wind speed: [m/s];
ρ is the mean air density: [kg/m^3].

The air kinetic energy going through the rotor section is directly proportional to the third power of wind speed and linearly proportional to the rotor swept areas, the power coefficient and the air density. Since air density contributes in a linear way to the expected energy yield, the importance of a precise calculation is beyond question [12].

In order to calculate the mean air density at the wind farm, measurements from PO1_mast have been taken into account. Global databases such as WorldClim and NOAA/NCAR have been used to correct the temperature for the long term and eliminate the soil affection if necessary.

The mean temperature at 78.5 meters high is found to be 27.823ºC. The mean air relative humidity at 10 meters high meets the value 74.705%. Air pressure has been measured at PO1_mast but the received data are not correct so a value of 1,013 mb at a height altitude of 0 meters has been assumed.

The following formulas, defined in annex F of [13] and [14], have been used to extrapolate the aforementioned atmospheric magnitudes to the mean altitude of the wind farm and calculate the mean air density at Pooneryn wind farm.

$$\rho = \frac{1}{T}\left(\frac{B}{R_0} - \phi P_w\left(\frac{1}{R_0} - \frac{1}{R_w}\right)\right)$$

where

B is the barometric pressure [Pa];

T is the absolute temperature [K];

ϕ is the relative humidity (range 0 to 1);

R_0 is the gas constant of dry air [287,05 J/kgK];

R_w is the gas constant of water vapour [461,5 J/kgK];

P_w is the vapour pressure [Pa].

$$P_w = 0{,}0000205 \exp(0{,}0631846 \cdot T)$$

$$T = To + L\,(h_2 - h_1)$$

$$B = Bo\left(\frac{To}{To + L\,(h2 - h1)}\right)^{\frac{\mathrm{Go\ M}}{\mathrm{Rg\ L}}}$$

Where

Rg is the universal gas constant: 8.3144598 [J/mol/K];

Go is the gravitational acceleration: 9.80665 [m/s^2];

M is the molar mass of Earth's air: 0.0289644 [kg/mol];

L is the standard temperature lapse rate: -0.0065 [K/m];

To, Bo are the temperature and barometric pressure at the measured height;

h_2, h_1 = heights [m].

The mean altitude above sea level of the wind farm is 118.09 meters, taking into account that the mean altitude of the bases of the wind turbines is 6.09 meters and that the mean hub height of all wind turbines is 112 meters. The mean air density at 118.09 meters is calculated and meets a value of 1.1582 kg/m^3.

Wind Turbines at Pooneryn wind farm are situated within a height range of 14 meters and therefore the variation of the air density at each wind turbine needs to be taken into account. This is done with the help of WindFarmer software which allows us to obtain the air density at each wind turbine position and therefore correct the power curve accordingly.

3. WIND RESOURCE MEASUREMENT

The target of a wind resource measurement program is to obtain sufficient high-quality data to support an accurate estimation of the energy production potential, as well as the design and turbine selection, for the proposed or planned wind project. A wind measurement campaign should be a minimum of 12 months in duration although typical campaign lengths range from 12 to 36 months or even longer. The number and location of the met masts should be representative of the different wind conditions affecting a wind farm [1], [14].

Correct mounting of anemometers is essential in order to avoid wind speed bias and unnecessary flow distortion. Standard practice is to ensure the flow distortion at the anemometers, due to the mast and booms, result in wind speed variations below 0.5 % for sectors outside direct mast wake. International standards such as [13] or [15] are strongly recommended to be followed in order to reduce the uncertainty in the wind resource measurement.

Anemometers should preferably be calibrated according to the MEASNET guideline [16] by a MEASNET approved institute, ideally during a single calibration campaign. Accurate alignment of the wind vanes shall be performed during their installation in order to allow for wind direction offset correction of the data. Site magnetic declination should be taken into account in order to be included in wind direction measurements so they are referenced to the geographic north (or true north) [14].

On site measurement of atmospheric variables such as temperature, air pressure or air relative humidity are highly recommended in order to accurately calculate the mean air density of the project [13].

3.1. MAST DESCRIPTION

The following information from Pooneryn wind farm has been received:

- Decoded data from PO1_mast.
- Meteorological mast installation scheme.

A meteorological mast known as PO1_mast has been used to carry out the current assessment of Pooneryn wind farm. PO1_mast is located within the limits of the project as it can be seen on the maps presented in annex B. Since the extension of the proposed wind farm is over 15 kilometers, it would be advisable to install extra met masts.

In the next tables a summary of the location of the masts along with the information about all the sensors installed is presented. The detailed equipment installed at each met mast can be found on annex A.

Met Mast	COORD X	COORD Y	Reference system	UTM Zone	Elevation	Measurement Levels	Reference period data availability	Start measurement	End measurement
MET MAST CHARACTERISTICS									
PO1_MAST	403.645	1.056.659	UTM WGS84	T44N	3.1	40-60-78.6 (double)	98.78%	23/02/2015	24/02/2016

Table 5. Met mast description.

Since there is not available mast installation report and the width of the mast is not included in the installation scheme, it is unknown whether the mounting arrangements at PO1_mast is fully consistent with [13] and [15]. This fact has been taken into account in the uncertainty calculation. It should be noted that a site visit has not been performed in order to verify the mast configuration.

Calibration certificates of all the anemometers at PO1_mast supposedly comply with the MEASNET standard [16] since they are Thies First Class sensors. Already decoded data has been received and therefore it has not been possible to verify whether the correct calibration equations have been applied to the data registered by the logger.

There is no indication to whether the boom orientations are referred to the geographic north (true north) or the magnetic north. Since the site magnetic declination is 1.88ºW, the expected uncertainty due to this issue is kept under control. The top wind vane has been selected as the correct one.

PO1_mast has been used in order to calculate the wind distributions, the expected energy and the associated losses at the wind turbines of Pooneryn wind farm. In order to calculate the mean air density at the wind farm, measurements from PO1_mast have been taken into account. On the next table it is possible to observe the use given to each mast considered in the site assessment of Pooneryn wind farm.

MET MAST	WIND DATA SIMULATION	WIND SHEAR	AIR DENSITY	WIND SPEED	ENERGY YIELD	WAKE LOSSES	LONG TERM
MET MAST USE							
PO1_MAST	YES	YES	YES	YES	YES	YES	YES

Table 6. Use of met masts at Pooneryn WRA analysis.

3.2 DATA QUALITY CONTROL

Measurements carried out at a wind farm project usually contain periods of missing data and non-plausible values. These are caused mainly by faulty installation procedures, lack of maintenance or natural disturbances like trees, icing in winter times and malfunction of the devices due to lightning, etc [1].

To get a valid and reliable wind data base, it is necessary to detect implausible values and to filter these out through detailed data quality-check procedures [1], [2]. The process of data quality control at Nayxa involves the analysis of each sensor and magnitude on a 10 minute basis.

As a general rule, missing or erroneous data at a met mast are synthetized only from sensors installed at the same met mast. Synthesis of 10 minute wind data among different masts is not done unless a very severe affection is detected and an almost perfect correlation is found with another met mast ($R^2 > 0.90$ and minor scatter). In this case, no synthetic data has been generated from other masts (only among sensors installed at PO1_mast).

In the annex A the daily availability of the anemometers is presented along with all the problems detected at PO1_mast. Colourful maps with the amount of available daily data during the whole measurement campaign are shown. Tables with the monthly availability at each mast, number of data and mean wind speed of each anemometer are also provided.

A detailed description of the different issues found in the wind data checking is presented on annex A of the present report. Main findings on each met mast are presented hereunder.

- PO1_mast: A temporary failure on the anemometer placed at 60 meters and oriented towards 120º.

3.3 SENSOR FUNCTIONALITY

In general recalibration of the anemometers should be performed at the end of the measuring period in the same wind tunnel where the sensors were calibrated before their installation at the mast [1]. In case a recalibration is not performed, a so called in-situ test shall be alternatively performed following the procedure in the Annex K described in [13].

This test allows us to verify the lack of potential temporal trends in the anemometer performance and check the calibration consistency which are indicators of the anemometer performance being constant over time and lying within an acceptable range of uncertainty during the measurement period [1].

The two highest wind vanes have also been compared in this test, and the differences analysed. Potential offsets among them have also been studied with the aim of reducing the uncertainty of the resulting wind rose at each met mast. The following plots show the results of this test at each mast with the following conclusions:

- PO1_mast: It can be seen that the correlation between the main anemometers (both placed at 78.6 meters) is excellent apart from the sectors affected by the mast shadow. The main anemometers show no temporal drift and their performance has been coherent and accurate throughout time.

  The performance of two highest wind vanes showed an excellent behaviour with no evidence of misalignment rather than the uncertainty present in the wind vane installation procedure.

  It can be concluded that the measurement conditions at PO1_mast show consistency in time and that anemometers as well as wind vanes have registered accurate measurements during the selected reference period.

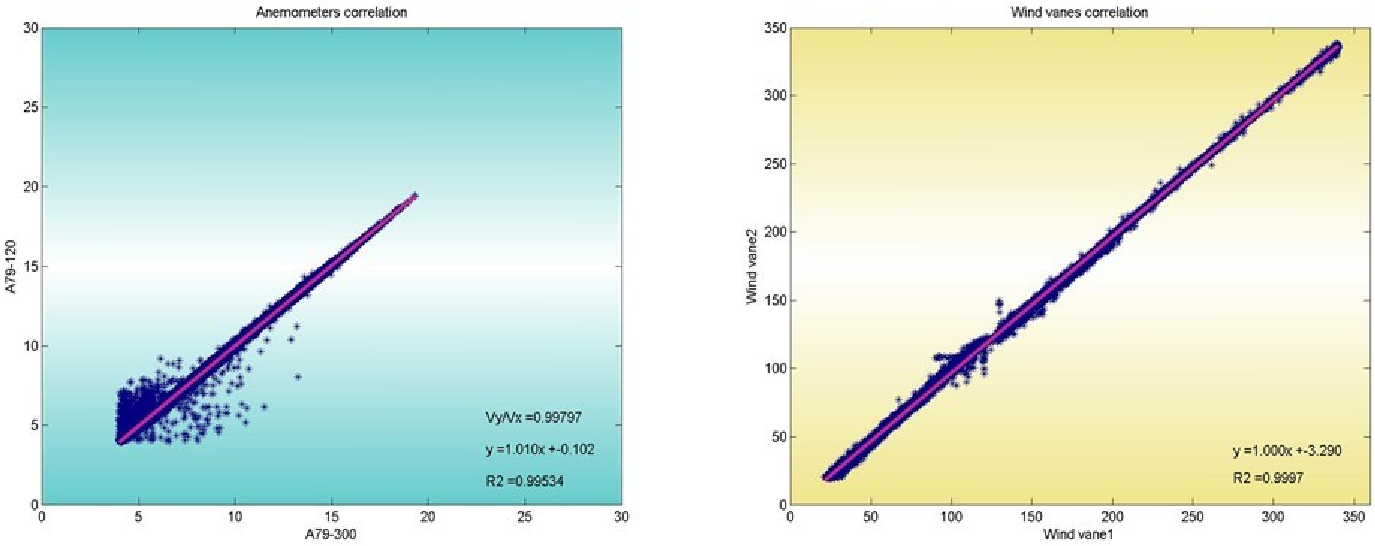


Figure 3. Main anemometers and correlation of the wind vanes, PO1_mast, reference period.

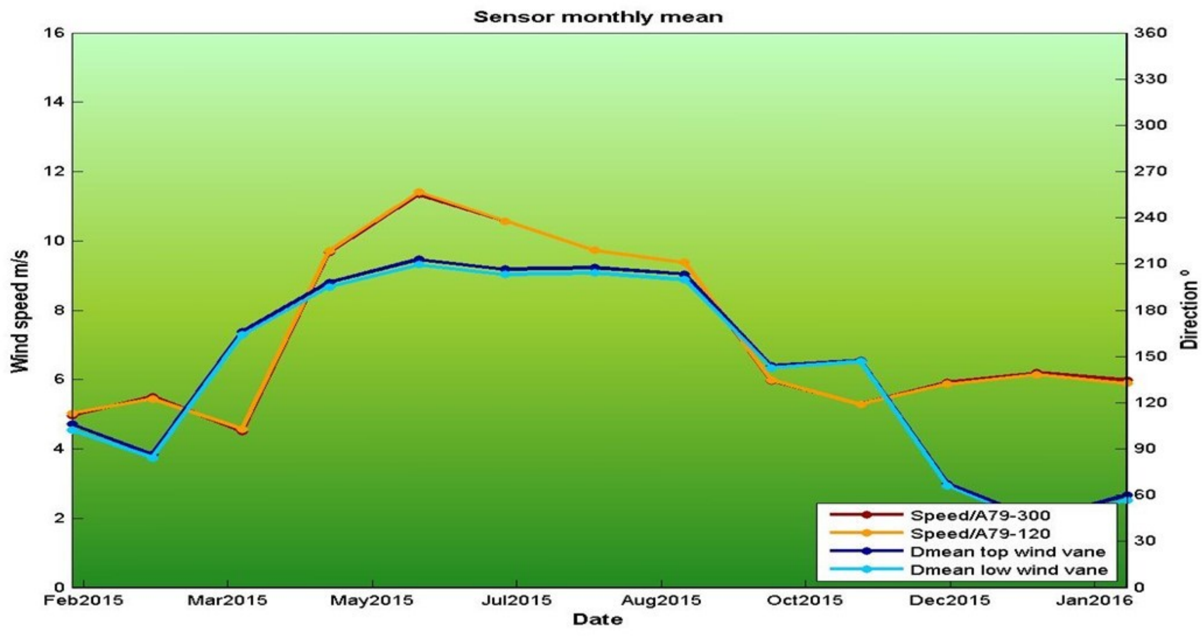


Figure 4. Monthly means of the sensors analysed PO1_mast, reference period.

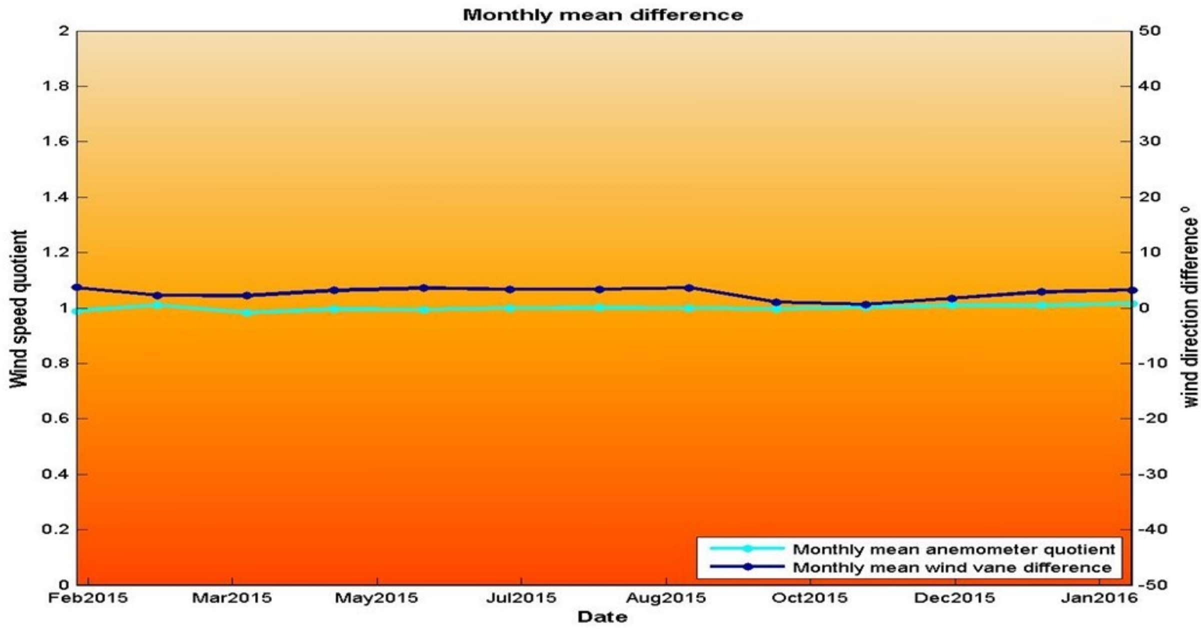


Figure 5. Monthly mean difference of the analysed sensors PO1_mast, reference period.

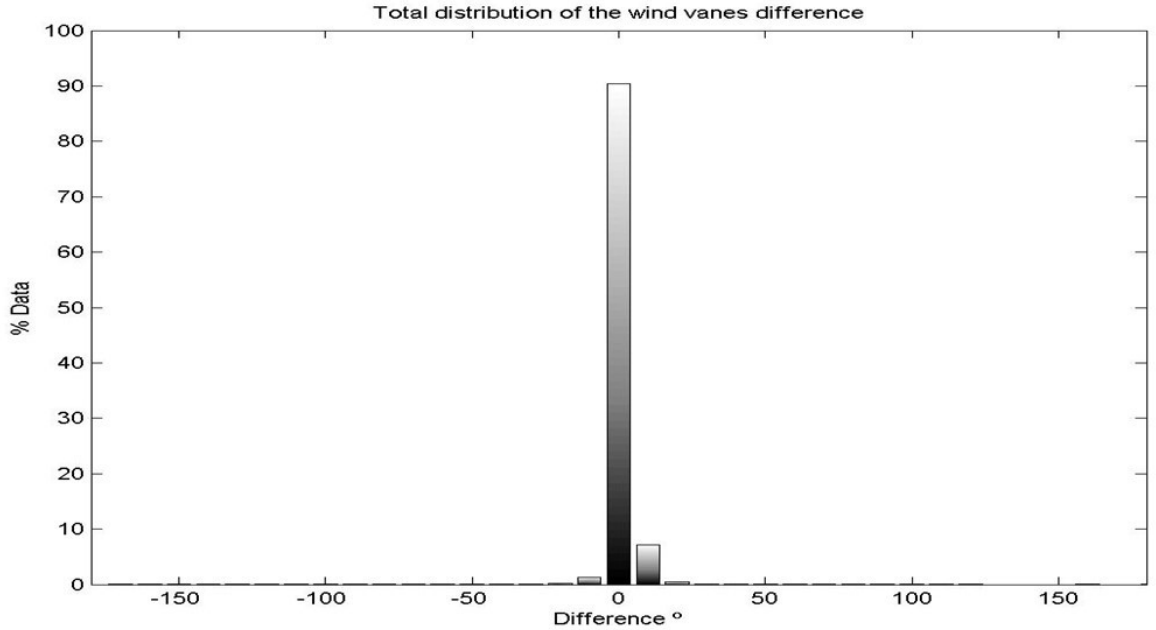


Figure 6. Distribution of the wind vane difference PO1_mast, reference period.

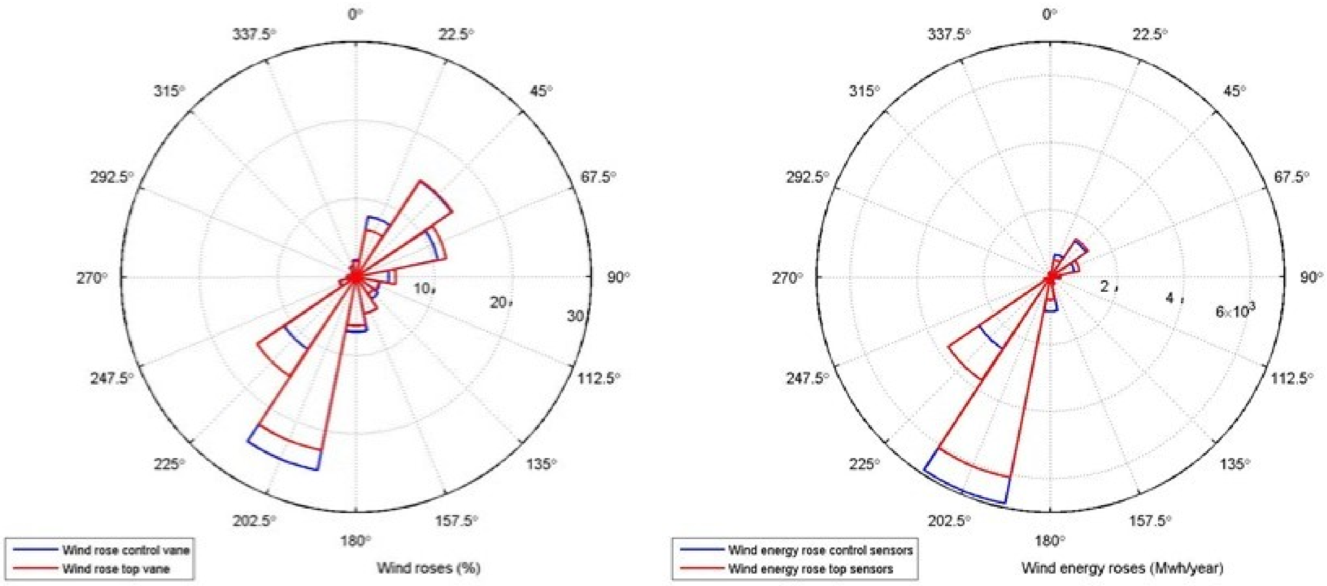


Figure 7. Wind rose and wind energy rose analysis PO1_mast, reference period.

3.4 MET MAST AFFECTION / LIGHTNING ROD AFFECTION

The tower supporting an anemometer modifies the local wind field and the measurements of the anemometer. The impact on wind speed is most pronounced within the tower wake, however, the entire local flow field is impacted. In fields such as wind energy resource assessment, where anemometer data must be as accurate as possible, tower-induced flow modification contributes a non-negligible amount of uncertainty to the wind resource assessment [14].

This uncertainty can be minimized by the use of one (or both) of the following strategies [14], [15]:

- Installation of a top mounted anemometer at a distance of at least 1.5 meters from the top of the met mast and a control anemometer on a side boom within 2.5 meters of the top anemometer. The affection of an eventual lightning rod on the top anemometer should be removed with the help of the control anemometer.

- Installation of two boom mounted anemometers at the same height. In order to eliminate the mast affection, a ratio analysis between these two anemometers should be done with the goal of identifying the angles in which the wind flow is distorted by the mast.

In this case, the second option was chosen as the preferred one at PO1_mast. Two anemometers were installed at 78.6 meters pointing 300º and 120º respectively and therefore both anemometers have been affected by the shadow of the met mast at a certain angle. This affection has been removed by the combination of both datasets using the following procedure [17]:

- Select data from the non-affected anemometer in the shadow of the met mast.
- Average both sets of data in non-affected directions.

The following picture shows the mast affection on wind speed measurements at the anemometers located at a height of 78.6 meters and oriented towards 300ª and 120ª respectively (Ane1, Ane2)).

- Ane1: Measurements affected by the met mast on the angle range 113º to 142º.
- Ane2: Measurements affected by the met mast on the angle range 281º to 312º.

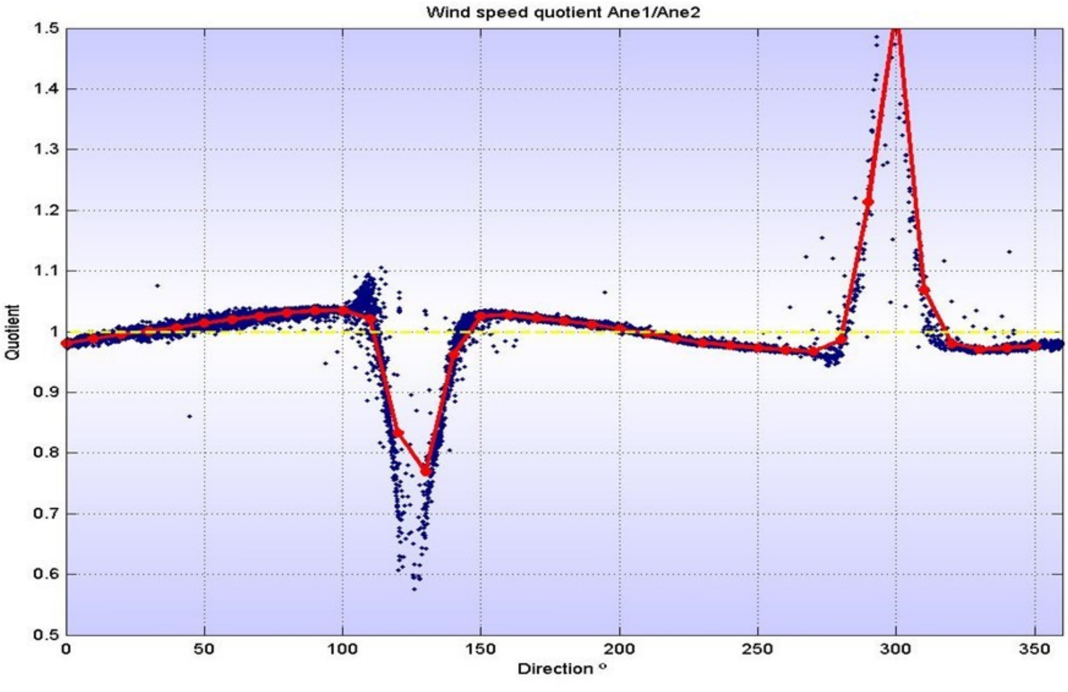


Figure 8. Met mast affection on the top anemometers, PO1_mast.

4. HUB HEIGHT WIND REGIME AND WIND SHEAR

The variation of the wind speed with height above ground is the vertical wind speed profile, also known as wind shear. The wind shear is a parameter used to estimate the wind speed time series at hub height should the height of the available masts be different from the projected hub height [14].

4.1 WIND SHEAR

In order to calculate the mean value of the wind shear, only for references purposes, a 16x1 matrix of shear values has been calculated at each mast, by means of Hellman's potential law of the wind speed profile with height [18]. Data are divided in 16 wind direction sectors according to the highest valid wind vane and the following formula is applied at each sector:

$$\alpha = \frac{\ln(Vtop) - \ln(Vlow)}{\ln(Htop) - \ln(Hlow)}$$

Where V stands for wind speed and H for height. The two heights in the wind shear calculation should preferably be separated by a distance meeting these two conditions, (20 meters; a ratio of at least 1.5) according to Nayxa's experience. This keeps the uncertainty in the calculated shear due to speed and height errors manageable. In this case both recommendations are followed.

Wind shear values for wind speeds lower than the cut-in of the wind turbines have been discarded and substituted with mean values in order to avoid the inaccuracy of anemometers at such low wind speeds.

In order to obtain the mean value of the wind shear at each mast, the previous 16x1 shear matrix is weighted with the help of another 16x1 matrix containing the data frequency, obtaining the following values:

MET MAST, LEVELS	WIND SHEAR
Mast_PO1, 78.6/40 (free mast affection)	0.153

Table 7. Wind shear values at the met masts

Anemometers used in the wind shear calculations should preferably measure the wind in a homogeneous way, using similar booms, sharing mast orientation and ideally free of the mast affection [14]. In this case, anemometers at 78.6 and 40 meters have been selected.

4.2 EXTRAPOLATION TO HUB HEIGHT

The previous calculation showed the finding of the mean wind shear at PO1_mast considered just for informative purposes. The calculation of the time series wind speed at hub height at each mast is explained below.

In order to calculate the time series at hub height (at each met mast), 10 minute data from the top anemometers, free of the mast affection, has been selected and the logarithmic law of wind profile has been applied on a 10 minute basis, using the following formula [18]:

$$\text{Vhub} = \text{Vtop} \times \frac{\ln(Hhub/Zo)}{\ln(Htop/Zo)}$$

Where V stands for wind speed, H for height and Zo is the so-called roughness coefficient length which is expressed in metres and depends basically on the land type. According to [18] Zo can be obtained by means of measurements at two different heights using the following estimator:

$$Zo = \mathrm{EXP}\ \frac{\mathrm{Htop}^{\propto} \times \ln(\mathrm{Hlow}) - \mathrm{Hlow}^{\propto} \times \ln(\mathrm{Hlow})}{\mathrm{Htop}^{\propto} - Hlow^{\propto}}$$

Where H stands for height and α is the ten minute wind shear, calculated according to Hellman's potential law of the wind speed profile. The anemometers underlined on table 7 have been used to calculate the α parameter on a 10 minute basis and therefore provide the information on the vertical profile of the wind speed. As a result a 10 minute time series at hub height has been obtained at PO1_mast.

The resulting long term (section 6) wind speed at hub height at each met mast in the selected reference period (section 5) is:

- 8.2223 m/s at PO1_mast (112 meters of height).

4.3 WIND STATISTICS AT HUB HEIGHT

Within the next pages, statistical information obtained at each mast is presented. These plots correspond to the registered wind speed data extrapolated to the hub height and to the highest valid wind vane within the selected reference periods.

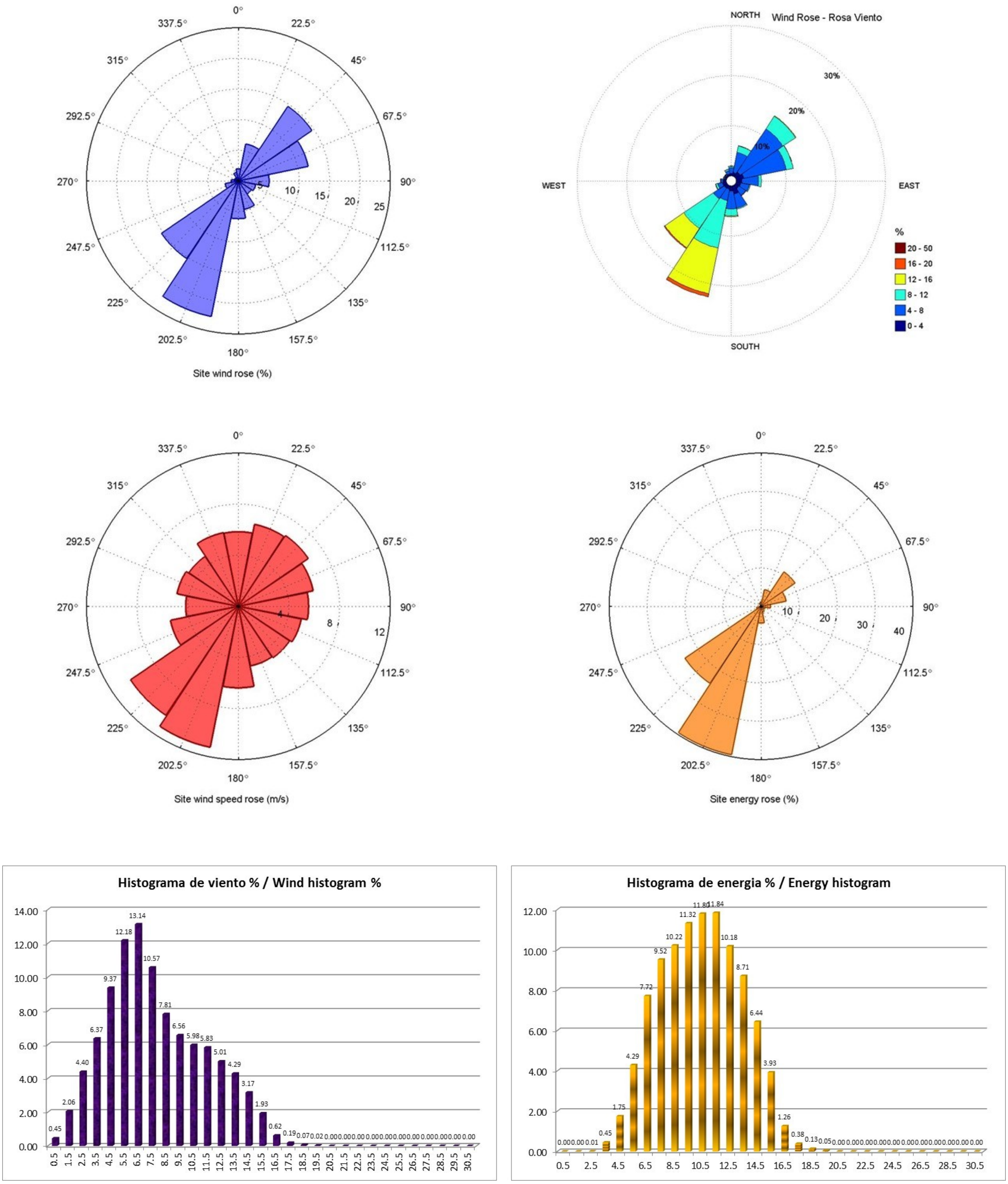


Figure 9. Wind roses and histograms, PO1_mast, reference period.

5. SELECTION OF THE REFERENCE PERIOD

In wind resource assessment it is essential to define a reference period which becomes the most representative one of the general wind conditions affecting the wind farm. It is strongly recommended to select entire blocks of years to constitute the reference period, especially at sites with different wind regimes depending on the season. Wind speed and wind direction data should be reliable in the selected reference period [14].

In order to maximize the wind data to be used in this analysis and comply with the conditions mentioned in the previous paragraph, the following reference period has been selected at PO1_mast:

- 24/02/2015 to 23/02/2016 at PO1_mast (1 year).

The selection of these reference periods have been done with the help of the long term sources (Merra2 reanalysis data) and with three different targets:

- Finding the most representative period compared to the long term wind regime.
- Maximizing the wind data availability.
- Minimizing the synthesis of wind data.

Once the selection of the reference period is done, the availability of the filtered wind data is calculated, meeting a value of 98.782% at PO1_mast. Nayxa always recommends working with availability values over 97%. The valid number of daily data, at each mast, during the reference period is presented on the next tables.

	DAY / DIA																														
MONTH / MES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Feb-15	####	####	####	####	####	####	####	####	####	####	####	####	####	####	####	####	####	####	####	####	####	####	####	144	144	139	144	144	####	####	####
Mar-15	144	144	144	144	144	144	143	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	143	144	144	144	144	144	144	144	144
Apr-15	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	141	144	144	####
May-15	144	144	144	137	33	0	0	0	73	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144
Jun-15	144	144	144	144	144	144	144	144	143	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	####
Jul-15	144	144	144	144	144	144	143	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144
Aug-15	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144
Sep-15	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	138	144	144	144	144	144	144	####
Oct-15	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144
Nov-15	144	144	144	144	144	144	144	143	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	####
Dec-15	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144
Jan-16	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144
Feb-16	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	####	####	####	####	####	####	####	####

0% data | 1% - 50% data | 51% - 99% data | 100% data | #### No data | > 100% data

Table 8. Final daily availability at hub height PO1_mast, reference period.

After the selection of the reference period, a series of wind speed correction factors have been calculated at each mast in order to avoid seasonal bias of the wind speed, account for leap years and data gaps and make the results representative of the long term wind regime.

The first wind speed correction factor has been calculated using the onsite time series, with the target of avoiding any seasonal bias of the wind speed and account for leap years and data gaps. This factor is calculated by using an algorithm known as "*Mean of monthly means*" which stands as:

- The mean wind speed or distribution for each month is determined from the average of all valid data recorded in that month, over the period. This is taken as the monthly mean, thereby assuming that the valid data are representative of any missing data.

- The mean of the monthly means (weighted by the number of days in a month) is taken, in order to determine the annual mean ("mean of means").

This factor is found to be 1.0000 at PO1_mast. Factors associated with the long term correction of the wind statistics will be presented on the next point.

6. LONG-TERM CORRECTION

The average annual wind speed fluctuates around a long-term average value depending on the area of the world. To get a reliable estimate of the wind conditions in the long-term it is necessary to compare the short-term data with a long-term reference data set. For this, consistent long-term reference data sets (or a suitable index) are required. The purpose is to decrease short-term wind fluctuations and to derive long-term representative wind statistics. The benefit of the longer data set must be considered against the uncertainty of the correlation between the reference and site data [14], [19].

Within the scope of extending the confidence in the wind speed and wind energy predictions from the duration of the selected reference periods to longer time periods, a long term analysis has been done. MCP is the abbreviation for Measure-Correlate-Predict techniques, which is widely in use for establishing long-term wind statistics, using limited wind data from the current site and long-term data from a more-or-less nearby site. The general methodology of the MCP process stands as follows [1], [2]:

- Collect wind data at the predictor site for a period of time as long as possible.
- Identify a reference site in the vicinity of the predictor site, for which high quality long term records exist and which has a similar exposure to main winds - this is hereafter referred to as the ‘reference’ site.
- Obtain wind data from the reference site for the same time period as for the predictor site -this period is hereafter referred to as the ‘concurrent period’.
- Establish a relationship, if statistically possible, between the data from the reference and predictor sites for the concurrent period.
- Obtain wind data from the reference site for a historic period of 10 to 20 years duration - this period is hereafter referred to as the ‘historic’ period.

- Apply the relationship determined above to the historic data from the reference site to 'predict' what the winds would have been at the predictor site over that period. Note that this is a prediction of the winds that would have been observed had measurements been made at the predictor site for the same period as the historic data, rather than a prediction of winds that will be observed in future.

6.1 LONG TERM CORRELATION WITH REANALYSIS DATA

An MCP analysis has been done with the help of Merra2 reanalysis data [3]. This is done with the target of extending the representativeness of the aforementioned reference periods to a longer time period.

Merra2 data is a NASA reanalysis project, which makes use of recent version satellite observation using the Goddard Earth Observing System Version 5 (GEOS-5) and Atmospheric Data Assimilation System (ADAS). The data is being provided from 1979 until present time in a horizontal resolution of 0.5 (latitude) x 2/3 (longitude) degrees, which corresponds to about 50 km spatial resolution. The data is provided at a height of 50 m above ground and in hourly time intervals [3].

Several nodes located near the project have been analysed, of which the node with the best properties is located at the global WGS84 coordinates 9.5ºN and 80.625ºE. Several characteristics such as the R^2 of the correlation, the potential existence of artificial trends and the distance to the project as well as exposure to the same wind regime have been assessed in order to make the selection of the best node [14].

Onsite wind data and reference wind data have been related by means of a PCA correlation based on monthly means of the wind speed. Since this correlation has proven to have good properties, a wind index long term assessment [20], based this time on daily means of the wind speed, has been implemented with the target of calculating a wind speed correction factor of the wind speed at each mast that extends in time the representativeness of the selected reference period.

Firstly, the common period of the site and reference data is going to be analysed. Monthly wind speed values of the reference data and the PO1_mast are shown in the next plot. The linear correlation on monthly mean wind speed between both sources of data has also been plotted.

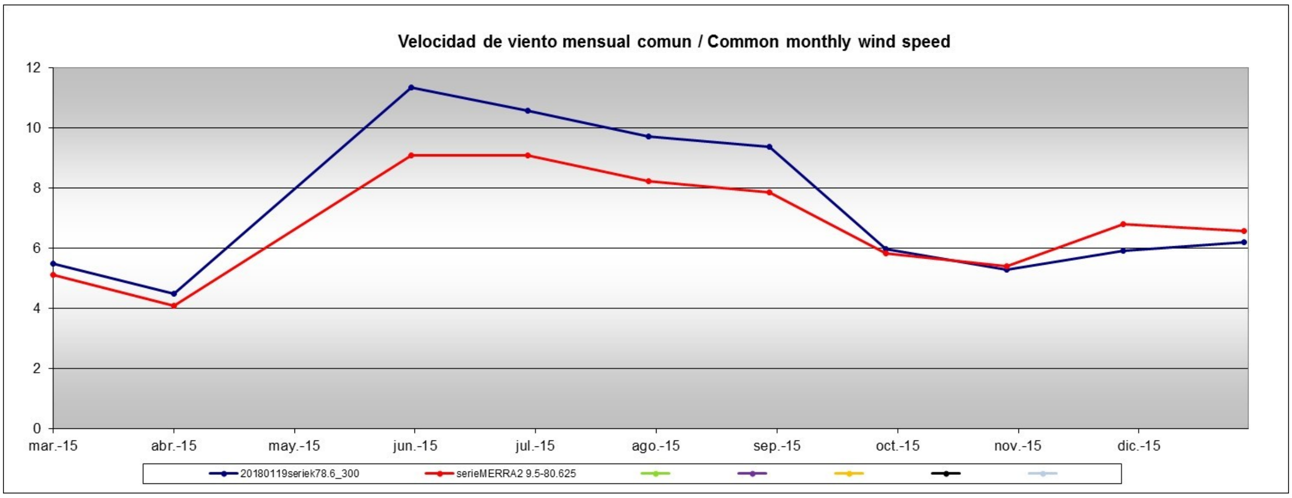


Figure 10. Monthly wind speed from PO1_mast and Merra2 data.

a) It can be seen that PO1_mast wind speed and Merra2 reanalysis data follow a similar tendency in the common period of measurements.

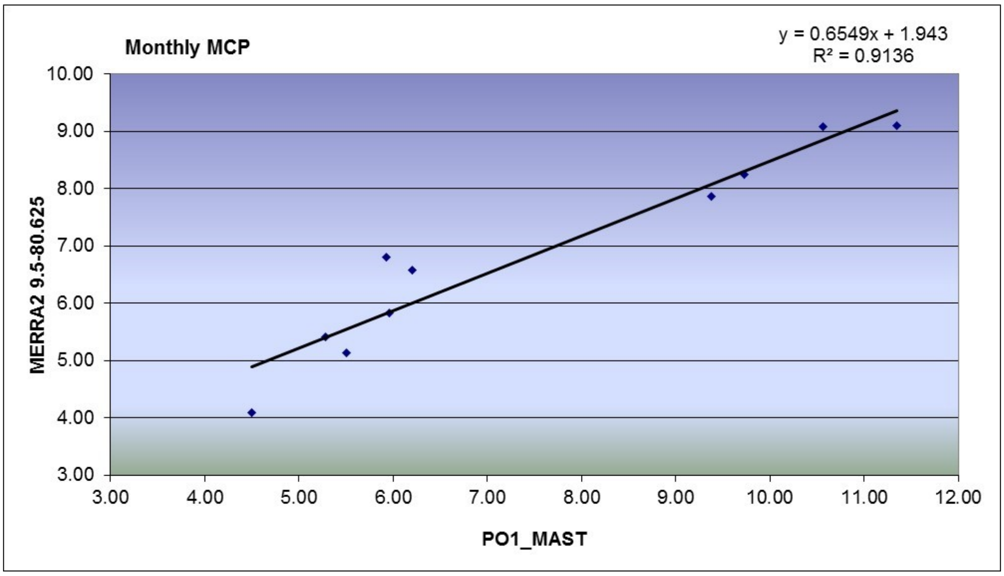


Figure 11. Global monthly wind speed correlation of PO1_mast and Merra2 data.

b) Minor scatter and a Pearson coefficient r^2 of 0.9136 in monthly mean wind speeds is obtained in the correlation reference data/site data, which is an indicator of an excellent relation between both datasets.

These last two statements allow us to conclude that a long term assessment can be implemented between onsite data and Merra2 reanalysis data and that therefore it is going to be possible to extend in time the representativeness of the selected reference period at each met mast.

It is extremely important that reference datasets do not show a temporal tendency and therefore they only represent the natural variability of the wind throughout the time [19]. In the following plot, the monthly mean wind speed of the reference data is presented along with the tendency line.

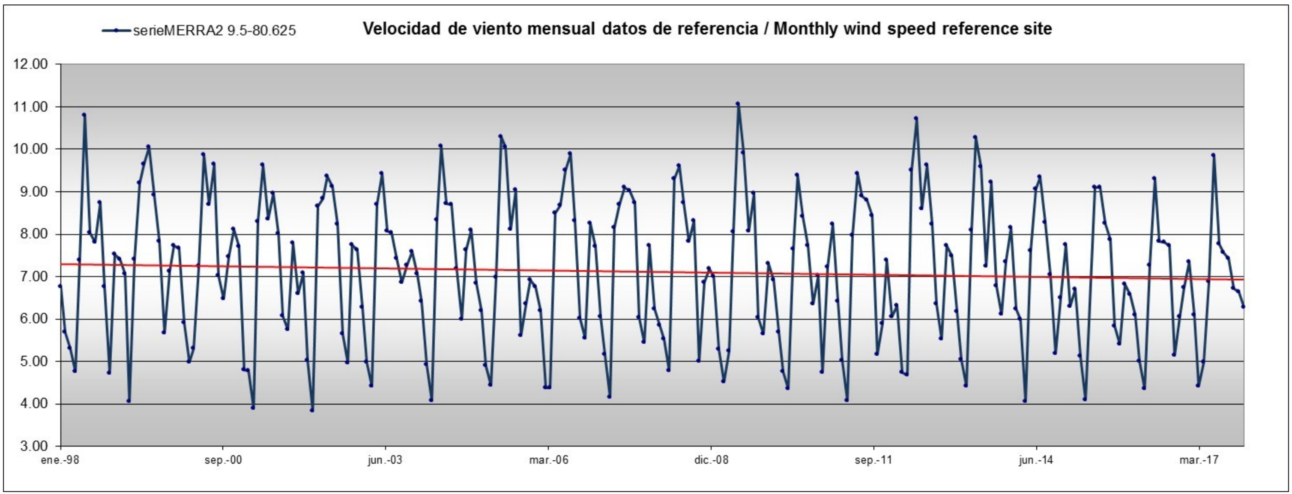


Figure 12. Monthly wind speed, reference data, analysis of potential artificial trends.

The potential presence of artificial temporal tendency at this node has been studied (figures 12 and 13) resulting in no apparent artificial contamination of the data. Therefore Merra2 reanalysis data has been used with the target of making the aforementioned reference period, representative of a total time period of 20 years, 01/01/1998 to 31/12/2017.

Long term correction factors of the wind speed have been found at each mast by means of a wind index correlation of the daily mean wind speeds. This process is illustrated on the next plots. These factors have been combined with the wind speed factor found on the previous point (in order to remove the seasonal bias of the wind speed).

In the following plot the yearly mean wind speed of the reference data is presented along with the historic mean wind speed of the reference data (red line) and the mean wind speed of the long-term data in the selected reference period at PO1_mast (green line).

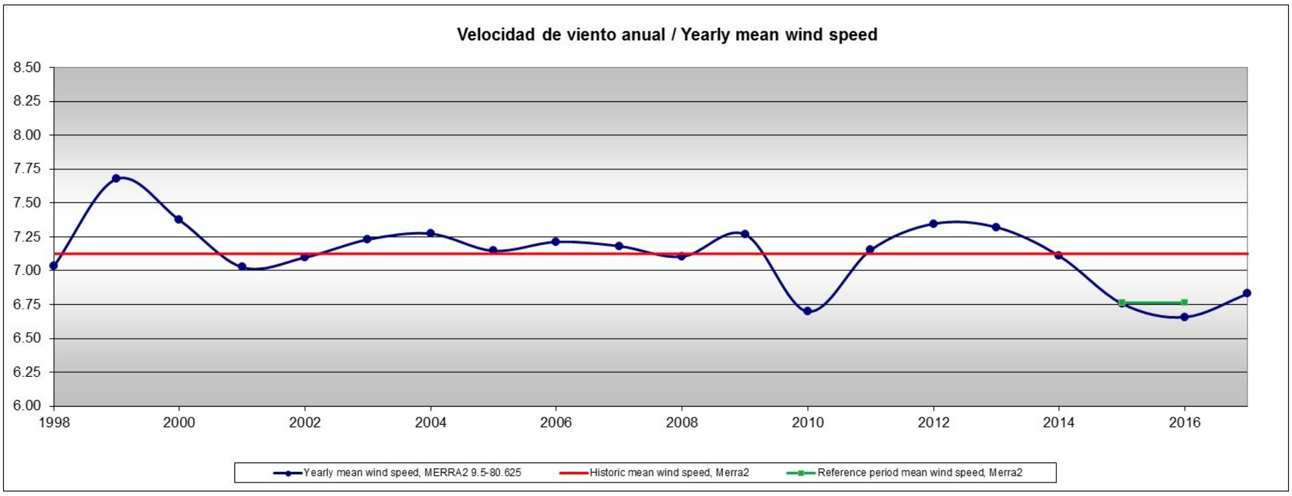


Figure 13. Merra2 wind speed during PO1_mast reference period vs historic wind regime.

The resulting wind speed factor to be applied to the onsite time series is 1.0533 at PO1_mast. This value is combined with the wind speed factor found on the previous point, to meet a total correction factor of the wind speed that equals 1.0000 x 1.0533 = 1.0533 at PO1_mast.

The mean wind to energy sensitivity factor has been calculated, meeting a mean value of 1.3659% at PO1_mast. This value corresponds to the wind turbine model Vestas V136-3600 at a hub height of 112 meters and at a mean air density of 1.1582 kg/m^3.

The energy sensitivity is defined as the value used to convert wind speed factors into energy magnitudes. It is defined as the percentage of energy increase obtained when wind speed is increased by 1%.

This sensitivity ratio shows how sensitive the net energy production is to changes in wind speed [21], and it is dependent mainly on the wind speed distribution and power curve of the wind turbine.

This ratio is used to convert the previous wind speed factors into energy correction factors to be applied to the estimated energy output at each of the wind turbine positions studied in this project.

The energy correction factor is found to be 1.0727 at PO1_mast for the Vestas V136-3600 model at a hub height of 112 meters and at a mean air density of 1.1582 kg/m^3. The wind speed and energy correction factors have been incorporated in the production table presented in the 10^{th} point of this report.

Wind speed and energy correction factors along with the methodology used to obtain them have been defined within sections 5 and 6 of the present report. The wind speed correction factor has been applied to the wind speed at the different wind turbine positions and wind speed distributions, and the energy correction factor has been applied to find the energy output of each wind turbine.

As a conclusion, the use of long term data allows us to extend the quality of the wind speed and energy production results, making them representative of a period of 20 years. The algorithm known as “*Mean of monthly means*” allows us to avoid any potential seasonal bias in the wind data used and account for leap years and data gaps.

7. WIND FLOW MODELLING

The wind flow modelling provides predictions of the flow conditions across the site area for locations other than the site mast positions [14]. The industry standard WAsP wind flow model is often used for this purpose.

Details of the WAsP wind flow model and its validation are given in [4] and [5]. In order to set up the wind modelling with the software WAsP 11.6, the following inputs have been used:

- Orographic map covering an extension of 20 kilometers around the wind farm limits derived from STRM Version 3 database.
- Roughness map covering an extension of 20 kilometers around the wind farm limits built from high resolution satellite imagery by Nayxa.
- Wind farm layout designed by Nayxa.
- Wind speed distributions at each met mast, corresponding to the selected reference period and extrapolated at hub height.

In the next plot, the wind speed distributions at hub height at the different masts considered to model the wind field with WAsP software are shown. The distributions have been calculated from the wind data registered at each mast, narrowed to selected reference period and extrapolated to hub height.

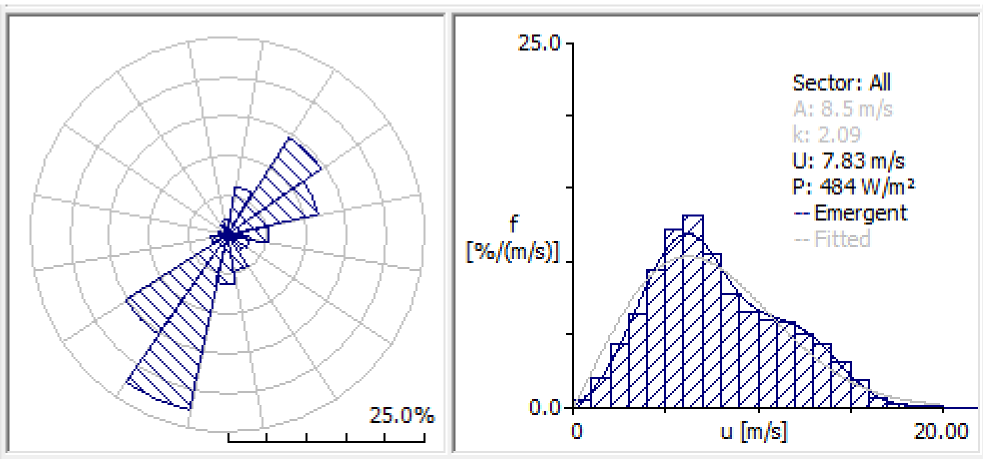


Figure 14. Wind speed distribution at hub height, PO1_mast, reference period.

Details of the WindFarmer software are given in [6] and [7]. In order to set up the simulations, the software version WindFarmer 5.3.38 has been used and the following inputs have been considered:

- Results of the wind flow modelling (WAsP).
- Wake calculation according to Eddy viscosity model.
- Mean air density of the project at hub height.
- Cp and Ct curves at the mean air density of the project.
- Air density lapse rate of -0.113 (kg/m^3)/km.
- Ambient turbulence intensity registered at PO1_mast.
- Direction shifted sector probabilities enabled.
- Correction for large wind farms enabled.
- Association method enabled [24].

The wake model used to estimate the wake losses among wind turbines is the Eddy Viscosity model provided within WindFarmer software which is a is a non-linear model that that takes into account the ambient turbulence intensity registered at each mast [6]. The Cp curve at the main air density of the project has been obtained by means of a shape-preserving piecewise cubic interpolation fed by the power curves at several air densities, extracted from document [34].

8. ENERGY ANALYSIS

The annual energy production assessment is presented within the following points. Matlab software has been used to horizontally extrapolate the hub height time series of each met mast to the wind turbine position with the help of the results provided by WAsP and WindFarmer and the different simulations performed (one from each available mast).

WAsP + WindFarmer results have been used to obtain the speed-up factors at each wind turbine location and to obtain the wind speed deficit at each wind turbine position caused by the wake effect respectively. The set-up of the simulations performed have been described on the previous point.

Matlab software, with the help of WAsP + WindFarmer results, has been used to calculate the gross energy yield at each wind turbine position based on a 10 minute time analysis, using a turbine site adapted power curve. The mean air density at each turbine position has been obtained with WindFarmer. The power curve at each wind turbine location has been calculated by means of a shape-preserving piecewise cubic interpolation fed by the power curves at several air densities, extracted from document [34].

As a final step the gross production at every position has been averaged to represent a time period of 365.25 days while being representative of the long term wind regime. The net energy output has been estimated by deducting computed losses from the calculated gross energy yield.

The wind speed and energy correction factors have been applied to the resulting wind speed and energy yield at each wind turbine position in order to make the results representative of the historical wind regime. The balance of losses for Pooneryn wind farm will be presented in the next point.

9. LOSSES

The net energy output is estimated by deducting expected losses from the estimated gross energy output. The loss definitions used in the analysis are based on industry-standard categories [25]. A detailed analysis of losses is conducted for the planned wind farm. Each identified source of loss is calculated relative to the total gross energy output and deducted in order to find the expected net energy yield [1], [2].

9.1 WAKE EFFECT

Wind turbines extract energy from the wind by converting the kinetic energy in wind into electricity. As wind flows through a turbine, the volume of air downwind of the turbine has a lower wind speed and higher turbulence than wind in the freestream. As the flow proceeds downstream, there is a spreading of the wake and the wake recovers towards free stream conditions. The wake effect is the aggregated influence on the energy production of the wind farm, which results from the changes in wind speed caused by the impact of the turbines on each other [6]. It is important to consider wake effects from neighboring wind farms and the possible impact of wind farms that will be built in the future [2].

In this assessment no adjacent and no future wind farms have been taken into account to model the wake losses at Pooneryn wind farm. Wake losses have been calculated using the Eddy Viscosity model included within the software WindFarmer 5.3.38. Directional and wind speed binned ambient turbulence intensity has been included as part of the wake model [2] and the association methodology has been applied [24].

9.2 TURBINE UNAVAILABILITY

This factor defines the expected average turbine availability of the wind farm over the life of the project. It represents, as a percentage, the factor which needs to be applied to the gross energy to account for the loss of energy associated with the amount of time the turbines are unavailable to produce electricity.

In this case, an unavailability factor of 3% is included which is the value generally signed between the wind farm developer and the turbine manufacturer.

9.3 ELECTRICAL EFFICIENCY

There will be electrical losses experienced between the low voltage terminals of each of the wind turbines and the wind farm point of connection, which is usually located within a wind farm switching station.

This factors includes the electrical losses encountered when the wind farm is operational and which are manifested as a reduction in the energy measured by an export meter at the point of connection. This is presented as an overall electrical efficiency, and is based on the long-term average expected production pattern of the wind farm. It is also necessary to consider the power that the wind farm consumes when the wind farm is not operational.

Based on common values considered in the wind energy sector, a mean energy loss of 3% has been included.

9.4 ADAPTATION FACTOR

Turbine Performance

In an energy production calculation, a power curve supplied by the turbine manufacturer is used within the analysis. Most wind turbines will shut down when the wind speed exceeds a certain limit. High wind speed shutdown events can cause significant fatigue loading. Therefore, to prevent repeated start up and shut down of the turbine when winds are close to the shutdown threshold, hysteresis is commonly introduced into the turbine control algorithm [11]. It is also necessary to adjust for any generic or site specific issues, which may mean that for a specific site the wind turbine will not perform in accordance with the supplied power curve [26].

Environmental losses

In certain conditions, dirt can form on the blades or, over time, the surface of the blade may degrade. Also, ice can build up on a wind turbine. These influences can affect the energy production of a wind farm. Extremes of weather can also affect the energy production of a wind farm; as can the growth or felling of nearby trees [25].

Plant and Grid Unavailability

Similar factors are needed for the 'Balance of Plant' availability, which relates to the electrical infrastructure of the site and 'Grid Availability', which relates to the availability of the grid over which power can be exported.

The sum of all these three factors is set to 5% and has been applied to obtain the net energy production of Pooneryn wind farm. It should be noted that this is a compilation of all potential factors affecting the production of the wind turbines and that each factor is set to 0% in case of no affection.

The adaptation factor reflects the particular conditions that wind turbines will face at Pooneryn wind farm. These losses are site-related and might be subjected to a deeper study in collaboration with the wind turbine manufacturer and the electrical network operator. A Value of 5% has been calculated.

9.5 CURTAILMENTS

Some or all of the turbines within a wind farm may need to be shut down in order to mitigate issues associated with turbine loading, export to the grid, or certain planning conditions. No curtailments have been pointed out by the client.

Turbine	Hub Height m	Rotor m	Model	Power Kw	UTM X / LONG.	UTM Y / LAT.	Height m	RIX %	Wind Farm Speed - Measurement Period m/s	Wind Speed Long-Term Factor	Wind Farm Speed - Long Term m/s	Gross Energy - Measurement Period MWh/year	Energy Long-Term Factor	Gross Energy - Long Term MWh/year	Wake Losses %	Adaptation Factor Loss %	Electrical Losses %	Unavailability %	Net Energy MWh/year	Net Equivalent Hours
POONERYN WIND FARM / P50 PRODUCTION RESULTS																				
WT-1	112	136	V136-3600	3600	396412	1061479	9	0.0	7.79	1.053	8.21	15597	1.073	16731	1.54	5.0	3.0	3.0	14726	4090
WT-2	112	136	V136-3600	3600	396659	1061306	10	0.0	7.77	1.053	8.18	15587	1.073	16720	1.90	5.0	3.0	3.0	14661	4072
WT-3	112	136	V136-3600	3600	396905	1061133	10	0.0	7.82	1.053	8.24	15677	1.073	16817	1.87	5.0	3.0	3.0	14752	4098
WT-4	112	136	V136-3600	3600	397153	1060961	10	0.0	7.81	1.053	8.23	15674	1.073	16813	1.93	5.0	3.0	3.0	14739	4094
WT-5	112	136	V136-3600	3600	397399	1060787	6	0.0	7.73	1.053	8.14	15474	1.073	16599	2.13	5.0	3.0	3.0	14521	4034
WT-6	112	136	V136-3600	3600	397646	1060614	4	0.0	7.66	1.053	8.07	15438	1.073	16561	3.05	5.0	3.0	3.0	14352	3987
WT-7	112	136	V136-3600	3600	397894	1060442	6	0.0	7.66	1.053	8.06	15520	1.073	16648	4.39	5.0	3.0	3.0	14228	3952
WT-8	112	136	V136-3600	3600	398518	1060715	15	0.0	7.92	1.053	8.34	15969	1.073	17130	2.09	5.0	3.0	3.0	14992	4165
WT-9	112	136	V136-3600	3600	398763	1060544	11	0.0	7.86	1.053	8.27	15853	1.073	17006	1.96	5.0	3.0	3.0	14902	4140
WT-10	112	136	V136-3600	3600	399010	1060373	9	0.0	7.82	1.053	8.24	15696	1.073	16837	1.87	5.0	3.0	3.0	14768	4102
WT-11	112	136	V136-3600	3600	399255	1060200	10	0.0	7.82	1.053	8.24	15710	1.073	16852	1.88	5.0	3.0	3.0	14780	4105
WT-12	112	136	V136-3600	3600	399500	1060027	9	0.0	7.81	1.053	8.23	15684	1.073	16824	1.85	5.0	3.0	3.0	14760	4100
WT-13	112	136	V136-3600	3600	399746	1059855	10	0.0	7.80	1.053	8.21	15675	1.073	16815	1.88	5.0	3.0	3.0	14748	4097
WT-14	112	136	V136-3600	3600	399992	1059684	8	0.0	7.77	1.053	8.19	15586	1.073	16719	1.85	5.0	3.0	3.0	14668	4074
WT-15	112	136	V136-3600	3600	400238	1059511	5	0.0	7.72	1.053	8.13	15495	1.073	16621	1.82	5.0	3.0	3.0	14587	4052
WT-16	112	136	V136-3600	3600	400485	1059338	6	0.0	7.76	1.053	8.17	15597	1.073	16731	1.78	5.0	3.0	3.0	14689	4080
WT-17	112	136	V136-3600	3600	400731	1059165	6	0.0	7.74	1.053	8.15	15553	1.073	16684	1.82	5.0	3.0	3.0	14642	4067
WT-18	112	136	V136-3600	3600	400976	1058991	5	0.0	7.73	1.053	8.14	15527	1.073	16656	1.83	5.0	3.0	3.0	14616	4060
WT-19	112	136	V136-3600	3600	401222	1058819	9	0.0	7.81	1.053	8.23	15745	1.073	16890	1.79	5.0	3.0	3.0	14826	4118
WT-20	112	136	V136-3600	3600	401470	1058647	8	0.0	7.82	1.053	8.24	15764	1.073	16910	1.73	5.0	3.0	3.0	14854	4126
WT-21	112	136	V136-3600	3600	401718	1058476	6	0.0	7.81	1.053	8.23	15786	1.073	16934	1.76	5.0	3.0	3.0	14870	4131
WT-22	112	136	V136-3600	3600	401963	1058303	7	0.0	7.84	1.053	8.26	15829	1.073	16980	1.72	5.0	3.0	3.0	14916	4143
WT-23	112	136	V136-3600	3600	402210	1058131	10	0.0	7.86	1.053	8.28	15878	1.073	17032	1.75	5.0	3.0	3.0	14957	4155
WT-24	112	136	V136-3600	3600	402457	1057959	6	0.0	7.82	1.053	8.23	15763	1.073	16909	1.72	5.0	3.0	3.0	14855	4126
WT-25	112	136	V136-3600	3600	402701	1057782	6	0.0	7.80	1.053	8.21	15705	1.073	16847	1.78	5.0	3.0	3.0	14791	4109
WT-26	112	136	V136-3600	3600	402950	1057612	9	0.0	7.81	1.053	8.22	15748	1.073	16893	1.78	5.0	3.0	3.0	14831	4120
WT-27	112	136	V136-3600	3600	403198	1057438	10	0.0	7.77	1.053	8.18	15762	1.073	16908	2.34	5.0	3.0	3.0	14761	4100
WT-28	112	136	V136-3600	3600	403444	1057263	7	0.0	7.72	1.053	8.14	15706	1.073	16848	2.96	5.0	3.0	3.0	14614	4059
WT-29	112	136	V136-3600	3600	403464	1056748	1	0.0	7.68	1.053	8.08	15495	1.073	16621	2.37	5.0	3.0	3.0	14505	4029
WT-30	112	136	V136-3600	3600	403705	1056569	3	0.0	7.69	1.053	8.10	15560	1.073	16691	2.45	5.0	3.0	3.0	14554	4043
WT-31	112	136	V136-3600	3600	403943	1056385	3	0.0	7.71	1.053	8.12	15566	1.073	16698	2.60	5.0	3.0	3.0	14538	4038
WT-32	112	136	V136-3600	3600	404184	1056205	5	0.0	7.72	1.053	8.13	15729	1.073	16872	3.47	5.0	3.0	3.0	14558	4044
WT-33	112	136	V136-3600	3600	404425	1056024	4	0.0	7.66	1.053	8.06	15687	1.073	16827	4.75	5.0	3.0	3.0	14327	3980
WT-34	112	136	V136-3600	3600	404666	1055844	4	0.0	7.59	1.053	7.99	15671	1.073	16810	6.36	5.0	3.0	3.0	14070	3908
WT-35	112	136	V136-3600	3600	404904	1055661	4	0.0	7.56	1.053	7.97	15667	1.073	16806	7.16	5.0	3.0	3.0	13946	3874
WT-36	112	136	V136-3600	3600	405145	1055481	5	0.0	7.56	1.053	7.97	15700	1.073	16841	7.41	5.0	3.0	3.0	13938	3872
WT-37	112	136	V136-3600	3600	405385	1055300	5	0.0	7.57	1.053	7.97	15696	1.073	16837	7.39	5.0	3.0	3.0	13938	3872
WT-38	112	136	V136-3600	3600	405626	1055118	6	0.0	7.57	1.053	7.97	15698	1.073	16839	7.31	5.0	3.0	3.0	13952	3876
WT-39	112	136	V136-3600	3600	405865	1054936	7	0.0	7.59	1.053	8.00	15714	1.073	16856	6.88	5.0	3.0	3.0	14031	3897
WT-40	112	136	V136-3600	3600	406105	1054755	5	0.0	7.56	1.053	7.96	15684	1.073	16824	6.52	5.0	3.0	3.0	14059	3905

Turbine	Hub Height m	Rotor m	Model	Power Kw	UTM X / LONG.	UTM Y / LAT.	Height m	RIX %	Wind Farm Speed - Measurement Period m/s	Wind Speed Long-Term Factor	Wind Farm Speed - Long Term m/s	Gross Energy - Measurement Period MWh/year	Energy Long-Term Factor	Gross Energy - Long Term MWh/year	Wake Losses %	Adaptation Factor Loss %	Electrical Losses %	Unavaila-bility %	Net Energy MWh/year	Net Equivalent Hours
POONERYN WIND FARM / P50 PRODUCTION RESULTS																				
WT-41	112	136	V136-3600	3600	406346	1054576	6	0.0	7.55	1.053	7.96	15616	1.073	16751	6.19	5.0	3.0	3.0	14047	3902
WT-42	112	136	V136-3600	3600	406472	1054197	5	0.0	7.59	1.053	8.00	15607	1.073	16742	5.43	5.0	3.0	3.0	14152	3931
WT-43	112	136	V136-3600	3600	406706	1054007	5	0.0	7.59	1.053	8.00	15601	1.073	16735	5.51	5.0	3.0	3.0	14134	3926
WT-44	112	136	V136-3600	3600	406944	1053823	5	0.0	7.60	1.053	8.00	15618	1.073	16754	5.55	5.0	3.0	3.0	14144	3929
WT-45	112	136	V136-3600	3600	407182	1053638	5	0.0	7.61	1.053	8.02	15622	1.073	16757	5.43	5.0	3.0	3.0	14165	3935
WT-46	112	136	V136-3600	3600	407419	1053451	5	0.0	7.59	1.053	7.99	15560	1.073	16691	5.38	5.0	3.0	3.0	14117	3921
WT-47	112	136	V136-3600	3600	407658	1053267	6	0.0	7.61	1.053	8.01	15574	1.073	16706	5.23	5.0	3.0	3.0	14153	3931
WT-48	112	136	V136-3600	3600	407895	1053083	6	0.0	7.56	1.053	7.97	15504	1.073	16631	5.16	5.0	3.0	3.0	14099	3916
WT-49	112	136	V136-3600	3600	408132	1052900	7	0.0	7.60	1.053	8.01	15559	1.073	16690	4.80	5.0	3.0	3.0	14203	3945
WT-50	112	136	V136-3600	3600	408369	1052714	7	0.0	7.62	1.053	8.02	15566	1.073	16698	4.40	5.0	3.0	3.0	14268	3963
WT-51	112	136	V136-3600	3600	408606	1052528	7	0.0	7.62	1.053	8.02	15516	1.073	16644	3.70	5.0	3.0	3.0	14326	3980
WT-52	112	136	V136-3600	3600	408848	1052346	6	0.0	7.61	1.053	8.01	15450	1.073	16574	3.12	5.0	3.0	3.0	14353	3987
WT-53	112	136	V136-3600	3600	409083	1052158	6	0.0	7.68	1.053	8.09	15409	1.073	16529	1.31	5.0	3.0	3.0	14581	4050
WT-54	112	136	V136-3600	3600	405493	1056767	3	0.0	7.42	1.053	7.82	15678	1.073	16818	8.16	5.0	3.0	3.0	13806	3835
WT-55	112	136	V136-3600	3600	405740	1056595	4	0.0	7.39	1.053	7.78	15650	1.073	16787	8.49	5.0	3.0	3.0	13731	3814
WT-56	112	136	V136-3600	3600	405987	1056420	6	0.0	7.47	1.053	7.87	15821	1.073	16971	8.13	5.0	3.0	3.0	13936	3871
WT-57	112	136	V136-3600	3600	406233	1056249	9	0.0	7.47	1.053	7.87	15850	1.073	17002	8.13	5.0	3.0	3.0	13962	3878
WT-58	112	136	V136-3600	3600	406482	1056076	4	0.0	7.43	1.053	7.83	15669	1.073	16808	8.07	5.0	3.0	3.0	13812	3837
WT-59	112	136	V136-3600	3600	406729	1055904	5	0.0	7.41	1.053	7.80	15672	1.073	16811	8.30	5.0	3.0	3.0	13779	3828
WT-60	112	136	V136-3600	3600	406971	1055733	4	0.0	7.43	1.053	7.83	15621	1.073	16757	7.77	5.0	3.0	3.0	13814	3837
WT-61	112	136	V136-3600	3600	407776	1055661	3	0.0	7.44	1.053	7.83	15602	1.073	16736	6.81	5.0	3.0	3.0	13940	3872
WT-62	112	136	V136-3600	3600	408024	1055491	2	0.0	7.45	1.053	7.85	15642	1.073	16779	6.89	5.0	3.0	3.0	13965	3879
WT-63	112	136	V136-3600	3600	408267	1055317	2	0.0	7.42	1.053	7.81	15597	1.073	16731	7.02	5.0	3.0	3.0	13906	3863
WT-64	112	136	V136-3600	3600	408513	1055146	3	0.0	7.51	1.053	7.91	15724	1.073	16867	6.20	5.0	3.0	3.0	14142	3928
WT-65	112	136	V136-3600	3600	408858	1054901	3	0.0	7.47	1.053	7.87	15707	1.073	16849	6.55	5.0	3.0	3.0	14075	3910
WT-66	112	136	V136-3600	3600	409107	1054729	4	0.0	7.48	1.053	7.88	15732	1.073	16876	6.55	5.0	3.0	3.0	14097	3916
WT-67	112	136	V136-3600	3600	409353	1054557	4	0.0	7.48	1.053	7.88	15734	1.073	16878	6.34	5.0	3.0	3.0	14130	3925
WT-68	112	136	V136-3600	3600	409600	1054383	5	0.0	7.50	1.053	7.90	15747	1.073	16892	6.07	5.0	3.0	3.0	14182	3939
WT-69	112	136	V136-3600	3600	409851	1054213	5	0.0	7.46	1.053	7.86	15631	1.073	16767	5.94	5.0	3.0	3.0	14098	3916
WT-70	112	136	V136-3600	3600	410101	1054043	5	0.0	7.54	1.053	7.94	15535	1.073	16665	4.04	5.0	3.0	3.0	14295	3971
Wind turbine results				252.00			6.09	0.00	7.64	1.053	8.05	15653	1.073	16790	4.31	5.0	3.0	3.0	14360	3989
Net Capacity Factor %		45.51%	Mean total loss %		15.31						Gross wind farm energy yield (MWh/year)			1,175,334		Net wind farm energy yield (MWh/year)			1,005,234	

Table 9. P50 production and losses of Pooneryn wind farm, Vestas V136-3600.

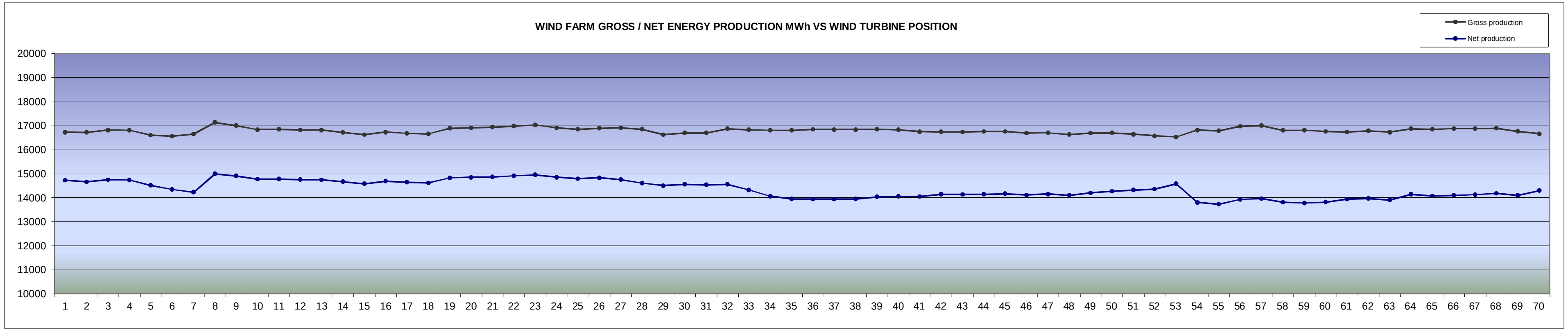


Figure 15. P50 gross and net production of Pooneryn wind farm, Vestas V136-3600 T112 wind turbine model.

Energy Yield GWh year

Hour / Month	January	February	March	April	May	June	July	August	September	October	November	December	TOTAL
0	2.371	2.093	1.627	1.146	4.135	6.326	6.587	6.313	4.373	2.518	1.225	2.149	40.86
1	2.294	2.025	1.594	1.204	4.069	6.447	6.650	6.066	4.540	2.476	1.216	2.102	40.68
2	2.137	1.908	1.301	1.432	4.096	6.305	6.659	5.992	4.308	2.485	1.443	2.018	40.08
3	1.961	1.799	1.172	1.009	4.100	6.083	6.389	5.952	4.390	2.452	1.284	1.981	38.57
4	1.936	1.547	1.034	0.878	4.230	6.048	6.033	5.742	4.445	2.342	1.478	1.797	37.51
5	1.891	1.304	0.729	0.634	4.212	5.940	5.868	5.535	4.325	2.179	1.660	1.933	36.21
6	1.944	1.233	0.823	0.706	4.163	5.671	5.551	5.398	4.313	2.265	1.675	1.947	35.69
7	1.833	1.190	0.948	0.547	4.007	5.518	5.406	5.191	4.208	2.272	1.607	1.889	34.62
8	1.755	1.009	1.062	0.577	3.941	5.627	5.594	5.102	4.218	2.152	1.854	1.776	34.67
9	2.584	1.462	1.413	0.737	3.702	5.784	5.635	4.924	4.532	2.069	1.697	2.313	36.85
10	3.106	1.473	1.744	0.980	3.951	6.169	5.782	4.676	4.701	2.127	1.756	2.775	39.24
11	3.173	1.659	2.035	1.064	4.008	6.396	5.884	4.670	4.894	2.285	2.249	2.722	41.04
12	3.291	1.937	2.353	1.071	4.112	6.389	5.963	4.804	4.851	2.482	2.566	2.885	42.70
13	3.274	2.265	2.480	1.094	4.124	6.188	5.996	4.870	4.758	2.357	2.541	3.046	42.99
14	3.403	2.440	2.707	1.072	4.134	6.177	5.832	4.877	4.868	2.615	2.610	3.554	44.29
15	3.593	2.835	3.062	1.170	4.026	6.244	6.184	5.123	5.121	2.709	2.643	3.553	46.26
16	3.917	3.101	3.410	1.400	4.062	6.179	6.574	5.423	5.173	2.750	2.606	3.434	48.03
17	4.138	3.418	2.890	1.499	4.018	6.472	6.851	5.800	5.166	2.903	2.643	3.624	49.42
18	3.747	3.434	2.730	1.459	4.039	6.713	6.970	6.008	5.202	3.059	2.284	3.165	48.81
19	3.166	3.018	2.760	1.374	4.100	6.674	7.074	6.187	5.295	2.976	2.070	2.723	47.42
20	2.997	2.514	2.724	1.580	4.189	6.541	6.973	6.307	4.983	2.906	2.171	2.675	46.56
21	2.912	2.273	2.606	1.541	4.398	6.472	6.846	6.211	4.623	3.001	2.369	2.773	46.02
22	2.579	2.244	2.219	1.348	4.204	6.484	6.787	6.566	4.582	2.873	1.724	2.449	44.06
23	2.359	2.169	1.909	1.385	4.179	6.189	6.738	6.473	4.496	2.741	1.443	2.553	42.63
TOTAL	66.36	50.35	47.33	26.91	98.20	149.04	150.83	134.21	112.36	60.99	46.81	61.84	1,005.23

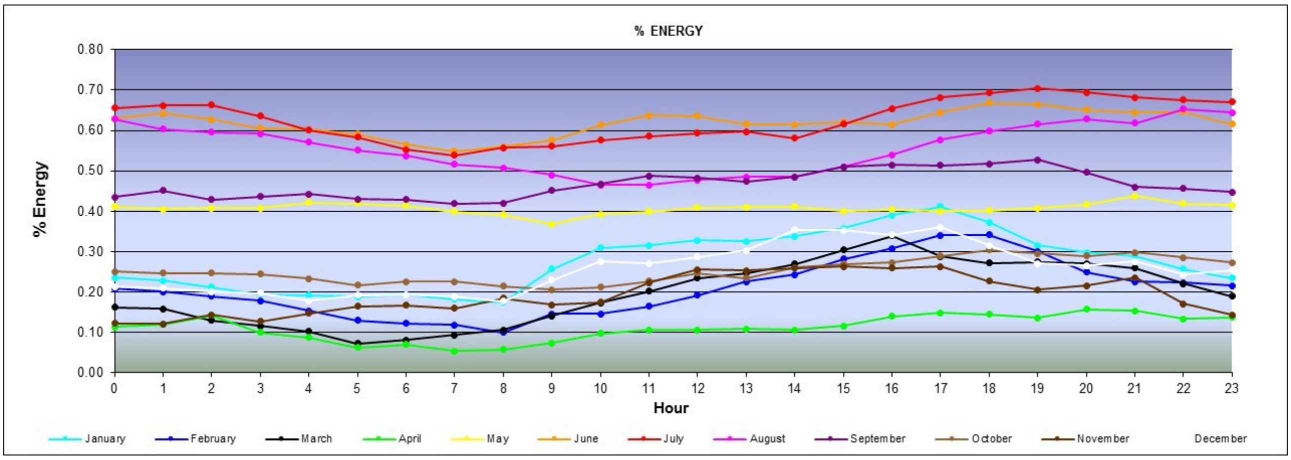
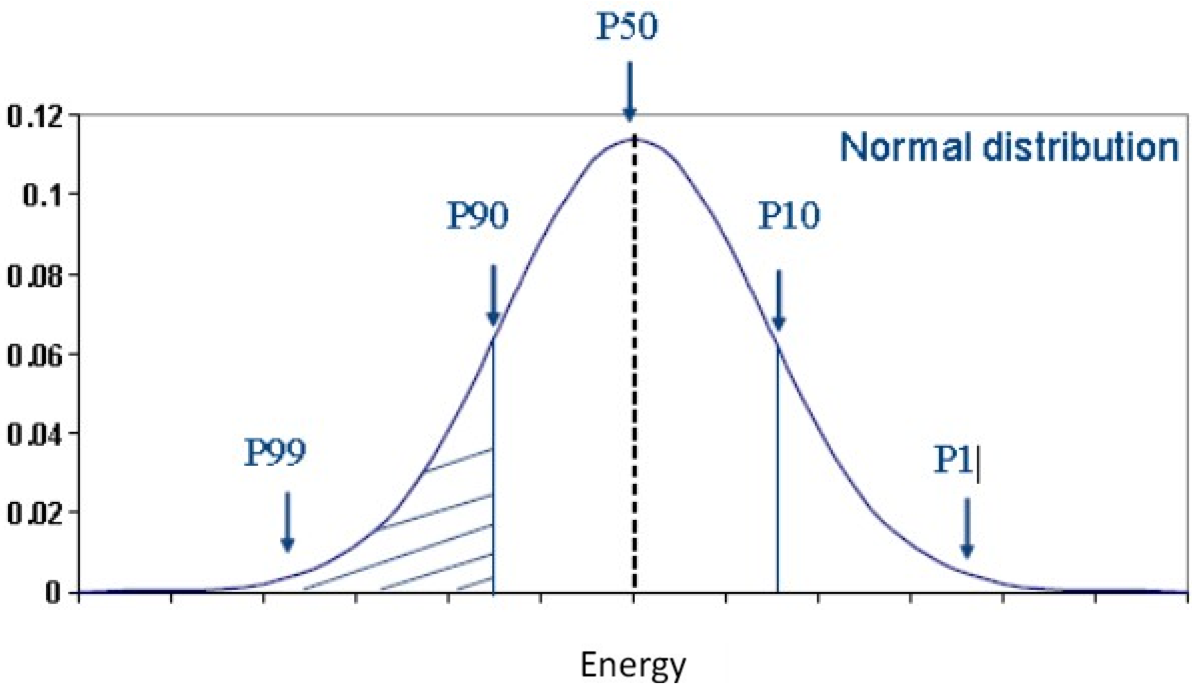


Figure 16. 24x12 matrix net expected energy yield, Pooneryn wind farm.

10. UNCERTAINTY ANALYSIS

The uncertainty in the net energy estimate provides a metric to determine the downside and upside production risk of a project over a specified time period [33]. The inputs into the uncertainty analysis include uncertainties around the wind speed inputs and modelling, uncertainty around the energy loss factors, and the inter-annual variability of production [14]. The analysis has been done considering publications [13] and [28].

An interesting way to present the project uncertainties is by giving the probabilities of exceedance in terms of expected annual production of the wind farm. The net AEP and total uncertainty determine, respectively, the mean and standard deviation for a normal Gaussian distribution. Uncertainty definitions taken into account are based on industry-standard categories [27].



The uncertainty analysis is divided in two different sections, variables affecting directly wind speed and variable affecting the energy production. Wind speed uncertainties are converted into energy uncertainties using the Sensitivity Ratio which shows how sensitive the net energy production is to changes in wind speed.

10.1 ANEMOMETER CALIBRATION AND MOUNTING

This part of the uncertainty is associated with the accuracy of the wind speed measurements. The value of uncertainty depends on the calibration and the mounting arrangements of the instruments. A figure of between 1.5% and 3.0% is typically estimated to account for these factors. Since the anemometer calibration procedure presumably follows the MEASNET standard [16] and it is unknown whether the mounting arrangement of the booms follow the recommendations described in [13] and [15] a value of 2.06% has been calculated.

10.2 FILTERING AND DATA SYNTHESIS

This factor accounts for the uncertainty generated in the filtering of wind data and in the synthesis of wind data among different masts. No synthesis of data has been done among different masts and therefore this component is set to 0. Since data availability in the reference period is almost 99%, no extra uncertainty has been added due to this issue.

10.3 LONG TERM WIND REGIME

Uncertainty of the long-term assessment considers quality, consistency and representativeness of the reference data, the correlation between site data and reference data as well as the uncertainty of the applied methodology. The long-term correction is referenced to a prediction horizon of 20 years with Merra2 dataset and has resulted in a value of 1.46% according to the following formula defined in [14].

$$\sigma \cong \sqrt{\frac{r^2}{N_R}\sigma_A^2 + \frac{1-r^2}{N_T}\sigma_A^2}$$

Here, σ_A is the standard deviation of the annual mean wind speeds as a percentage of the mean, which we assume is the same for the reference and target sites; NR and NT are the number of years of reference and overlapping reference-target data, respectively; r is the Pearson correlation coefficient based on a monthly correlation of the data, and σ is the uncertainty in the derived historical mean wind speed at the target site or inter annual variability.

10.4 FUTURE WIND

The uncertainty in the future wind resource can be divided into two components: that due to normal variability in the wind climate, and that due to the risk of long-term climate change [14]. For a plant life of 20 years, Nayxa estimates the combined uncertainty to be in the range of 1.5% of the expected wind speed.

10.5 VERTICAL EXTRAPOLATION

The wind shear uncertainty captures the uncertainty associated with the shear calculation as well as the possible change in shear above the mast height. According to [14], the corresponding uncertainty in the hub height speed is approximated by the following equation:

$$\boldsymbol{\sigma_{hh}} = \mathbf{100}\left[\left(\frac{h_h}{h_2}\right)^{\Delta\alpha} - \mathbf{1}\right](\%)$$

, where

h_h is the hub height.

h_2 in the height of the top anemometer.

$\Delta_\alpha = 15\% \times \alpha_{site}$.

The calculation of the vertical extrapolation uncertainty according to the aforementioned formula has resulted in a value of 0.82%.

10.6 INTER ANNUAL VARIABILITY

Even if the central estimate is perfectly defined, wind farm energy production varies from year-to-year due to a natural variation in the wind regime. This is not really part of the uncertainty since we are certain that this variation will occur. The uncertainty lies in the developer field, precisely on what the energy yield is to be expected is within a random year.

The inter-annual variability has been calculated with the help of Merra2 reanalysis data used in the long term assessment of Pooneryn wind farm, following the recommendations given in [29] and [30]. The resulting value is 4.01%.

10.7 HORIZONTAL MODELLING

This uncertainty represents the uncertainty in the ability to extrapolate from the measurement locations to the wind turbine locations. This uncertainty component is based on the wind flow model ability to cross-predict wind speeds at measurement locations and how representative the measurement locations of turbine locations are.

Taking into account that a single met mast has been installed within the limits of the project which is planned in non-complex terrain, a value of 3.0% has been estimated to represent the uncertainty in the horizontal modelling.

10.8 DENSITY CALCULATION

This factor accounts for the uncertainty generated in the calculation of the mean air density at Pooneryn wind farm. Since reputable atmospheric sensors have been installed and produced a dataset with excellent availability, a default value of 1% has been assigned.

10.9 POWER CURVE

The power curve used for the energy calculations has been provided by the client and constitute a certified power curve from a trustable manufacturer. The uncertainty corresponding to a certified power curve is estimated to be 3.0%.

10.10 WAKE MODEL

Uncertainties on wakes are modeled as a normal distribution centered on the median estimate. The standard deviation of the distribution depends on site specific conditions such as power curve, large wind farm wake effect and external wakes but is typically around 20-25% of the overall wake effect.

10.11 TOPOGRAPHIC & ROUGHNESS MAPS

Wind flow modeling relies on characterization of the surface, including terrain elevation and surface roughness. As input to atmospheric flow models, both terrain elevation and roughness have uncertainties associated with their assignment. In practice, terrain elevation uncertainty tends to be dominated by the resolution of elevation maps.

Overall, uncertainty related to roughness tends to be dominant over elevation-related uncertainty, particularly in wind-energy applications [31]. Given the detailed and high resolution derived maps, a value of 1% has been set to account for this factor.

10.12 PLANT PERFORMANCE & LOSSES ESTIMATION

This factor includes the uncertainty of estimating the production of the wind turbines, efficiencies with respect to atmospheric conditions, and all plant losses, except for wake losses which have been considered on point 10.10. A value equal to 25% of the total loss value has been estimated to represent the uncertainty described in this point.

In evaluating the wind speed estimate uncertainty, factors affecting the wind speed (10.1 to 10.6) have been combined by means of the following formula and assuming that each source of uncertainty is normally distributed and statistically independent from the others [32].

$$\sigma_{total} = \sqrt{\sum_{i=1}^{J} \sigma_i^2}$$

where each σ_i represents the uncertainty associated with each source (measurement, long term adjustment, extrapolation to hub height, etc.). Wind speed uncertainty is converted into energy yield uncertainty with the help of the mean wind speed sensitivity. In order to complete the process the recently calculated magnitude is combined with other factors affecting the energy yield (10.7 to 10.12) by means of the same formula.

$$\sigma_{total} = \sqrt{\sum_{i=1}^{J} \sigma_i^2}$$

The expected energy yield is connected with this uncertainty assessment and presented for different probability of exceedance (PoE) levels. The most frequently used PoE levels are P50, P75 and P90/P99. A given AEP such as P75 has a 75% probability of being exceeded in a random year. Given the calculated P50 value and applying a Gaussian distribution for the statistical analysis, other PoE levels such as P75, P90 or P99 have also been calculated.

An exhaustive uncertainty analysis of wind energy production has been done in which the most important sources of uncertainty have been included. There might be other sources of uncertainty but their values are negligible compared to all the issues considered. Values resulting from the uncertainty analysis along with the different PoE are presented in the next table.

UNCERTAINTY ANALYSIS & VARIABILITY 1 YEAR		
Long term wind speed at hub height	Anemometer calibration and mounting	2.06
	Filtering and data synthesis	0.00
	Long term wind regime	1.46
	Future wind	1.50
	Vertical extrapolation	0.82
	Other	0.00
	Wind speed uncertainty %	3.05
Variability 1 year		4.01
	Annual variability + Wind speed uncertainty %	5.04
Sensitivity		1.3659
Wind farm energy yield	Wind uncertainty	6.88
	Horizontal modelling	3.00
	Density calculation	1.00
	Power curve	3.00
	Wake model	1.08
	Topographic map & roughness map	1.00
	Plant performance & losses estimation	2.75
	Annual variability + Production uncertainty %	8.72
Quantile		
99	Full net load hours	3180
90	Full net load hours	3543
75	Full net load hours	3754
50	Full net load hours	3989
25	Full net load hours	4224
10	Full net load hours	4435
1	Full net load hours	4798
Quantile		
99	Capacity factor %	36.27
90	Capacity factor %	40.42
75	Capacity factor %	42.83
50	Capacity factor %	45.51
25	Capacity factor %	48.18
10	Capacity factor %	50.59
1	Capacity factor %	54.74
Quantile		
99	Wind farm yearly net production GWh	801.31
90	Wind farm yearly net production GWh	892.89
75	Wind farm yearly net production GWh	946.11
50	Wind farm yearly net production GWh	1005.23
25	Wind farm yearly net production GWh	1064.36
10	Wind farm yearly net production GWh	1117.57
1	Wind farm yearly net production GWh	1209.16

UNCERTAINTY ANALYSIS & VARIABILITY 10 YEARS		
Long term wind speed at hub height	Anemometer calibration and mounting	2.06
	Filtering and data synthesis	0.00
	Long term wind regime	1.46
	Future wind	1.50
	Vertical extrapolation	0.82
	Other	0.00
	Wind speed uncertainty %	3.05
Variability 10 years		1.27
	Annual variability + Wind speed uncertainty %	3.30
Sensitivity		1.3659
Wind farm energy yield	Wind uncertainty	4.51
	Horizontal modelling	3.00
	Density calculation	1.00
	Power curve	3.00
	Wake model	1.08
	Topographic map & roughness map	1.00
	Plant performance & losses estimation	2.75
	Annual variability + Production uncertainty %	7.00
Quantile		
99	Full net load hours	3339
90	Full net load hours	3631
75	Full net load hours	3801
50	Full net load hours	3989
25	Full net load hours	4177
10	Full net load hours	4347
1	Full net load hours	4639
Quantile		
99	Capacity factor %	38.09
90	Capacity factor %	41.42
75	Capacity factor %	43.36
50	Capacity factor %	45.51
25	Capacity factor %	47.65
10	Capacity factor %	49.59
1	Capacity factor %	52.92
Quantile		
99	Wind farm yearly net production GWh	841.47
90	Wind farm yearly net production GWh	915.02
75	Wind farm yearly net production GWh	957.75
50	Wind farm yearly net production GWh	1005.23
25	Wind farm yearly net production GWh	1052.72
10	Wind farm yearly net production GWh	1095.45
1	Wind farm yearly net production GWh	1169.00

Table 10. Pooneryn wind farm uncertainty analysis for the model V136-3600.

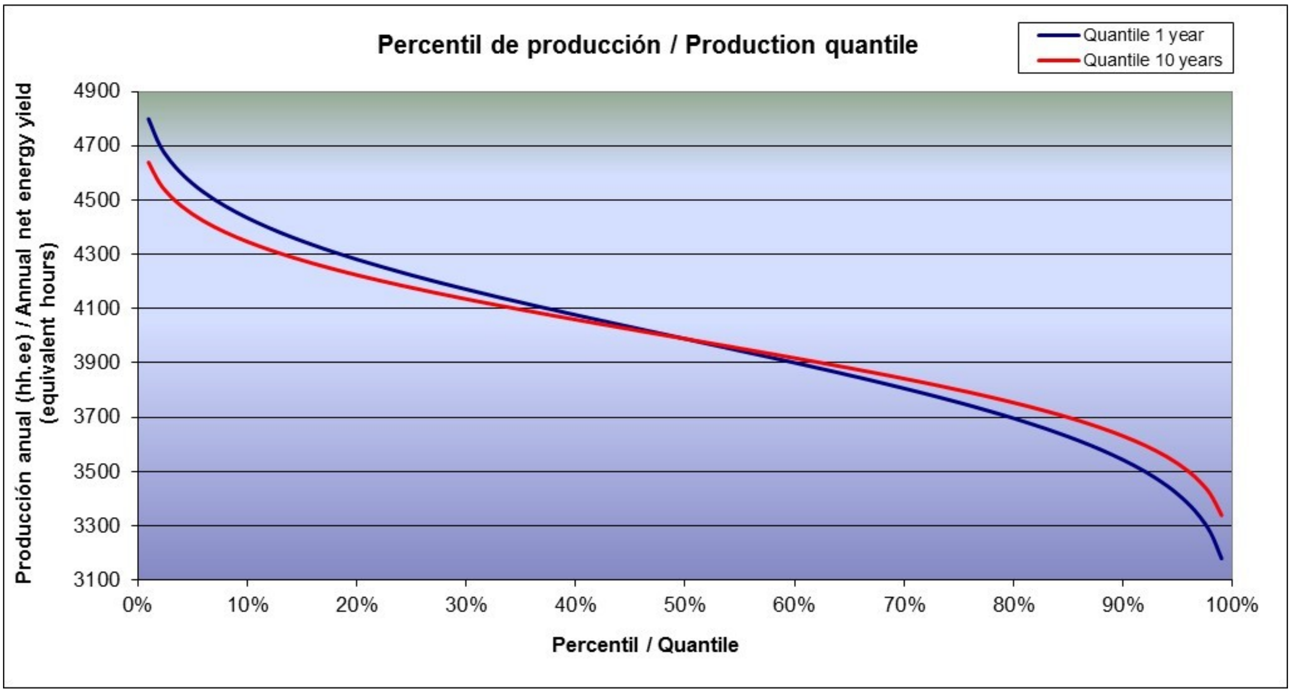


Figure 17. Pooneryn production quantile for the Vestas V136-3600 model.

MONTHLY STATISTICS										
MONTH	WIND SPEED m/s	% ENERGY	P50 C.FACTOR %	P75 C.FACTOR %	P90 C.FACTOR %	P99 C.FACTOR %	P50 ENERGY GWh	P75 ENERGY GWh	P90 ENERGY GWh	P99 ENERGY GWh
1	7.17	6.60	3.00	2.83	2.67	2.39	66.35	62.44	58.93	52.89
2	6.60	5.01	2.28	2.15	2.03	1.82	50.36	47.40	44.73	40.15
3	6.23	4.71	2.14	2.02	1.90	1.71	47.35	44.56	42.06	37.74
4	5.01	2.68	1.22	1.15	1.08	0.97	26.94	25.36	23.93	21.48
5	10.39	9.77	4.45	4.18	3.95	3.54	98.21	92.43	87.24	78.29
6	12.23	14.82	6.74	6.35	5.99	5.38	148.98	140.21	132.33	118.75
7	11.28	15.00	6.83	6.42	6.06	5.44	150.79	141.92	133.93	120.20
8	10.47	13.35	6.07	5.72	5.40	4.84	134.20	126.31	119.20	106.97
9	10.04	11.18	5.09	4.79	4.52	4.06	112.39	105.77	99.83	89.59
10	6.58	6.07	2.76	2.60	2.45	2.20	61.02	57.43	54.20	48.64
11	6.01	4.66	2.12	2.00	1.88	1.69	46.84	44.09	41.61	37.34
12	6.80	6.15	2.80	2.63	2.49	2.23	61.82	58.19	54.91	49.28
TOTAL	8.22	100.00	45.51	42.83	40.42	36.27	1005.23	946.11	892.89	801.31

Table 11. Pooneryn wind farm monthly production based on 1 year uncertainty values.

11. CONCLUSIONS

The main conclusions and recommendations obtained from the present assessment are:

- In order to perform this WRA, a meteorological mast known as PO1_mast has been analysed. Merra2 reanalysis data [3] has been used in order to make the obtained results representative of the long term wind regime.

- There is no indication to whether the boom orientations are referred to the geographic north (true north) or the magnetic north. Since the site magnetic declination is 1.88ºW, the expected uncertainty due to this issue is kept under control.

- The layout has been designed and optimized by Nayxa. Distance between wind turbines ranges from 2.18 to 2.21 rotor diameters, RD.

- The mean wind shear meets a value of 0.153 at PO1_mast (78.6/40 m levels). Hellman's potential law of the wind profile with height [18] has been used to calculate this value.

- The height of the met mast, 78.6 meters, agrees with Measnet recommendation [1] on having a met mast with a height of at least 2/3 of the selected hub height, 112 meters in this case. The uncertainty due to the vertical wind speed extrapolation has been calculated on section 10.

- WAsP has been selected as the wind flow model to horizontally extrapolate the climatology registered at the met masts, to the wind turbine locations.

- In this assessment no adjacent wind farms have been taken into account to model the wake losses of the wind turbines at Pooneryn wind farm.

- The annual net energy output of the wind farm is found to be 1005.23 GWh with a capacity factor of 45.51% for the Vestas V136-3600 wind turbine model at a hub height of 112 meters.

- A detailed uncertainty analysis has been performed, focusing on the quality of input data, the calculation procedures, the turbine type parameters as well as the applied losses. The uncertainty analysis is performed considering prediction horizons of 1 and 10 years and P50, P75, P90 and P99 levels [33].

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ANNEX A – MET MAST STATISTICS

A.1 PO1_MAST

Met Mast	Sensor type	Serial number / Channel	Make	Height / Orientation	Boom Lenght, cm	Start mesurement	End measurement	Measnet Calibration	Slope applied	Offset applied
DEBSK MET MAST										
PO1_MAST	anemometer	10143649 / C1	Thies First Class	78.6 / 120º	150	23/02/2015	24/02/2016	Presumably	Unknown	0.25400
PO1_MAST	anemometer	10143645 / C2	Thies First Class	78.6 / 300º	150	23/02/2015	24/02/2016	Presumably	Unknown	Unknown
PO1_MAST	anemometer	10143637 / C3	Thies First Class	60 / 120º	150	23/02/2015	24/02/2016	Presumably	Unknown	Unknown
PO1_MAST	anemometer	10143654 / C4	Thies First Class	60 / 300º	150	23/02/2015	24/02/2016	Presumably	Unknown	Unknown
PO1_MAST	anemometer	10143650 / C5	Thies First Class	40 / 120º	150	23/02/2015	24/02/2016	Presumably	Unknown	Unknown
PO1_MAST	anemometer	10143656 / C6	Thies First Class	40 / 300º	150	23/02/2015	24/02/2016	Presumably	Unknown	Unknown
PO1_MAST	wind vane	10238 / A1	SWI	75 / 300º	150	23/02/2015	24/02/2016		Unknown	Unknown
PO1_MAST	wind vane	10239 / A3	SWI	55 / 300º	150	23/02/2015	24/02/2016		Unknown	Unknown
PO1_MAST	temperature	395 / A5	SWI	78.5		23/02/2015	24/02/2016		Unknown	Unknown
PO1_MAST	relative humidity	Q49934 / A6	Unknown	10.0		23/02/2015	24/02/2016		Unknown	Unknown
PO1_MAST	barometer	4645502 / A7	Setra 276	3.0		23/02/2015	24/02/2016		Unknown	Unknown
PO1_MAST	temperature	395 / A4	SWI	3.0		23/02/2015	24/02/2016		Unknown	Unknown

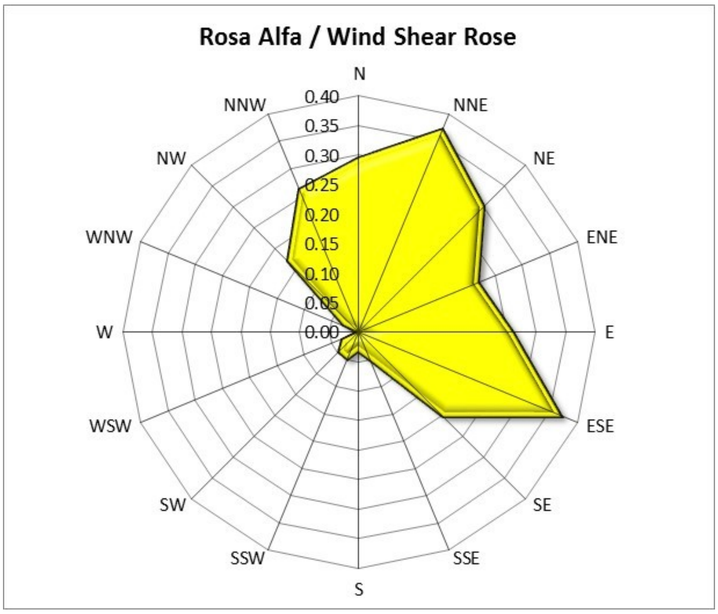
Table 12. PO1_mast configuration and equipment.

SENSOR	DAY	MONTH	YEAR	HOUR	MINUTE	DAY	MONTH	YEAR	HOUR	MINUTE	PROBLEM
All	24	9	2015	8	40	24	9	2015	8	40	Spike
Ane60_120º	9	10	2015	2	0	5	11	2015	9	30	Failure

Table 13. Data filtering PO1_mast.

POONERYN MAST													
YEAR	**MONTH**	**H112**	**D/A %**	**Data**	**H78.6**	**D/A %**	**Data**	**H60**	**D/A %**	**Data**	**H40**	**D/A %**	**Data**
2015	FEBRUARY	5.27	99.86	715	4.92	99.86	715	4.62	99.86	715	4.25	99.86	715
	MARCH	5.91	99.96	4462	5.50	99.96	4462	5.25	99.96	4462	4.73	99.96	4462
	APRIL	4.76	99.93	4317	4.59	99.93	4317	4.39	99.93	4317	4.27	99.93	4317
	MAY	9.86	86.09	3843	9.64	86.09	3843	9.51	86.09	3843	9.24	86.09	3843
	JUNE	11.61	99.98	4319	11.39	99.98	4319	11.29	99.98	4319	10.97	99.98	4319
	JULY	10.71	99.98	4463	10.56	99.98	4463	10.53	99.98	4463	10.25	99.98	4463
	AUGUST	9.94	100.00	4464	9.79	100.00	4464	9.77	100.00	4464	9.51	100.00	4464
	SEPTEMBER	9.53	99.86	4314	9.37	99.86	4314	9.31	99.86	4314	9.06	99.86	4314
	OCTOBER	6.25	100.00	4464	6.01	100.00	4464	5.86	100.00	4464	5.56	100.00	4464
	NOVEMBER	5.71	99.98	4319	5.33	99.98	4319	5.02	99.98	4319	4.60	99.98	4319
	DECEMBER	6.46	100.00	4464	5.88	100.00	4464	5.52	100.00	4464	4.78	100.00	4464
2016	JANUARY	6.81	100.00	4464	6.18	100.00	4464	5.80	100.00	4464	4.99	100.00	4464
	FEBRUARY	6.49	100.00	3312	5.96	100.00	3312	5.67	100.00	3312	4.96	100.00	3312
TOTAL		**7.81**	**98.782**	**51,920**	**7.49**	**98.782**	**51,920**	**7.30**	**98.782**	**51,920**	**6.88**	**98.782**	**51,920**

Table 14. Summary of monthly wind data, PO1_mast / Reference period.



DIRECTION	SHEAR
N	0.296
NNE	0.372
NE	0.302
ENE	0.220
E	0.263
ESE	0.372
SE	0.202
SSE	0.052
S	0.034
SSW	0.051
SW	0.048
WSW	0.030
W	0.004
WNW	0.029
NW	0.171
NNW	0.263
MEAN	0.153

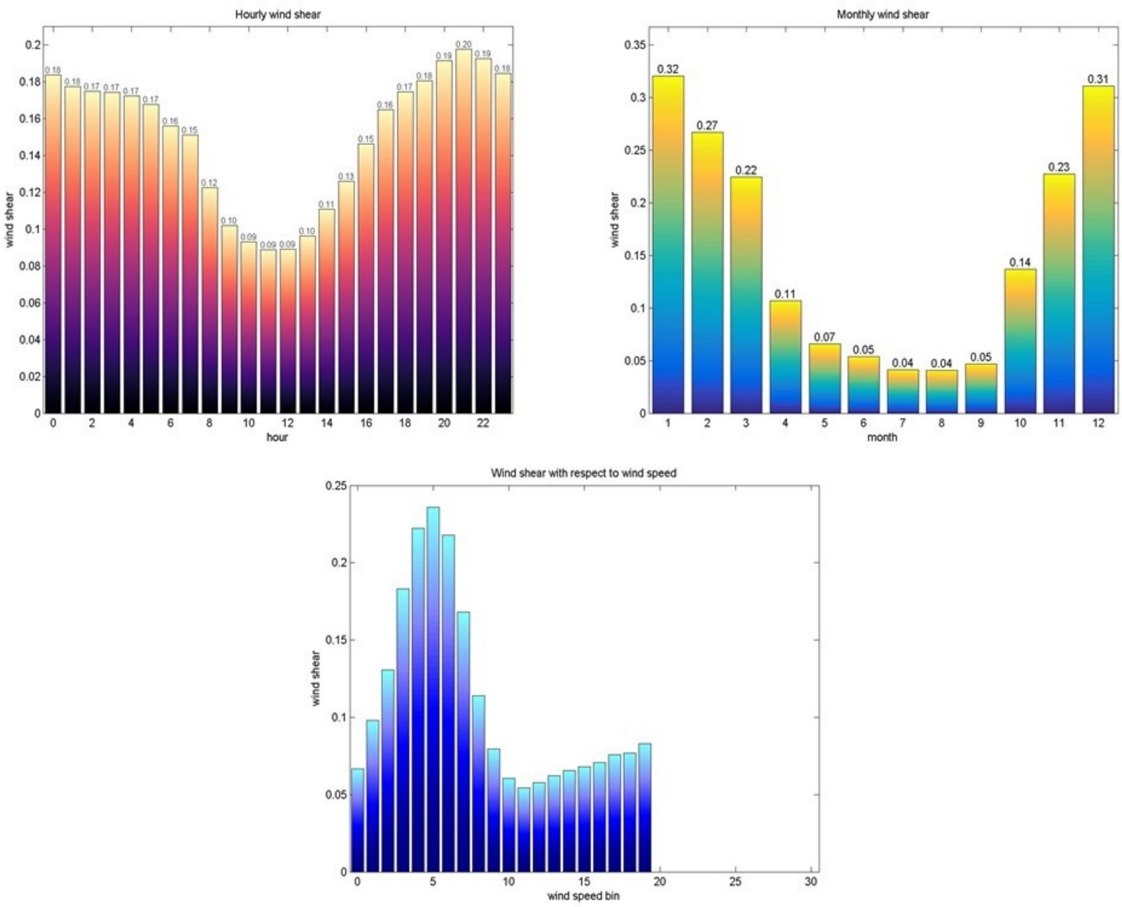


Figure 18. Wind shear levels 78.6/40 PO1_mast, reference period.

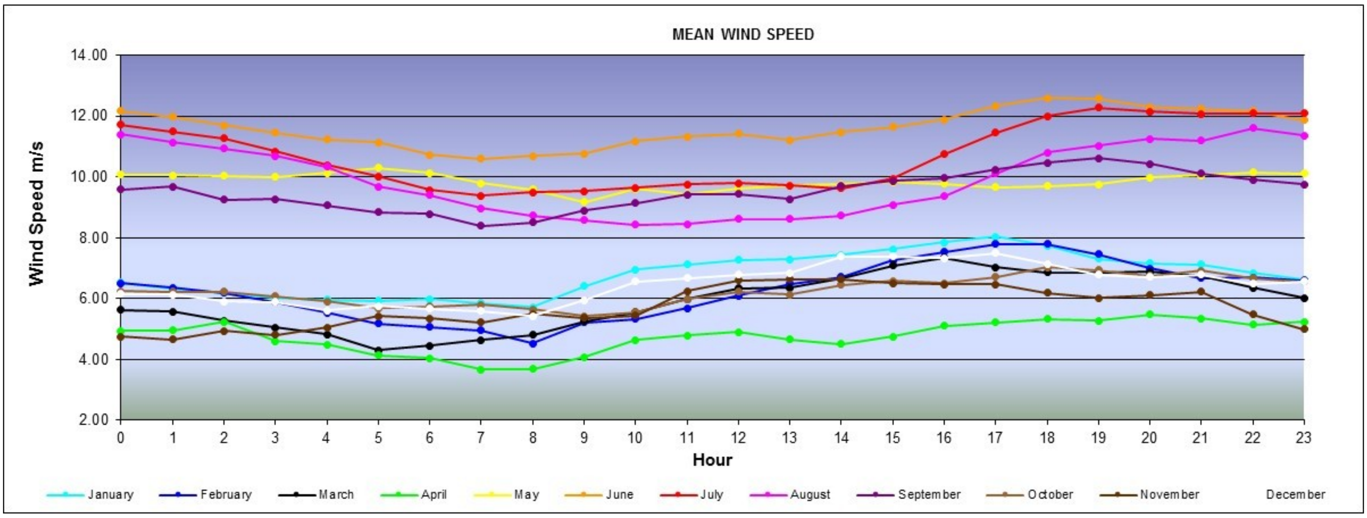


Figure 19. Hourly mean wind speed by month at 112 meters, PO1_mast / Reference period.

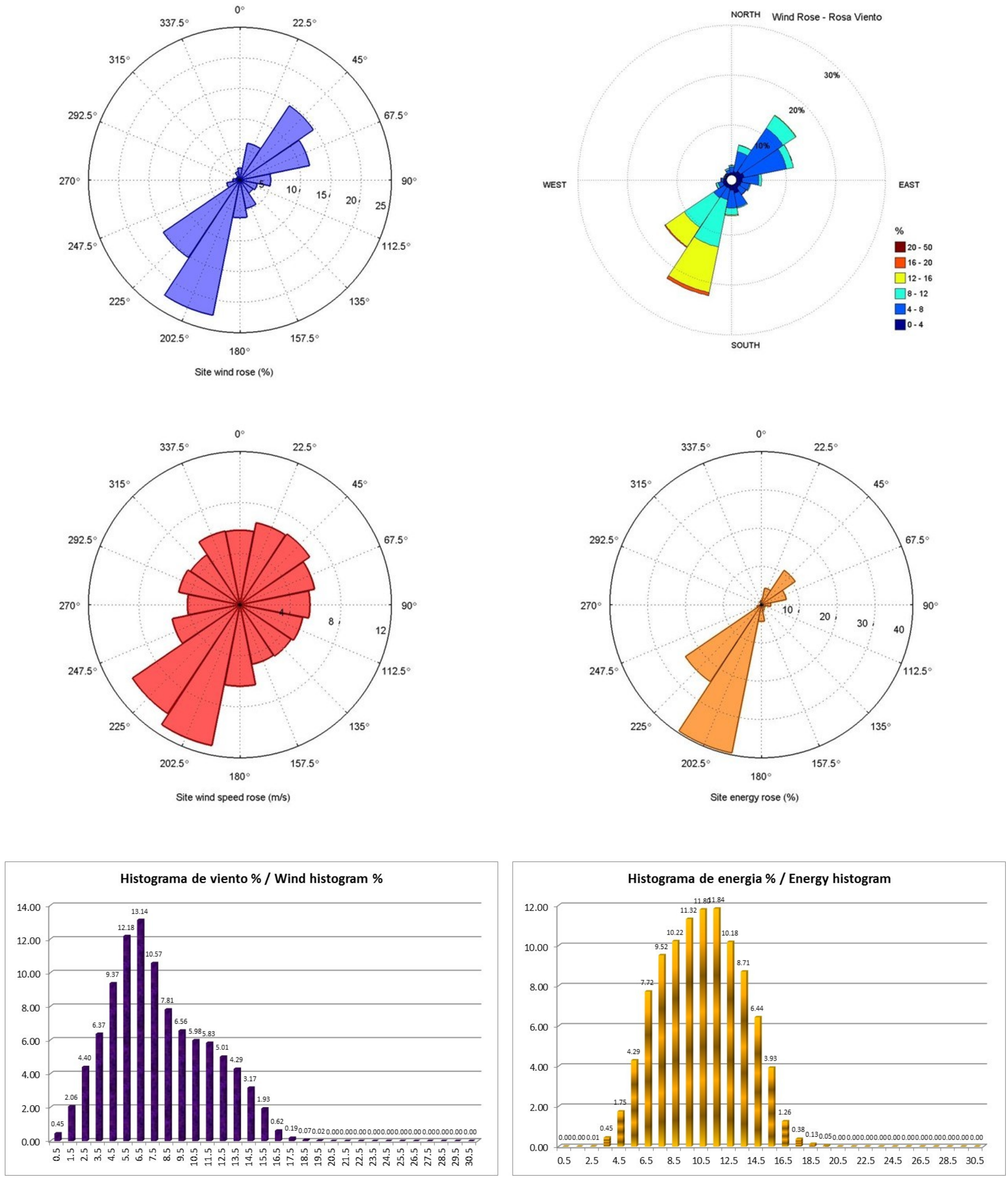


Figure 20. Wind roses and histograms, PO1_mast, wind speed at 112 meters and top wind vane / Reference period.

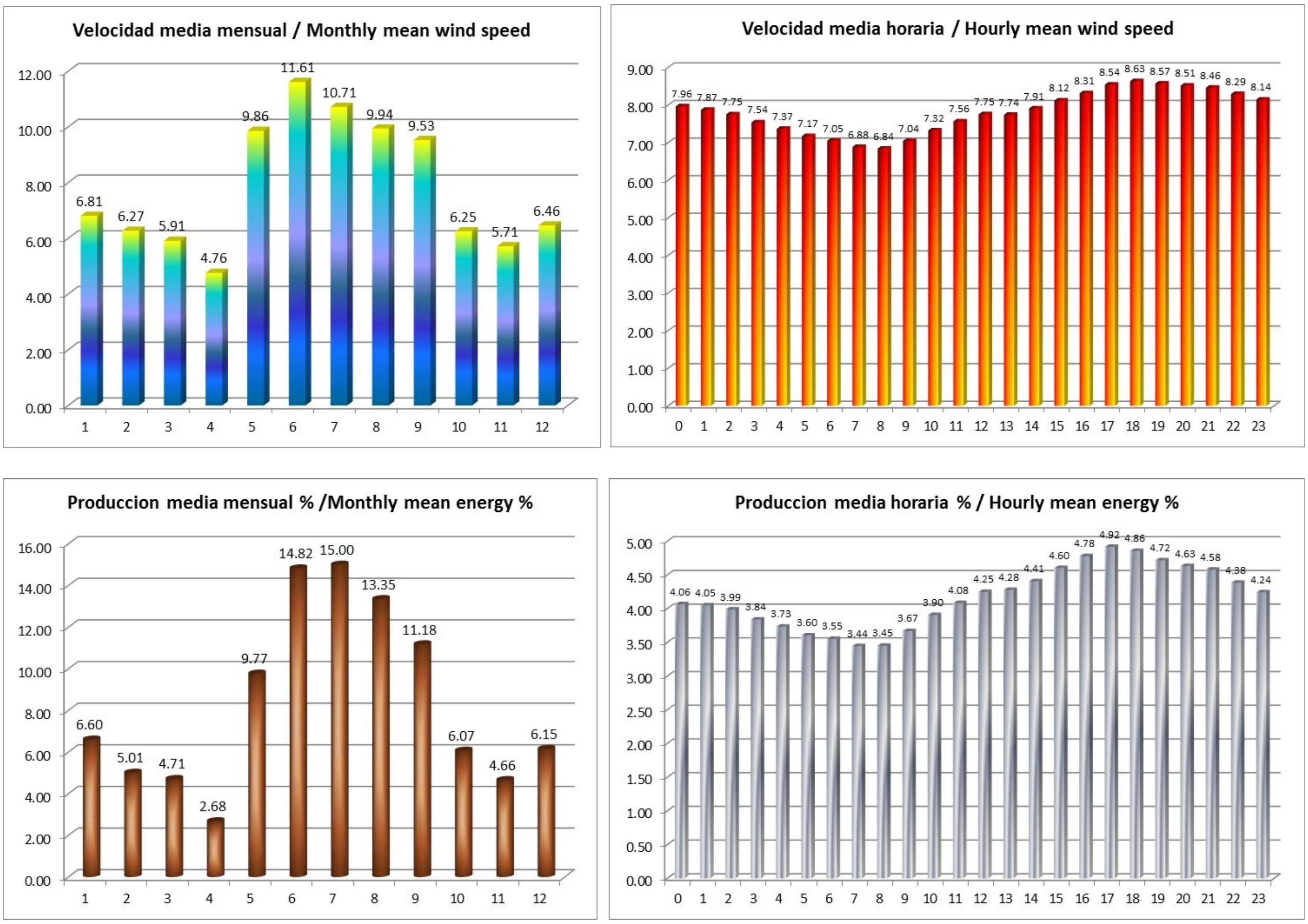


Figure 21. Hourly and monthly wind speed and energy at 112 meters, PO1_mast / Reference period.

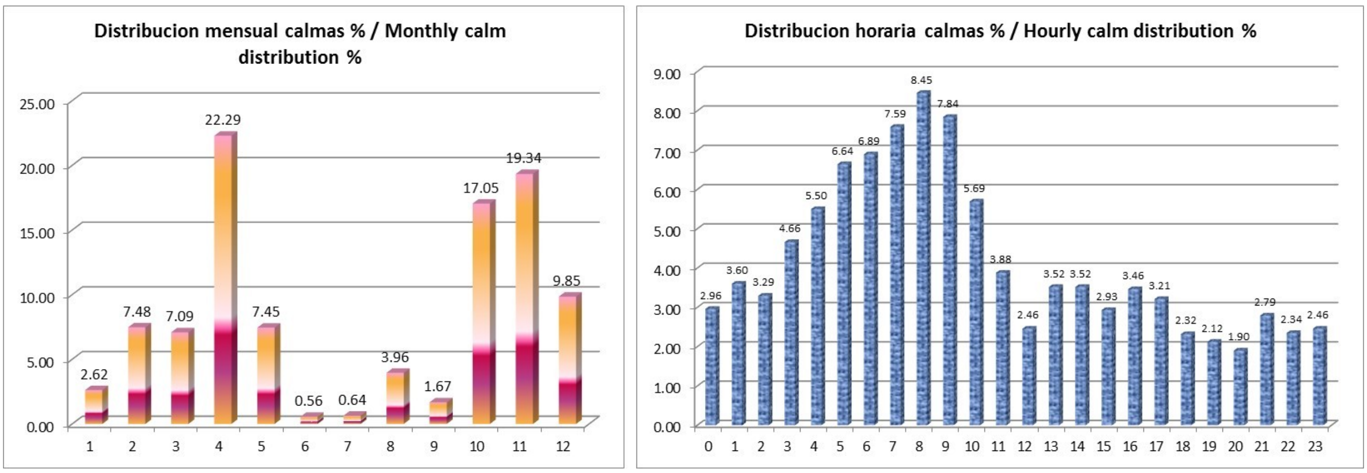


Figure 22. Monthly and hourly calm episodes distribution at 112 meters, PO1_mast / Reference period

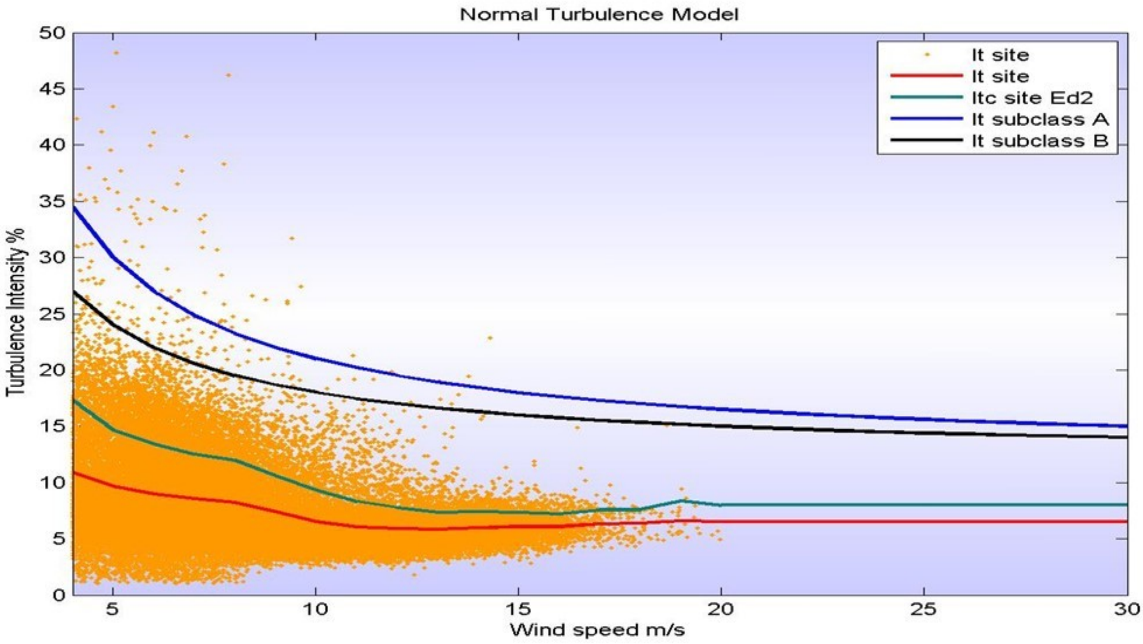


Figure 23. Ambient turbulence intensity at 112 meters PO1_mast / Reference period.

SECTOR WISE STATISTICS						
SECTOR	**FREQ**	**WIND SPEED m/s**	**% ENERGY**	**MAX WIND SPEED m/s**	**TI amb %**	**% CALM**
0	1.98	5.83	1.13	16.62	10.89	3.71
22.5	6.15	6.54	4.42	14.25	8.25	3.68
45	14.64	6.67	10.79	14.68	9.15	7.03
67.5	11.72	6.03	6.71	16.53	11.25	9.49
90	5.06	5.54	2.46	14.32	10.97	7.37
112.5	2.91	5.07	1.15	13.35	6.79	8.37
135	2.59	4.86	0.86	9.68	6.78	6.86
157.5	4.75	4.76	1.49	11.71	8.09	10.99
180	6.18	6.38	4.34	15.59	7.54	8.09
202.5	22.59	11.25	39.50	19.90	5.83	6.50
225	15.28	10.28	24.19	19.96	5.62	7.09
247.5	2.23	5.47	1.21	15.61	7.39	6.33
270	1.18	4.16	0.29	14.58	9.80	5.19
292.5	0.68	4.94	0.33	13.57	9.99	3.13
315	0.66	4.70	0.27	15.37	11.56	2.90
337.5	1.41	5.88	0.87	15.84	12.06	3.26

Table 15. Sector wise wind statistics at 112 meters, PO1_mast / Reference period.

MONTHLY STATISTICS								
MONTH	WIND SPEED m/s	ENERGY MWh	% ENERGY	% CALM	DENSITY kg/m^3	T MIN	T MEAN	T MAX
1	6.81	1025	6.60	2.62	1.161	23.65	26.92	30.52
2	6.27	778	5.01	7.48	1.159	23.16	27.50	31.98
3	5.91	731	4.71	7.09	1.156	23.47	28.41	34.96
4	4.76	416	2.68	22.29	1.153	23.97	29.16	34.21
5	9.86	1517	9.77	7.45	1.152	24.04	29.33	34.39
6	11.61	2302	14.82	0.56	1.151	25.10	29.52	31.43
7	10.71	2329	15.00	0.64	1.154	26.22	28.95	31.39
8	9.94	2073	13.35	3.96	1.154	23.27	28.74	33.02
9	9.53	1735	11.18	1.67	1.155	23.92	28.55	32.12
10	6.25	942	6.07	17.05	1.156	22.42	28.26	33.83
11	5.71	723	4.66	19.34	1.162	22.96	26.71	32.44
12	6.46	955	6.15	9.85	1.161	24.12	27.03	30.63

Table 16. Monthly wind statistics at PO1_mast at 112 meters, reference period.

HOURLY STATISTICS					
HOUR	WIND SPEED m/s	ENERGY MWh	% ENERGY	% CALM	DENSITY kg/m^3
0	7.96	631	4.06	2.96	1.160
1	7.87	628	4.05	3.60	1.160
2	7.75	619	3.99	3.29	1.161
3	7.54	596	3.84	4.66	1.161
4	7.37	579	3.73	5.50	1.161
5	7.17	559	3.60	6.64	1.160
6	7.05	551	3.55	6.89	1.159
7	6.88	535	3.44	7.59	1.157
8	6.84	535	3.45	8.45	1.155
9	7.04	569	3.67	7.84	1.153
10	7.32	606	3.90	5.69	1.151
11	7.56	634	4.08	3.88	1.150
12	7.75	660	4.25	2.46	1.150
13	7.74	664	4.28	3.52	1.150
14	7.91	684	4.41	3.52	1.151
15	8.12	714	4.60	2.93	1.152
16	8.31	742	4.78	3.46	1.154
17	8.54	763	4.92	3.21	1.155
18	8.63	754	4.86	2.32	1.156
19	8.57	732	4.72	2.12	1.157
20	8.51	719	4.63	1.90	1.158
21	8.46	711	4.58	2.79	1.158
22	8.29	680	4.38	2.34	1.159
23	8.14	658	4.24	2.46	1.159

Table 17. Hourly wind statistics at PO1_mast at 112 meters, reference period.

ITamb (%)	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	Sector 7	Sector 8	Sector 9	Sector 10	Sector 11	Sector 12	Sector 13	Sector 14	Sector 15	Sector 16
0 - 0.25	65535.000	65535.000	104.103	58.644	53.484	25.517	86.818	62.302	39.608	49.196	45.554	374.041	49.395	81.428	36.238	25.010
0.5 - 1.5	29.892	36.868	38.570	16.652	24.989	18.764	20.047	22.549	23.972	28.767	23.225	27.992	27.276	27.805	25.558	31.361
1.5 - 2.5	18.698	17.547	16.101	14.952	18.843	12.878	12.486	14.270	15.220	15.917	14.283	15.746	18.608	21.504	16.468	15.368
2.5 - 3.5	12.767	10.207	12.478	14.831	14.709	7.929	9.390	10.043	10.427	11.200	10.683	10.854	12.663	13.851	13.094	14.753
3.5 - 4.5	12.074	8.966	10.803	13.340	12.392	7.567	7.793	8.449	8.781	9.282	7.705	7.778	8.703	12.379	14.018	14.349
4.5 - 5.5	10.080	9.047	9.539	11.535	10.937	7.094	6.724	7.372	7.783	8.139	7.113	7.046	7.887	8.480	8.950	11.241
5.5 - 6.5	10.158	8.410	8.589	11.337	10.461	5.976	6.130	7.370	7.532	7.555	5.728	6.496	9.227	9.352	10.504	11.443
6.5 - 7.5	10.947	7.467	8.716	10.909	10.365	5.287	5.463	7.200	7.410	6.347	5.223	6.113	6.845	11.964	11.439	9.984
7.5 - 8.5	10.176	7.310	9.285	10.718	9.991	5.554	4.773	7.574	7.185	5.744	5.032	6.066	6.845	6.490	8.512	11.207
8.5 - 9.5	10.970	7.788	9.263	9.757	9.700	8.408	5.442	6.795	6.903	5.403	5.041	5.921	6.845	6.623	11.820	11.328
9.5 - 10.5	11.403	8.533	9.072	9.112	9.364	10.596	5.442	6.795	6.593	5.375	5.150	5.801	6.774	6.930	11.290	12.406
10.5 - 11.5	9.780	9.174	9.076	9.740	9.364	10.596	5.442	6.795	6.794	5.442	5.318	6.469	6.774	6.346	11.290	12.907
11.5 - 12.5	10.264	9.264	9.217	10.367	9.364	10.596	5.442	6.795	6.590	5.523	5.477	6.400	6.774	6.346	11.290	12.610
12.5 - 13.5	10.264	9.264	8.616	10.367	9.364	10.596	5.442	6.795	6.572	5.809	5.805	6.995	6.774	6.346	11.290	12.610
13.5 - 14.5	10.264	9.264	8.616	10.367	9.364	10.596	5.442	6.795	6.870	6.001	6.103	6.995	6.774	6.346	11.290	12.610
14.5 - 15.5	10.264	9.264	8.616	10.367	9.364	10.596	5.442	6.795	6.870	6.025	6.044	6.995	6.774	6.346	11.290	12.610
15.5 - 16.5	10.264	9.264	8.616	10.367	9.364	10.596	5.442	6.795	6.870	6.136	6.090	6.995	6.774	6.346	11.290	12.610
16.5 - 17.5	10.264	9.264	8.616	10.367	9.364	10.596	5.442	6.795	6.870	6.370	6.618	6.995	6.774	6.346	11.290	12.610
17.5 - 18.5	10.264	9.264	8.616	10.367	9.364	10.596	5.442	6.795	6.870	6.320	6.100	6.995	6.774	6.346	11.290	12.610
18.5 - 19.5	10.264	9.264	8.616	10.367	9.364	10.596	5.442	6.795	6.870	6.613	7.173	6.995	6.774	6.346	11.290	12.610
19.5 - 20.5	10.264	9.264	8.616	10.367	9.364	10.596	5.442	6.795	6.870	6.613	7.173	6.995	6.774	6.346	11.290	12.610
20.5 - 21.5	10.264	9.264	8.616	10.367	9.364	10.596	5.442	6.795	6.870	6.613	7.173	6.995	6.774	6.346	11.290	12.610
21.5 - 22.5	10.264	9.264	8.616	10.367	9.364	10.596	5.442	6.795	6.870	6.613	7.173	6.995	6.774	6.346	11.290	12.610
22.5 - 23.5	10.264	9.264	8.616	10.367	9.364	10.596	5.442	6.795	6.870	6.613	7.173	6.995	6.774	6.346	11.290	12.610
23.5 - 24.5	10.264	9.264	8.616	10.367	9.364	10.596	5.442	6.795	6.870	6.613	7.173	6.995	6.774	6.346	11.290	12.610
+ 24.5	10.264	9.264	8.616	10.367	9.364	10.596	5.442	6.795	6.870	6.613	7.173	6.995	6.774	6.346	11.290	12.610
TOTAL V>5 m/s	**10.448**	**8.170**	**9.068**	**11.148**	**10.604**	**6.270**	**6.257**	**7.506**	**7.404**	**5.811**	**5.508**	**6.556**	**8.018**	**8.507**	**10.315**	**11.475**

Vmean (m/s)	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	Sector 7	Sector 8	Sector 9	Sector 10	Sector 11	Sector 12	Sector 13	Sector 14	Sector 15	Sector 16
7.81	5.83	6.54	6.67	6.03	5.54	5.07	4.86	4.76	6.38	11.25	10.28	5.47	4.16	4.94	4.70	5.88

Nº Data	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	Sector 7	Sector 8	Sector 9	Sector 10	Sector 11	Sector 12	Sector 13	Sector 14	Sector 15	Sector 16
51920	1028	3195	7601	6086	2626	1511	1343	2465	3209	11728	7932	1157	612	354	343	730

Frequency (%)	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	Sector 7	Sector 8	Sector 9	Sector 10	Sector 11	Sector 12	Sector 13	Sector 14	Sector 15	Sector 16
100.00	1.98	6.15	14.64	11.72	5.06	2.91	2.59	4.75	6.18	22.59	15.28	2.23	1.18	0.68	0.66	1.41

Table 18. Sector wise ambient turbulence intensity PO1_mast at 112 meters / Reference period.

WIND SPEED STATISTICS										
BIN VEL.	FREQ	Nº DATA	ANNUAL Nº HOURS	% ENERGY	TI amb %	ITc // ITr	P84 / P90 σV	Gust Factor [1]	Gust Factor [2]	DENSITY kg/m^3
0.5	0.45	233	39	0.00	40.92	155.93	0.14	1.82	2.11	1.160
1.5	2.06	1069	180	0.00	19.91	33.08	0.19	1.40	1.54	1.157
2.5	4.40	2282	385	0.01	12.99	20.95	0.20	1.26	1.35	1.157
3.5	6.37	3305	558	0.45	10.92	17.30	0.22	1.22	1.30	1.157
4.5	9.37	4865	821	1.75	9.66	14.65	0.22	1.19	1.26	1.158
5.5	12.18	6322	1067	4.29	8.96	13.41	0.25	1.18	1.24	1.158
6.5	13.14	6820	1151	7.72	8.59	12.52	0.26	1.17	1.23	1.158
7.5	10.57	5488	926	9.52	8.22	11.96	0.28	1.16	1.22	1.157
8.5	7.81	4057	685	10.22	7.41	10.64	0.27	1.15	1.20	1.155
9.5	6.56	3406	575	11.32	6.54	9.30	0.26	1.13	1.18	1.154
10.5	5.98	3106	524	11.80	6.05	8.32	0.24	1.12	1.16	1.154
11.5	5.83	3028	511	11.84	5.89	7.77	0.22	1.12	1.16	1.154
12.5	5.01	2601	439	10.18	5.83	7.33	0.19	1.12	1.16	1.153
13.5	4.29	2225	375	8.71	5.99	7.39	0.19	1.12	1.16	1.153
14.5	3.17	1644	277	6.44	6.08	7.35	0.18	1.12	1.16	1.153
15.5	1.93	1003	169	3.93	6.09	7.19	0.17	1.12	1.17	1.153
16.5	0.62	322	54	1.26	6.33	7.56	0.20	1.13	1.17	1.152
17.5	0.19	98	17	0.38	6.37	7.57	0.21	1.13	1.17	1.152
18.5	0.07	34	6	0.13	6.60	8.37	0.33	1.13	1.18	1.151
19.5	0.02	12	2	0.05	6.60	8.37	0.33	1.13	1.18	1.151
20.5	0.00	0	0	0.00	6.60	8.37	0.33	1.13	1.18	1.151
21.5	0.00	0	0	0.00	6.60	8.37	0.33	1.13	1.18	1.151
22.5	0.00	0	0	0.00	6.60	8.37	0.33	1.13	1.18	1.151
23.5	0.00	0	0	0.00	6.60	8.37	0.33	1.13	1.18	1.151
24.5	0.00	0	0	0.00	6.60	8.37	0.33	1.13	1.18	1.151
25.5	0.00	0	0	0.00	6.60	8.37	0.33	1.13	1.18	1.151
26.5	0.00	0	0	0.00	6.60	8.37	0.33	1.13	1.18	1.151
27.5	0.00	0	0	0.00	6.60	8.37	0.33	1.13	1.18	1.151
28.5	0.00	0	0	0.00	6.60	8.37	0.33	1.13	1.18	1.151
29.5	0.00	0	0	0.00	6.60	8.37	0.33	1.13	1.18	1.151
30.5	0.00	0	0	0.00	6.60	8.37	0.33	1.13	1.18	1.151

[1] Estimating overwater turbulence from routine gust factor measurements.pdf [2] Hurricane Gust Factors Revisited.pdf

Table 19. Gust factor, ambient turbulence VS wind speed, PO1_mast at 112 meters / Reference period.

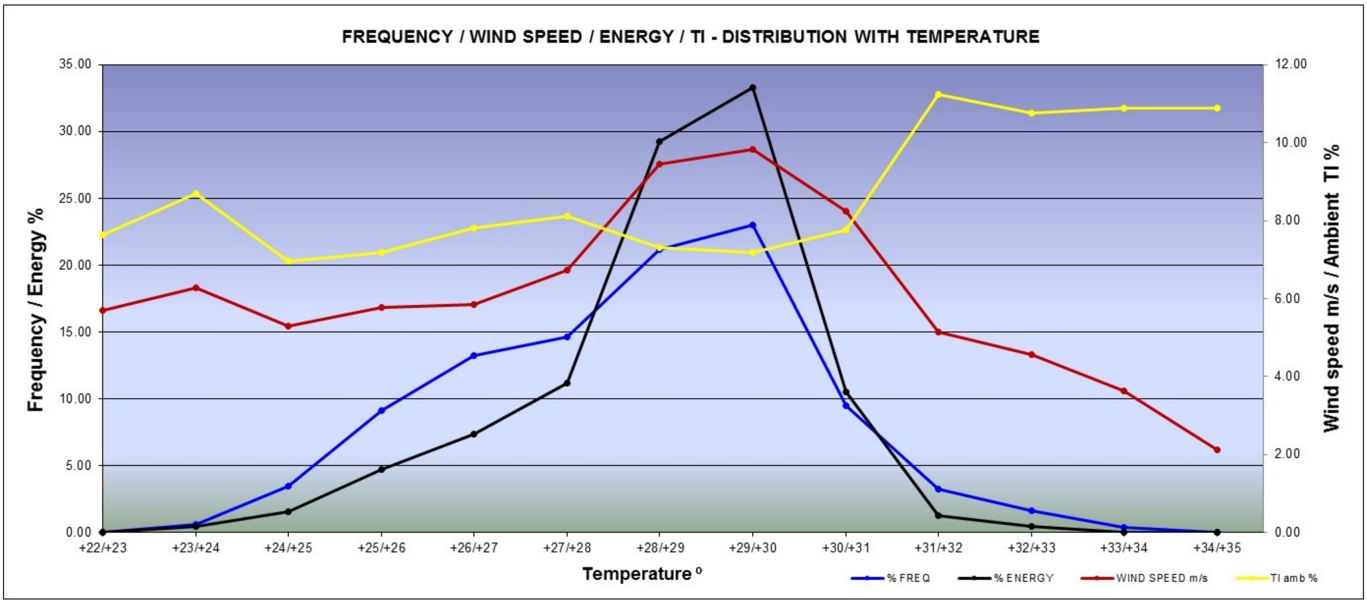


Figure 24. Distribution of magnitudes with temperature at PO1_mast / Reference period.

TEMPERATURE STATISTICS											
TEMPERATURE	% FREQ	Nº DATA	ANNUAL Nº HOURS	MEAN TEMP º	WIND SPEED m/s	TI amb %	% ENERGY	DENSITY kg/m^3	PRESSURE mb	ACCUMULATED ENERGY GAIN	ACCUMULATED ENERGY LOSS
+22/+23	0.01	6	1.01	22.66	5.70	7.64	0.006	1.178	#N/A	0.006	99.994
+23/+24	0.61	319	53.82	23.68	6.27	8.70	0.441	1.174	#N/A	0.447	99.553
+24/+25	3.49	1813	305.89	24.63	5.29	6.94	1.574	1.170	#N/A	2.021	97.979
+25/+26	9.09	4718	796.03	25.54	5.77	7.19	4.707	1.167	#N/A	6.728	93.272
+26/+27	13.25	6881	1160.97	26.53	5.86	7.82	7.377	1.163	#N/A	14.105	85.895
+27/+28	14.62	7591	1280.76	27.50	6.72	8.12	11.145	1.159	#N/A	25.250	74.750
+28/+29	21.20	11009	1857.45	28.55	9.44	7.30	29.227	1.155	#N/A	54.477	45.523
+29/+30	22.98	11932	2013.18	29.46	9.84	7.18	33.270	1.152	#N/A	87.747	12.253
+30/+31	9.50	4933	832.30	30.40	8.23	7.77	10.487	1.148	#N/A	98.233	1.767
+31/+32	3.21	1668	281.43	31.46	5.16	11.25	1.280	1.144	#N/A	99.513	0.487
+32/+33	1.61	838	141.39	32.41	4.55	10.76	0.439	1.141	#N/A	99.952	0.048
+33/+34	0.39	204	34.42	33.30	3.63	10.89	0.048	1.137	#N/A	100.000	0.000
+34/+35	0.02	8	1.35	34.33	2.13	10.89	0.000	1.134	#N/A	100.000	0.000

Table 20. Distribution of wind statistics with temperature at 112 meters, PO1_mast / Reference period.

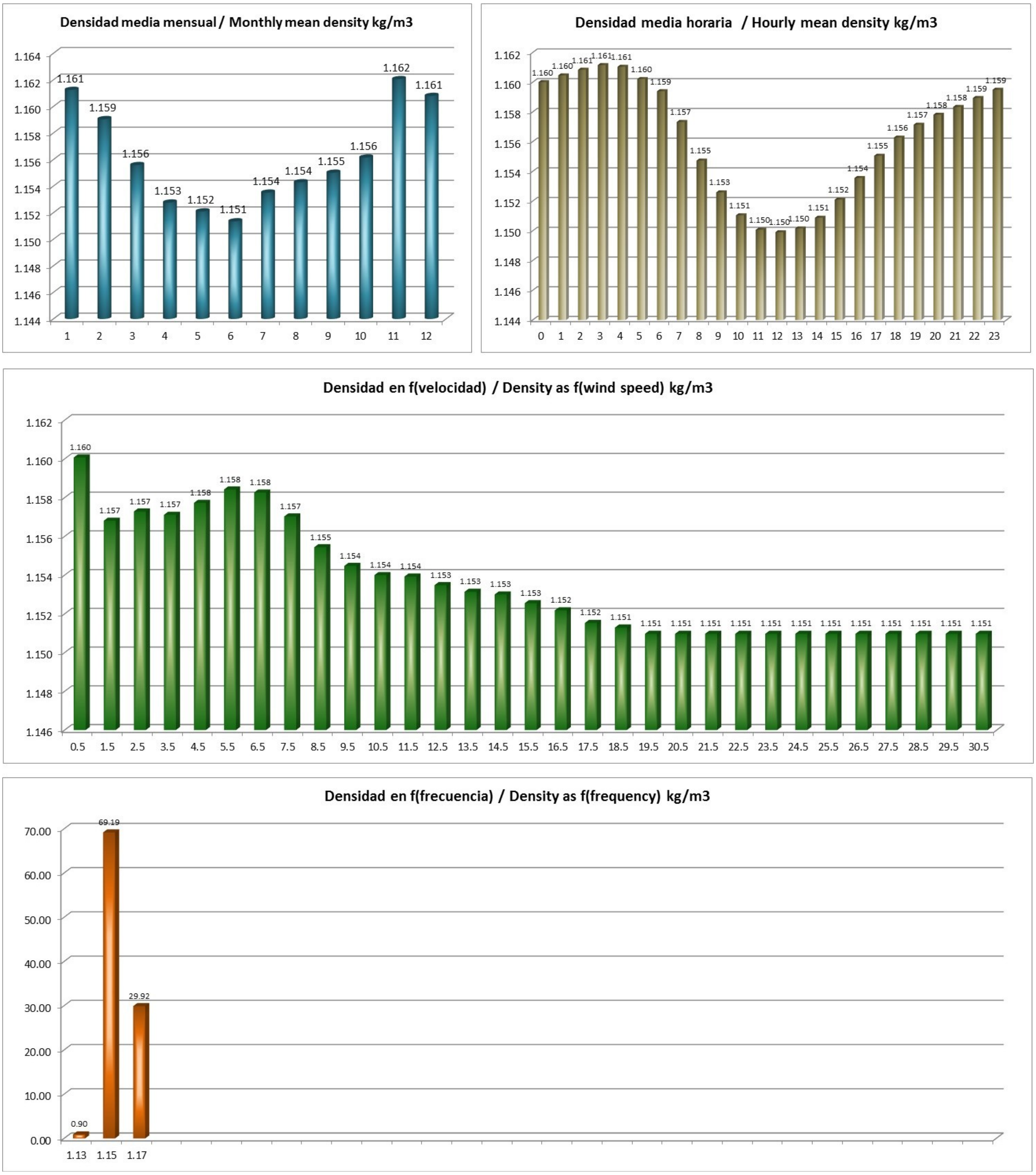
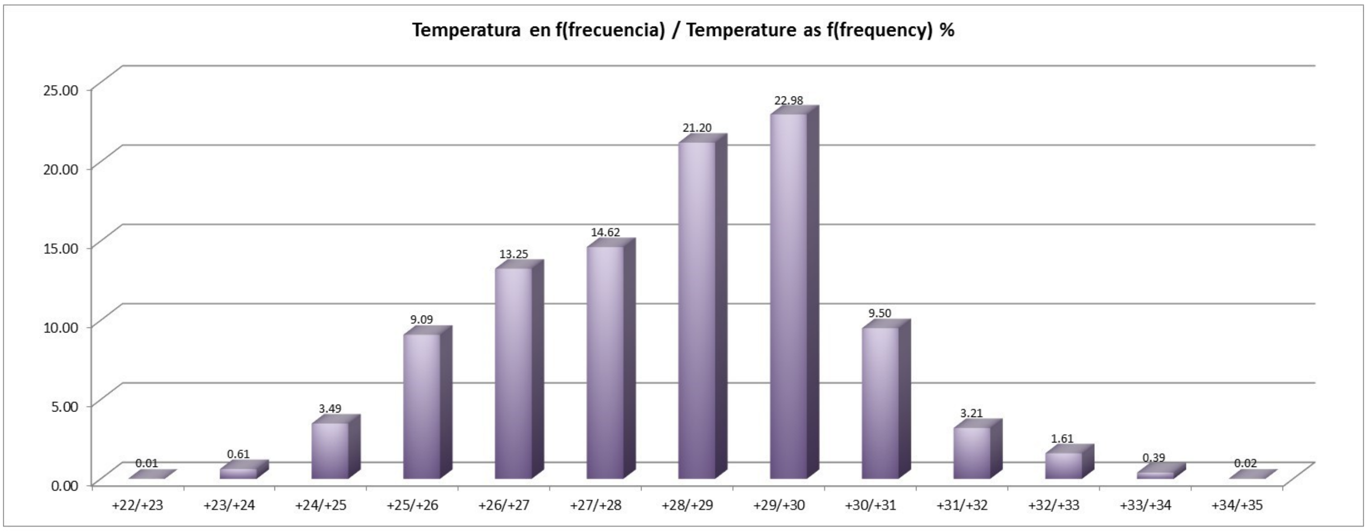
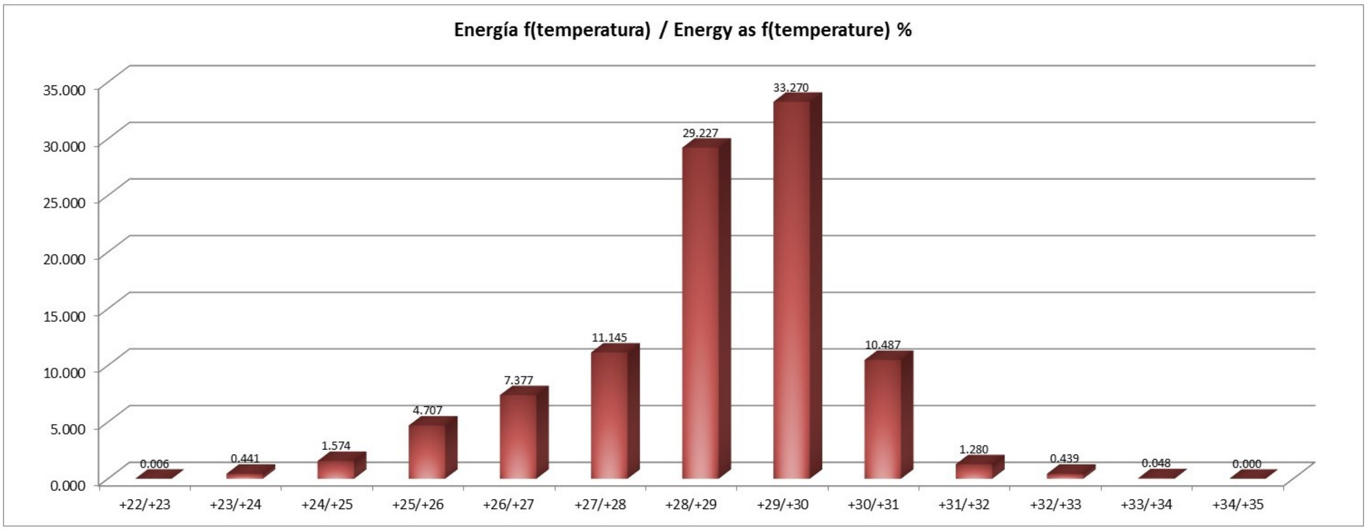


Figure 25. Distribution of mean air density at Pooneryn wind farm.





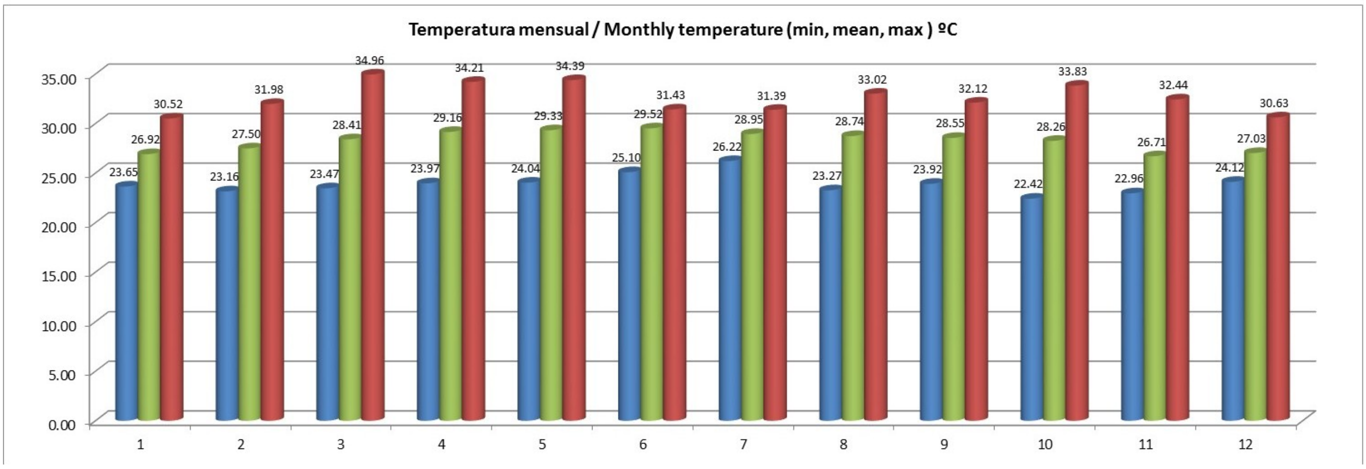
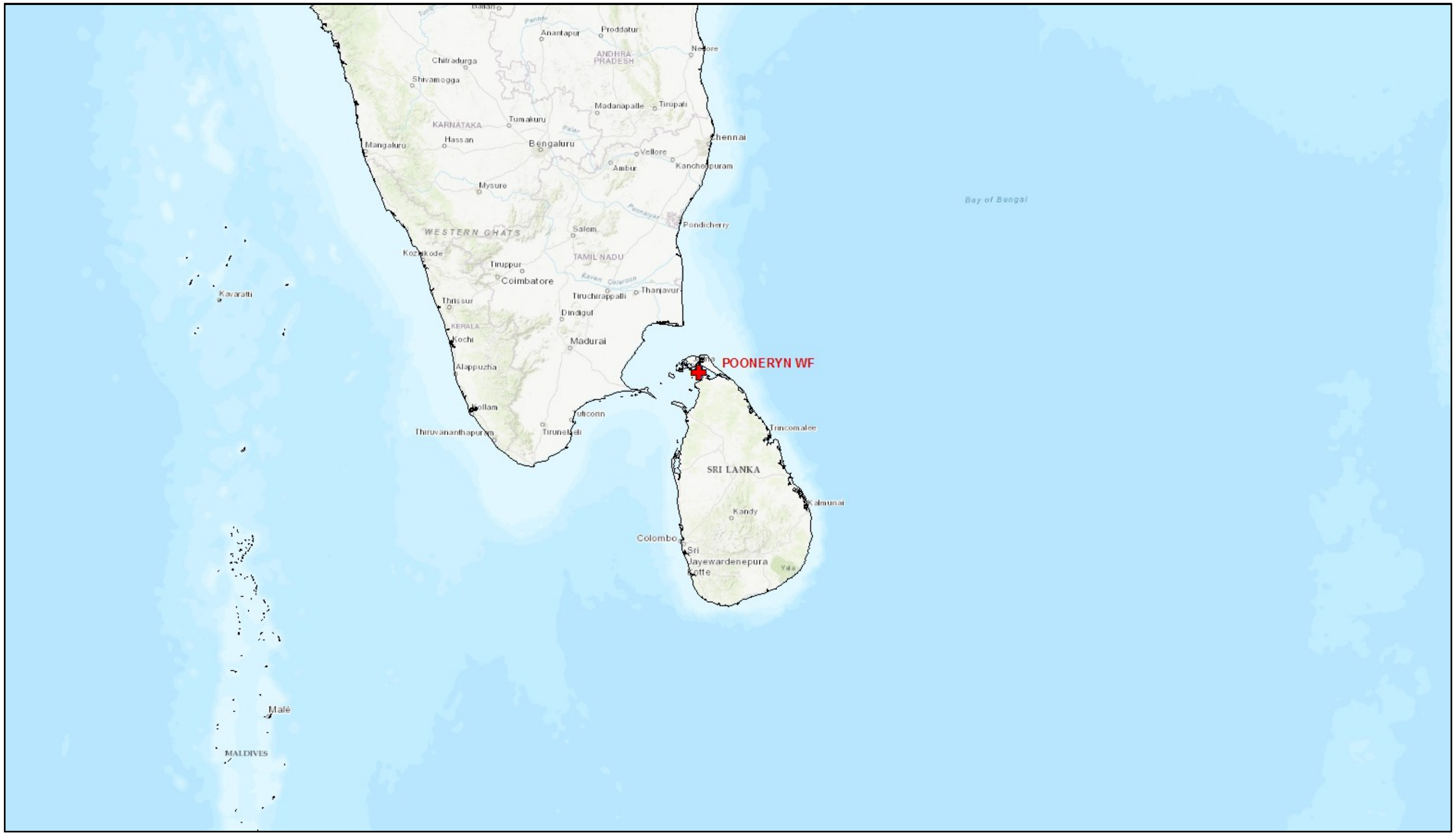
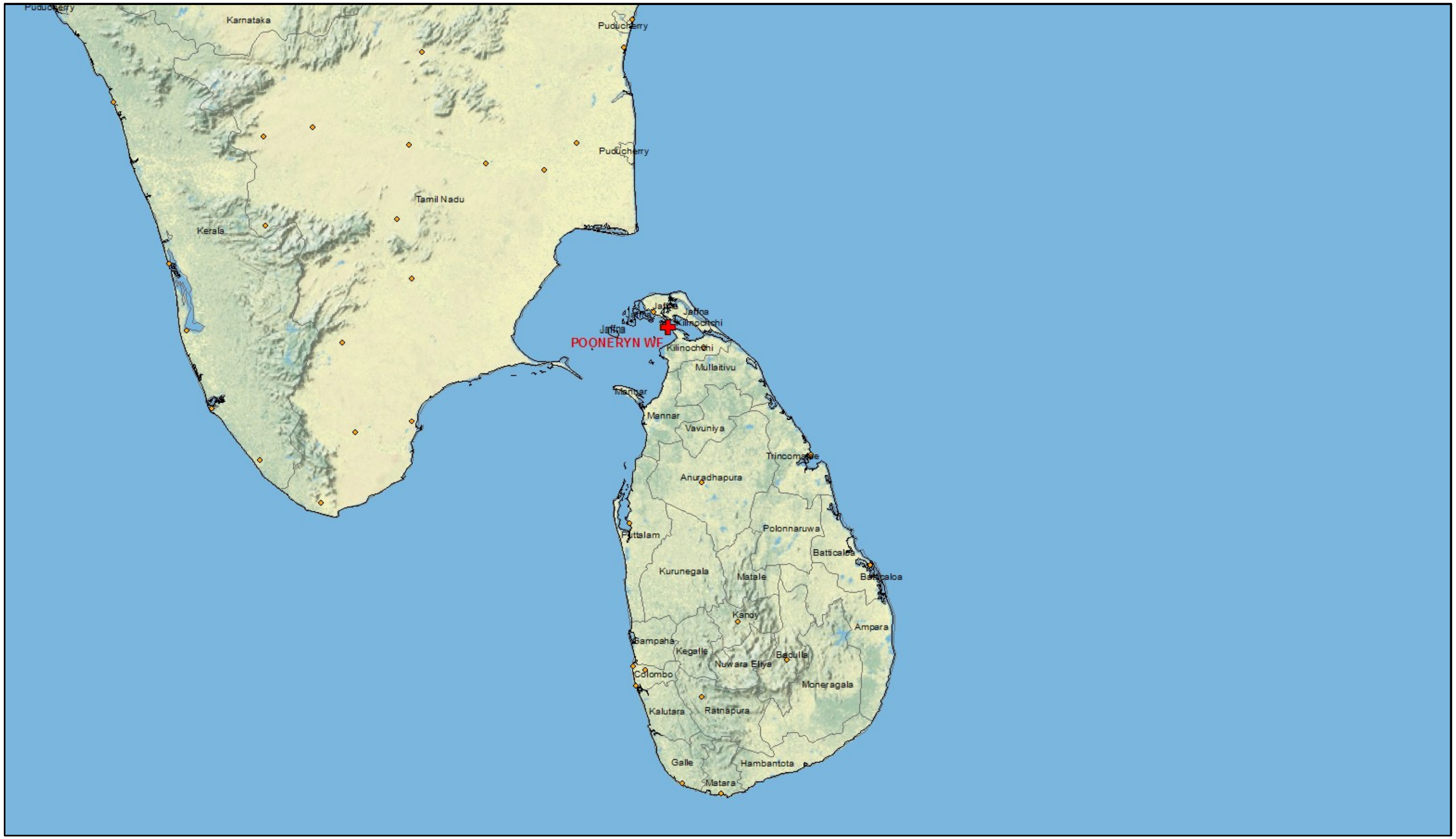


Figure 26. Temperature analysis at Pooneryn wind farm.

ANNEX B: SITE MAPS

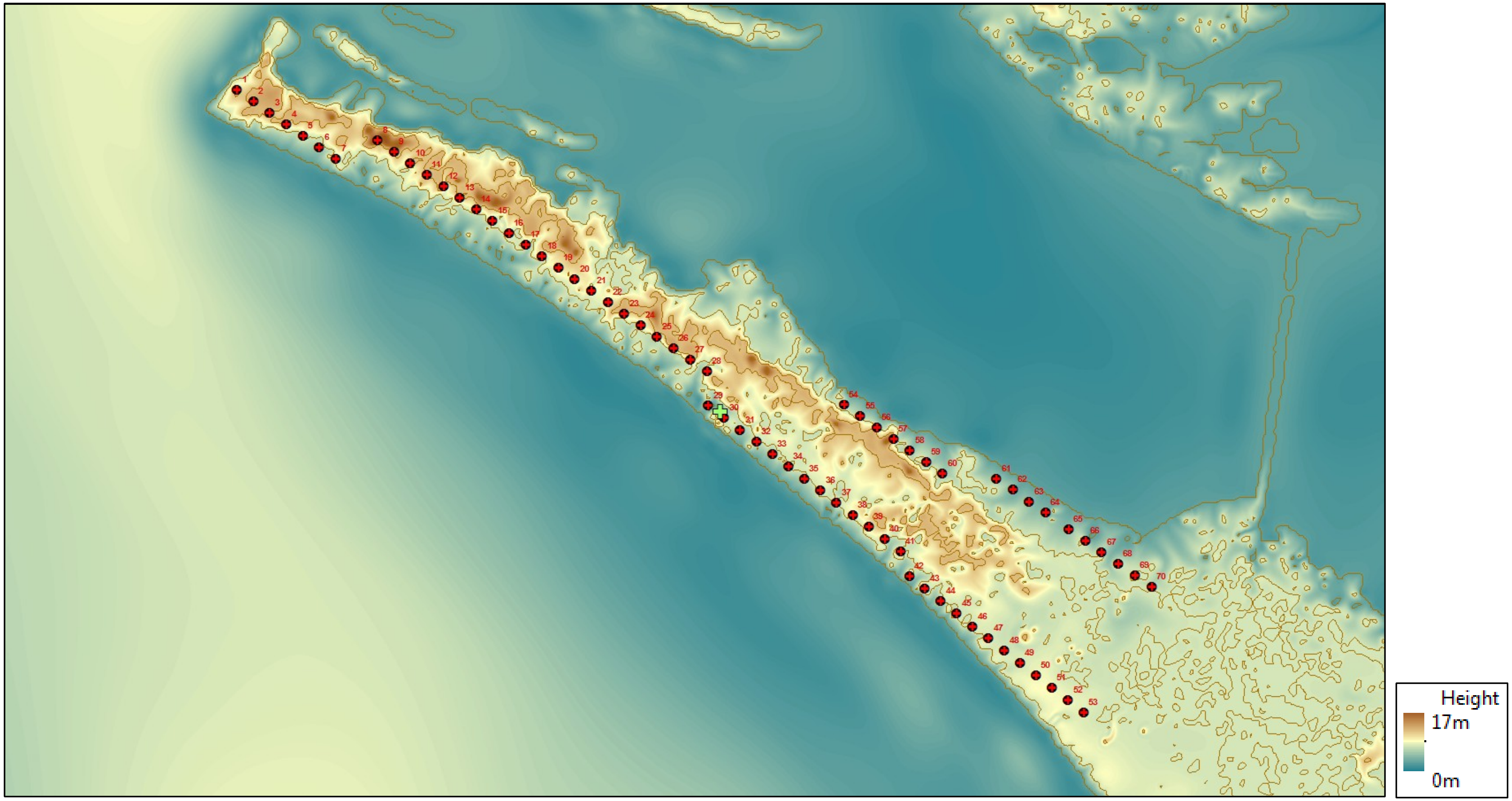


Map 1. Location of Pooneryn wind project.



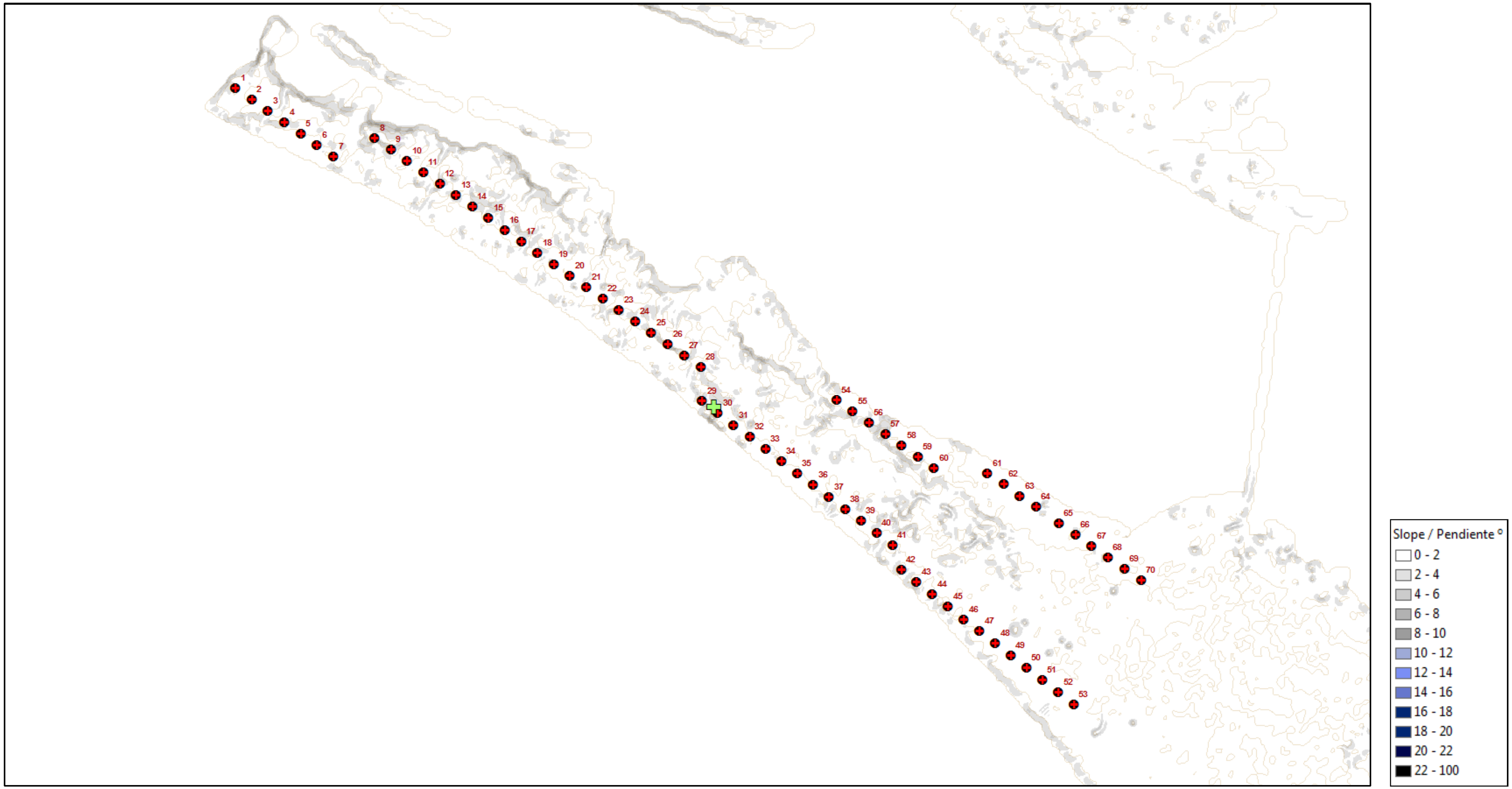
Map 2. Location of Pooneryn wind project.

Map 3. Location of Pooneryn wind project.

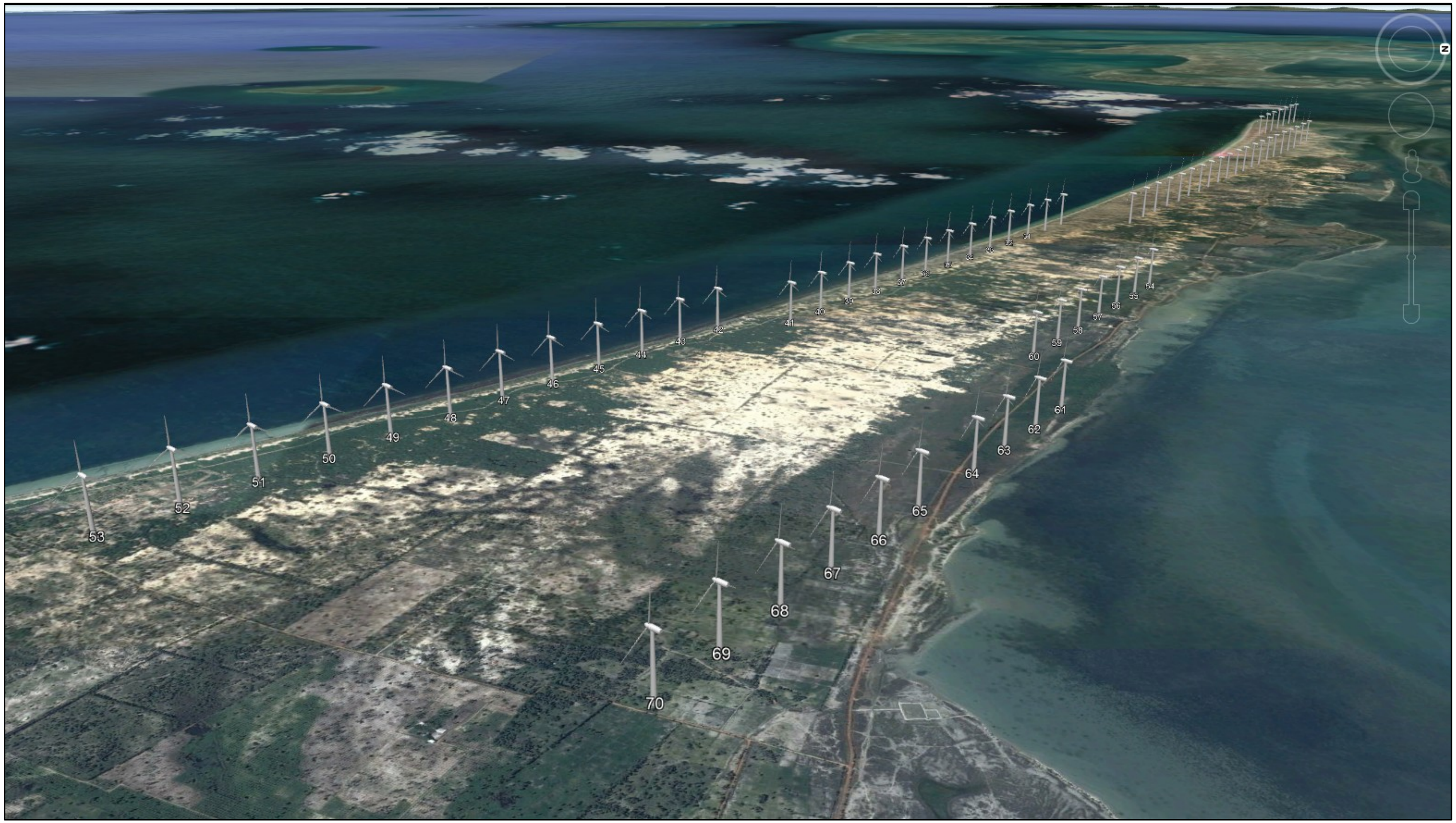


Map 4. Orographic raster of Pooneryn wind farm along with met masts and neighbour wind farms (if any).

Map 5. Roughness map of Pooneryn wind farm.



Map 6. Slope raster of Pooneryn wind farm.



Map 7. Aerial picture of Pooneryn wind farm.

Map 8. Aerial picture of Pooneryn wind farm.

ANNEXES II: PVSYST OUTPUTS FOR POONERYN SOLAR FIELD

Grid-Connected System: Simulation parameters

Project : **EN2530-Pooneryn-SolarGIS-SYN**

Geographical Site	**EN2530-Pooneryn-SolarGIS-SYN**		Country	**Sri Lanka**
Situation	Latitude	9.53° N	Longitude	80.17° E
Time defined as	Legal Time	Time zone UT+5.5	Altitude	6 m
	Albedo	0.20		
Meteo data:	**EN2530-Pooneryn-SolarGIS-SYN**	SolarGIS Monthly aver. , period not spec. - Synthetic		

Simulation variant : **77.55MVA - 7.5 Pitch - 1.29 - 15º - NoShadows**

Simulation date	03/05/18 18h00
Simulation for the	**first year of operation**

Simulation parameters	System type	**Sheds on ground**		
Collector Plane Orientation	Tilt	15°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	According to strings		Electrical effect	100 %

PV Array Characteristics

PV module Si-poly	Model	**JKM 335PP-72-2016**		
Custom parameters definition	Manufacturer	Jinkosolar		
Number of PV modules	In series	30 modules	In parallel	9250 strings
Total number of PV modules	Nb. modules	277500	Unit Nom. Power	335 Wp
Array global power	Nominal (STC)	**92963 kWp**	At operating cond.	83788 kWp (50°C)
Array operating characteristics (50°C)	U mpp	1032 V	I mpp	81213 A
Total area	Module area	**538448 m²**	Cell area	486313 m²

Inverter	Model	**R15015TL**		
Custom parameters definition	Manufacturer	FIMER SPA		
Characteristics	Operating Voltage	850-1320 V	Unit Nom. Power	1410 kWac
Inverter pack	Nb. of inverters	55 units	Total Power	77550 kWac
			Pnom ratio	1.20

PV Array loss factors

Array Soiling Losses			Loss Fraction	2.0 %
Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	0.21 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	1.8 %
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Module average degradation	Year no	1	Loss factor	0.68 %/year
Mismatch due to degradation	Imp RMS dispersion	0.4 %/year	Vmp RMS dispersion	0.4 %/year

Incidence effect (IAM): User defined IAM profile

0°	20°	30°	40°	50°	60°	70°	80°	90°
1.000	1.000	1.000	1.000	1.000	1.000	0.950	0.770	0.000

System loss factors

AC wire loss inverter to transfo	Inverter voltage	550 Vac tri		
	Wires: 3x30000.0 mm²	53 m	Loss Fraction	1.0 % at STC
External transformer	Iron loss (24H connexion)	91181 W	Loss Fraction	0.1 % at STC
	Resistive/Inductive losses	0.0 mOhm	Loss Fraction	1.2 % at STC

Grid-Connected System: Simulation parameters

User's needs :	Unlimited load (grid)					
Auxiliaries loss	Proportionnal to Power	4.0	W/kW	... from Power thresh.	0.0	kW

Grid-Connected System: Near shading definition

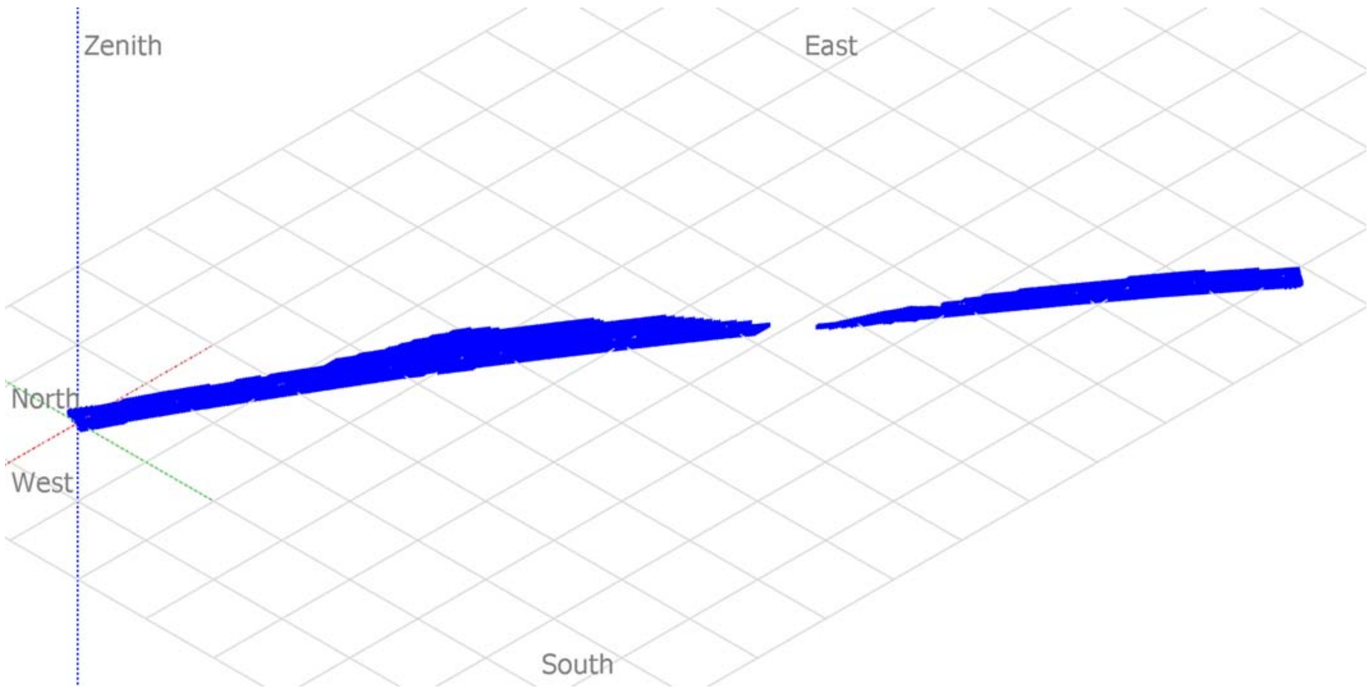
Project : **EN2530-Pooneryn-SolarGIS-SYN**

Simulation variant : **77.55MVA - 7.5 Pitch - 1.29 - 15º - NoShadows**

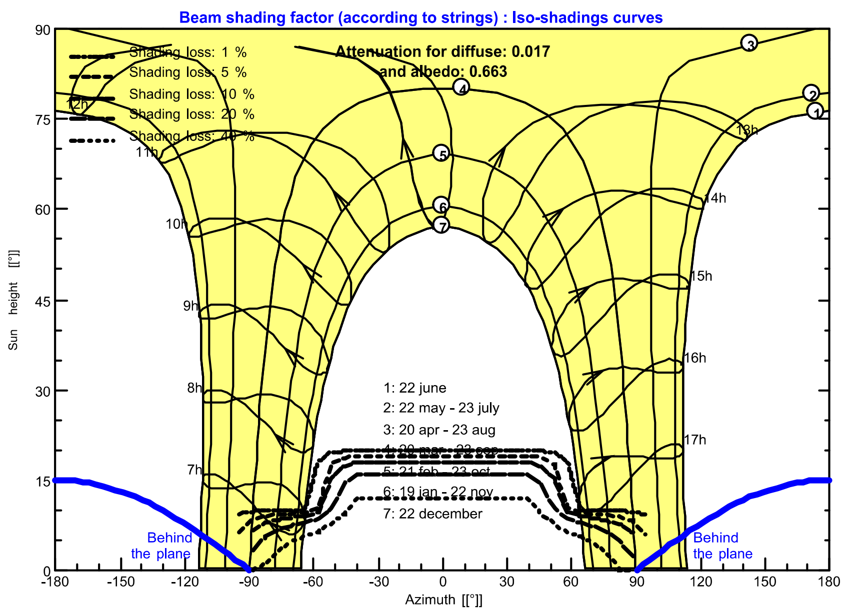
Simulation for the first year of operation

Main system parameters	System type	**Grid-Connected**		
Near Shadings	According to strings		Electrical effect	100 %
PV Field Orientation	tilt	15°	azimuth	0°
PV modules	Model	JKM 335PP-72-2016	Pnom	335 Wp
PV Array	Nb. of modules	277500	Pnom total	**92963 kWp**
Inverter	Model	R15015TL	Pnom	1410 kW ac
Inverter pack	Nb. of units	55.0	Pnom total	**77550 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



Grid-Connected System: Main results

Project : **EN2530-Pooneryn-SolarGIS-SYN**

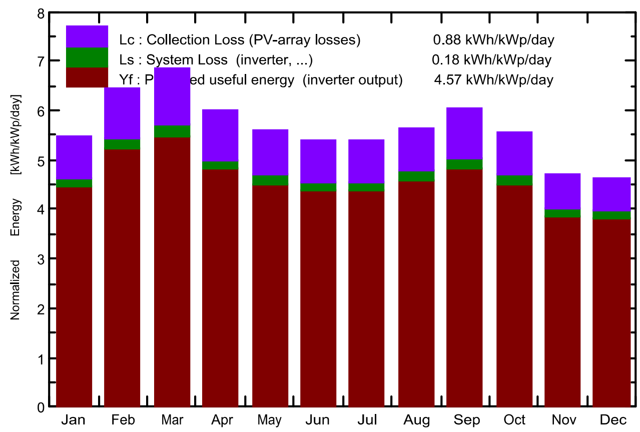
Simulation variant : **77.55MVA - 7.5 Pitch - 1.29 - 15º - NoShadows**

Simulation for the first year of operation

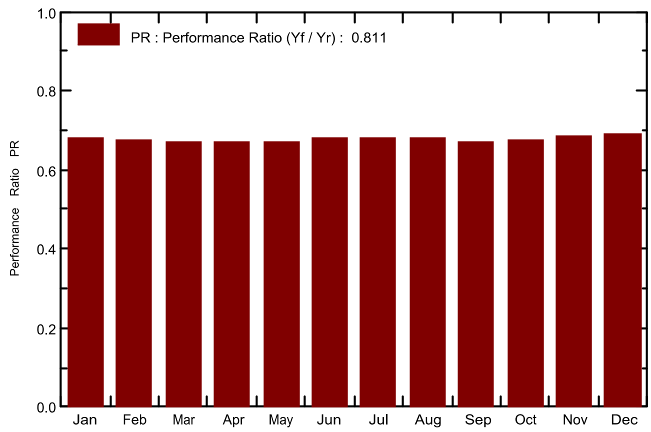
Main system parameters	System type	**Grid-Connected**		
Near Shadings	According to strings		Electrical effect	100 %
PV Field Orientation	tilt	15°	azimuth	0°
PV modules	Model	JKM 335PP-72-2016	Pnom	335 Wp
PV Array	Nb. of modules	277500	Pnom total	**92963 kWp**
Inverter	Model	R15015TL	Pnom	1410 kW ac
Inverter pack	Nb. of units	55.0	Pnom total	**77550 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**155092 MWh/year**	Specific prod.	1668 kWh/kWp/year
	Performance Ratio PR	81.10 %		

Normalized productions (per installed kWp): Nominal power 92963 kWp



Performance Ratio PR



77.55MVA - 7.5 Pitch - 1.29 - 15º - NoShadows

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	153.0	70.00	26.00	169.4	162.8	13358	12831	0.815
February	167.0	63.00	26.80	180.7	173.9	14142	13584	0.809
March	207.0	73.00	28.20	212.2	204.2	16464	15815	0.802
April	186.0	72.00	29.70	180.1	172.9	13957	13416	0.801
May	188.0	87.00	30.00	173.8	166.1	13536	13025	0.806
June	178.0	81.00	29.40	161.3	154.1	12680	12205	0.814
July	182.0	86.00	29.00	166.8	159.5	13139	12647	0.815
August	184.0	86.00	28.90	175.3	168.0	13782	13260	0.814
September	181.0	77.00	28.80	180.6	173.4	14069	13520	0.805
October	164.0	74.00	28.10	172.2	165.6	13518	12989	0.811
November	129.0	68.00	27.10	140.9	135.2	11186	10747	0.820
December	129.0	69.00	26.30	143.8	137.8	11496	11052	0.827
Year	2048.0	905.99	28.20	2057.1	1973.5	161327	155092	0.811

Legends:				
	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

Grid-Connected System: Loss diagram

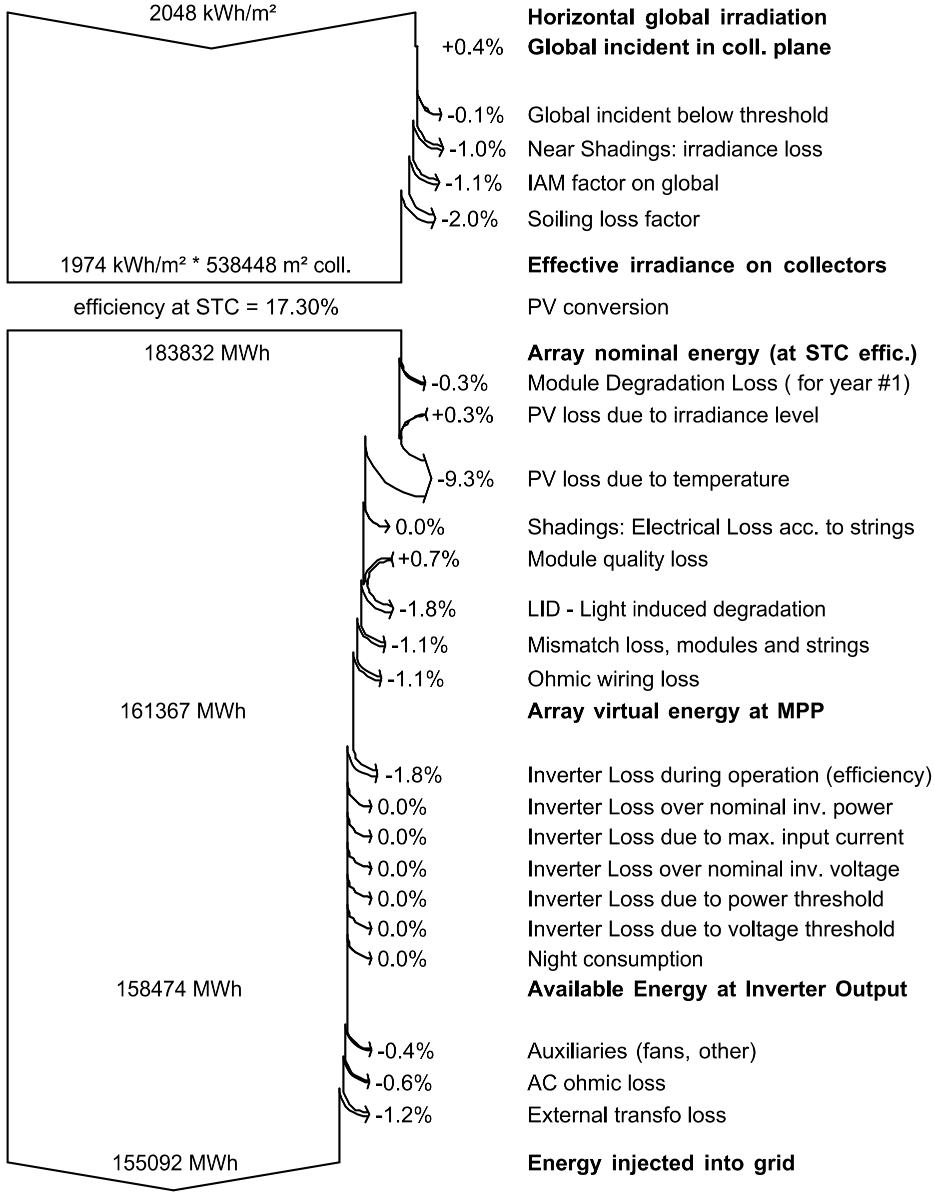
Project : **EN2530-Pooneryn-SolarGIS-SYN**

Simulation variant : **77.55MVA - 7.5 Pitch - 1.29 - 15º - NoShadows**

Simulation for the first year of operation

Main system parameters	System type	**Grid-Connected**		
Near Shadings	According to strings		Electrical effect	100 %
PV Field Orientation	tilt	15°	azimuth	0°
PV modules	Model	JKM 335PP-72-2016	Pnom	335 Wp
PV Array	Nb. of modules	277500	Pnom total	**92963 kWp**
Inverter	Model	R15015TL	Pnom	1410 kW ac
Inverter pack	Nb. of units	55.0	Pnom total	**77550 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Grid-Connected System: Simulation parameters

Project : **EN2530-Pooneryn-SolarGIS-SYN**

Geographical Site	**EN2530-Pooneryn-SolarGIS-SYN**		Country	**Sri Lanka**
Situation	Latitude	9.53° N	Longitude	80.17° E
Time defined as	Legal Time	Time zone UT+5.5	Altitude	6 m
	Albedo	0.20		
Meteo data:	**EN2530-Pooneryn-SolarGIS-SYN**	SolarGIS Monthly aver. , period not spec. - Synthetic		

Simulation variant : **77.55MVA - 7.5 Pitch - 1.29 - 15º -FirstSolar**

	Simulation date	03/05/18 18h58
	Simulation for the	**first year of operation**

Simulation parameters	System type	**Sheds on ground**		
Collector Plane Orientation	Tilt	15°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	According to strings		Electrical effect	100 %

PV Array Characteristics

PV module CdTe	Model	**FS-6420_prelim_Dec16**		
Custom parameters definition	Manufacturer	First Solar Preliminary		
Number of PV modules	In series	6 modules	In parallel	36888 strings
Total number of PV modules	Nb. modules	221328	Unit Nom. Power	420 Wp
Array global power	Nominal (STC)	**92958 kWp**	At operating cond.	86679 kWp (50°C)
Array operating characteristics (50°C)	U mpp	966 V	I mpp	89692 A
Total area	Module area	**544467 m²**	Cell area	535171 m²

Inverter	Model	**R15015TL**		
Custom parameters definition	Manufacturer	FIMER SPA		
Characteristics	Operating Voltage	850-1320 V	Unit Nom. Power	1410 kWac
Inverter pack	Nb. of inverters	55 units	Total Power	77550 kWac
			Pnom ratio	1.20

PV Array loss factors

Array Soiling Losses			Loss Fraction	2.0 %
Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	0.18 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	0.0 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Module average degradation	Year no	1	Loss factor	0.5 %/year
Mismatch due to degradation	Imp RMS dispersion	0.4 %/year	Vmp RMS dispersion	0.4 %/year

Incidence effect (IAM): User defined IAM profile

0°	30°	50°	60°	65°	70°	75°	80°	90°
1.000	1.000	0.990	0.960	0.940	0.890	0.820	0.690	0.000

System loss factors

AC wire loss inverter to transfo	Inverter voltage	550 Vac tri		
	Wires: 3x30000.0 mm²	53 m	Loss Fraction	1.0 % at STC
External transformer	Iron loss (24H connexion)	91502 W	Loss Fraction	0.1 % at STC
	Resistive/Inductive losses	0.0 mOhm	Loss Fraction	1.2 % at STC

Grid-Connected System: Simulation parameters

User's needs :	Unlimited load (grid)					
Auxiliaries loss	Proportionnal to Power	4.0	W/kW	... from Power thresh.	0.0	kW

Grid-Connected System: Near shading definition

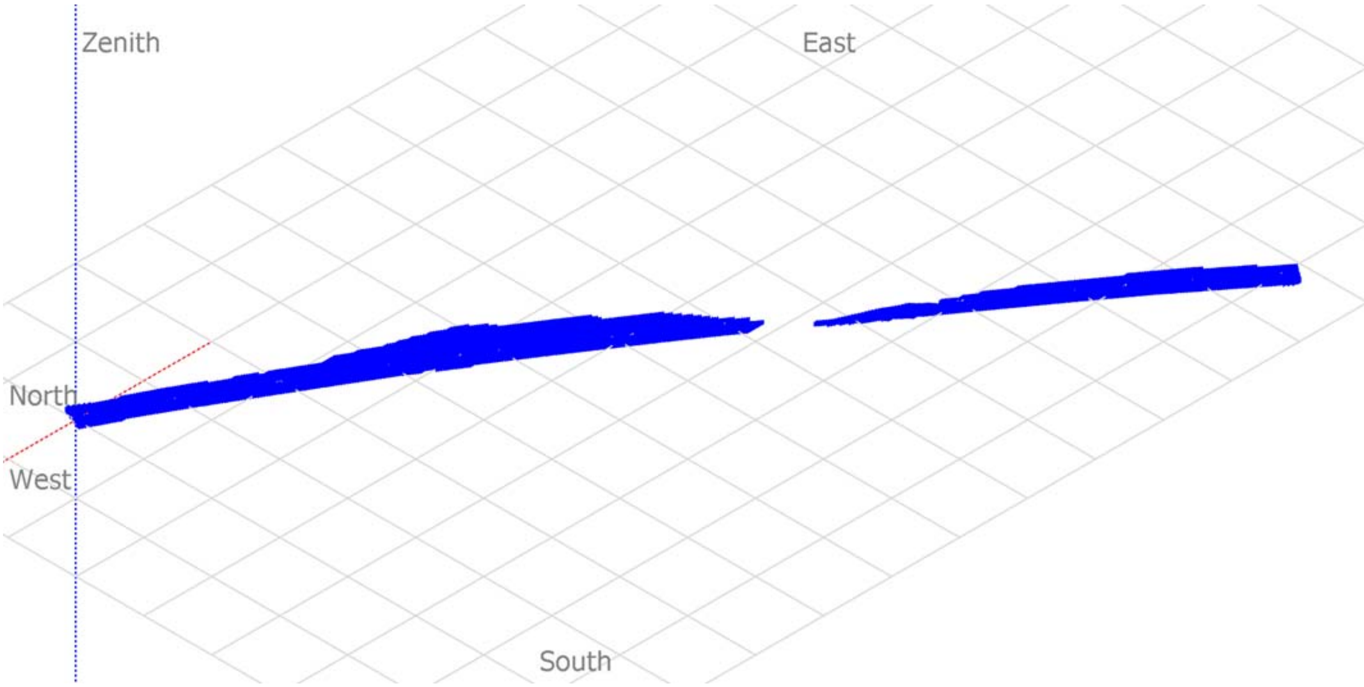
Project : **EN2530-Pooneryn-SolarGIS-SYN**

Simulation variant : **77.55MVA - 7.5 Pitch - 1.29 - 15º -FirstSolar**

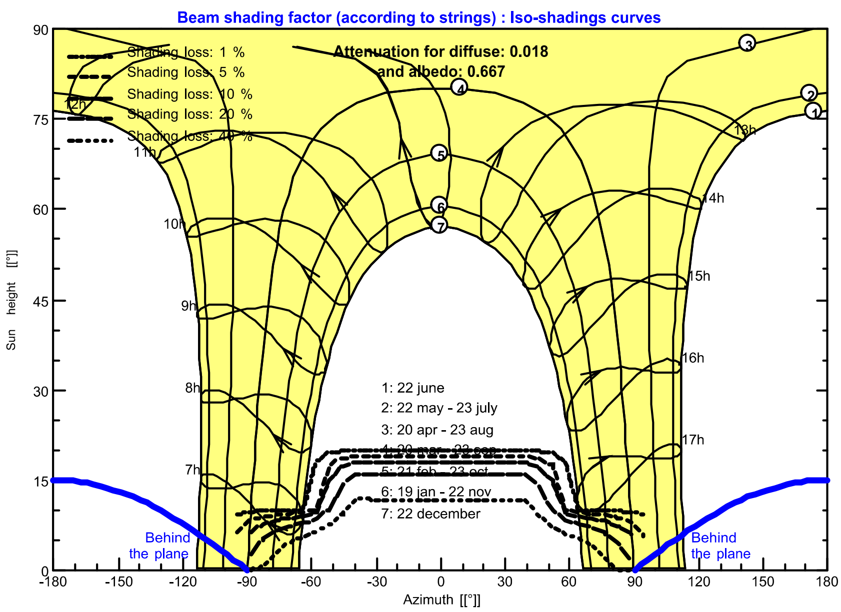
Simulation for the first year of operation

Main system parameters	System type	**Grid-Connected**		
Near Shadings	According to strings		Electrical effect	100 %
PV Field Orientation	tilt	15°	azimuth	0°
PV modules	Model	FS-6420_prelim_Dec16	Pnom	420 Wp
PV Array	Nb. of modules	221328	Pnom total	**92958 kWp**
Inverter	Model	R15015TL	Pnom	1410 kW ac
Inverter pack	Nb. of units	55.0	Pnom total	**77550 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



Grid-Connected System: Main results

Project : **EN2530-Pooneryn-SolarGIS-SYN**

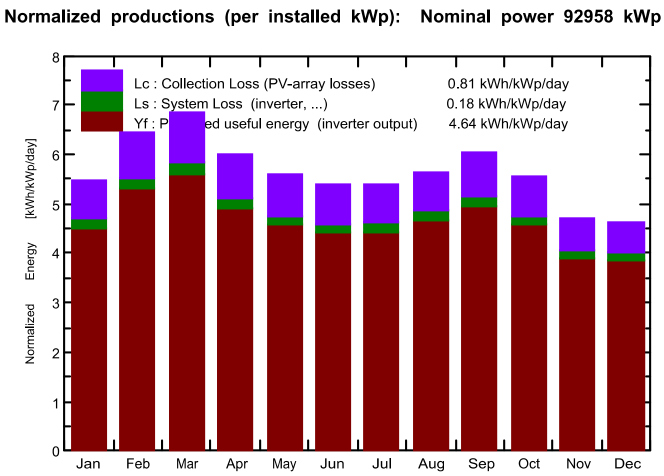
Simulation variant : **77.55MVA - 7.5 Pitch - 1.29 - 15º -FirstSolar**

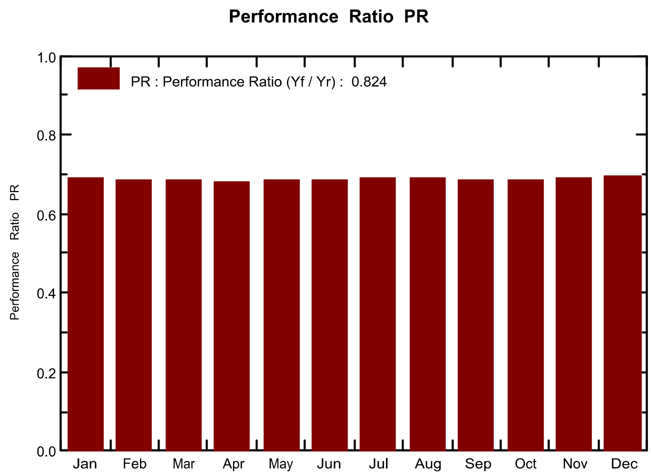
Simulation for the first year of operation

Main system parameters	System type	**Grid-Connected**		
Near Shadings	According to strings		Electrical effect	100 %
PV Field Orientation	tilt	15°	azimuth	0°
PV modules	Model	FS-6420_prelim_Dec16	Pnom	420 Wp
PV Array	Nb. of modules	221328	Pnom total	**92958 kWp**
Inverter	Model	R15015TL	Pnom	1410 kW ac
Inverter pack	Nb. of units	55.0	Pnom total	**77550 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results

System Production	**Produced Energy**	**157502 MWh/year**	Specific prod.	1694 kWh/kWp/year
	Performance Ratio PR	82.36 %		





77.55MVA - 7.5 Pitch - 1.29 - 15º -FirstSolar

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	153.0	70.00	26.00	169.4	160.9	13534	13007	0.826
February	167.0	63.00	26.80	180.7	171.9	14405	13843	0.824
March	207.0	73.00	28.20	212.2	201.8	16814	16158	0.819
April	186.0	72.00	29.70	180.1	170.7	14239	13693	0.818
May	188.0	87.00	30.00	173.8	163.6	13739	13229	0.819
June	178.0	81.00	29.40	161.3	151.8	12818	12347	0.824
July	182.0	86.00	29.00	166.8	157.1	13276	12789	0.825
August	184.0	86.00	28.90	175.3	165.7	13983	13463	0.826
September	181.0	77.00	28.80	180.6	171.3	14331	13778	0.821
October	164.0	74.00	28.10	172.2	163.6	13709	13180	0.823
November	129.0	68.00	27.10	140.9	133.5	11293	10859	0.829
December	129.0	69.00	26.30	143.8	136.1	11591	11155	0.834
Year	2048.0	905.99	28.20	2057.1	1947.8	163731	157502	0.824

Legends:				
	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

Grid-Connected System: Loss diagram

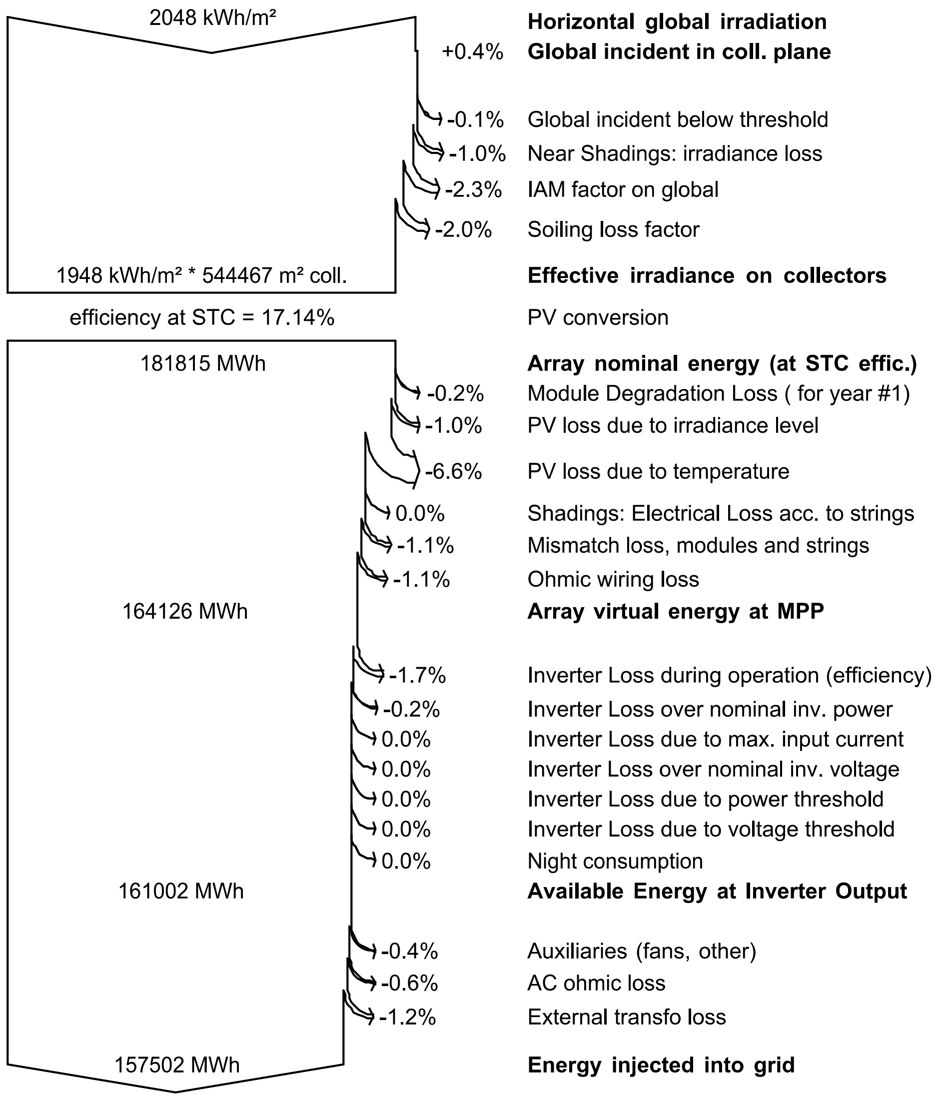
Project : **EN2530-Pooneryn-SolarGIS-SYN**

Simulation variant : **77.55MVA - 7.5 Pitch - 1.29 - 15º -FirstSolar**

Simulation for the first year of operation

Main system parameters	System type	**Grid-Connected**		
Near Shadings	According to strings		Electrical effect	100 %
PV Field Orientation	tilt	15°	azimuth	0°
PV modules	Model	FS-6420_prelim_Dec16	Pnom	420 Wp
PV Array	Nb. of modules	221328	Pnom total	**92958 kWp**
Inverter	Model	R15015TL	Pnom	1410 kW ac
Inverter pack	Nb. of units	55.0	Pnom total	**77550 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Grid-Connected System: Simulation parameters

Project : **EN2530-Pooneryn-SolarGIS-SYN**

Geographical Site	**EN2530-Pooneryn-SolarGIS-SYN**		Country	**Sri Lanka**
Situation	Latitude	9.53° N	Longitude	80.17° E
Time defined as	Legal Time	Time zone UT+5.5	Altitude	6 m
	Albedo	0.20		
Meteo data:	**EN2530-Pooneryn-SolarGIS-SYN**	SolarGIS Monthly aver. , period not spec. - Synthetic		

Simulation variant : **77.55MVA - 4 Pitch - 1.29 - Trackers - Jinko**

Simulation date	03/05/18 19h28
Simulation for the	**first year of operation**

Simulation parameters	System type	**Tracking system, with backtracking**		
Tracking plane, tilted Axis	Axis Tilt	0°	Axis Azimuth	0°
Rotation Limitations	Minimum Phi	-60°	Maximum Phi	60°
Backtracking strategy	Nb. of trackers	3080	Identical arrays	
	Tracker Spacing	4.00 m	Collector width	1.96 m
Backtracking limit angle	Phi limits	+/- 60.5°	Ground cov. Ratio (GCR)	48.9 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			

PV Array Characteristics

PV module Si-poly	Model	**JKM 335PP-72-2016**		
Custom parameters definition	Manufacturer	Jinkosolar		
Number of PV modules	In series	30 modules	In parallel	9250 strings
Total number of PV modules	Nb. modules	277500	Unit Nom. Power	335 Wp
Array global power	Nominal (STC)	**92963 kWp**	At operating cond.	83788 kWp (50°C)
Array operating characteristics (50°C)	U mpp	1032 V	I mpp	81213 A
Total area	Module area	**538448 m²**	Cell area	486313 m²
Inverter	Model	**R15015TL**		
Custom parameters definition	Manufacturer	FIMER SPA		
Characteristics	Operating Voltage	850-1320 V	Unit Nom. Power	1410 kWac
Inverter pack	Nb. of inverters	55 units	Total Power	77550 kWac
			Pnom ratio	1.20

PV Array loss factors

Array Soiling Losses			Loss Fraction	2.0 %
Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	0.21 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	1.8 %
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Module average degradation	Year no	1	Loss factor	0.68 %/year
Mismatch due to degradation	Imp RMS dispersion	0.4 %/year	Vmp RMS dispersion	0.4 %/year

Incidence effect (IAM): User defined IAM profile

0°	20°	30°	40°	50°	60°	70°	80°	90°
1.000	1.000	1.000	1.000	1.000	1.000	0.950	0.770	0.000

Grid-Connected System: Simulation parameters

System loss factors				
AC wire loss inverter to transfo	Inverter voltage	550 Vac tri		
	Wires: 3x30000.0 mm²	53 m	Loss Fraction	1.0 % at STC
External transformer	Iron loss (24H connexion)	91181 W	Loss Fraction	0.1 % at STC
	Resistive/Inductive losses	0.0 mOhm	Loss Fraction	1.2 % at STC
User's needs :	Unlimited load (grid)			
Auxiliaries loss	Proportionnal to Power	4.0 W/kW	... from Power thresh.	0.0 kW

Grid-Connected System: Near shading definition

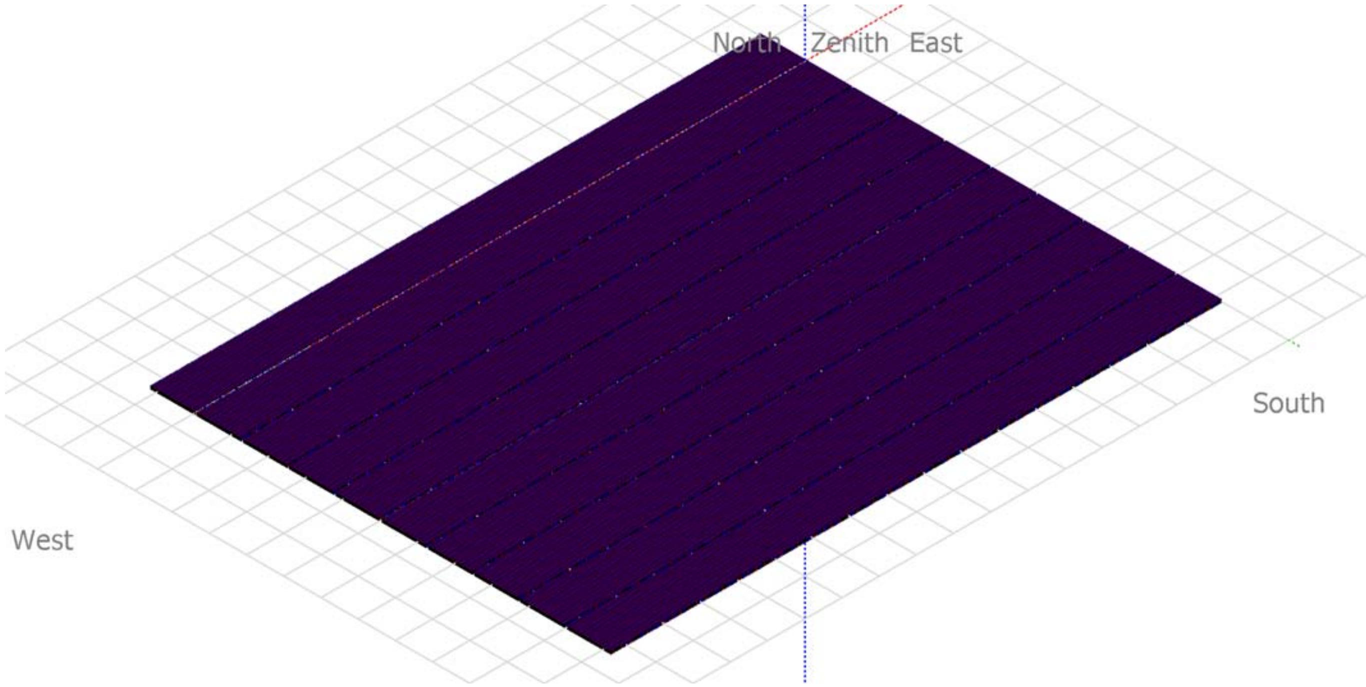
Project : **EN2530-Pooneryn-SolarGIS-SYN**

Simulation variant : **77.55MVA - 4 Pitch - 1.29 - Trackers - Jinko**

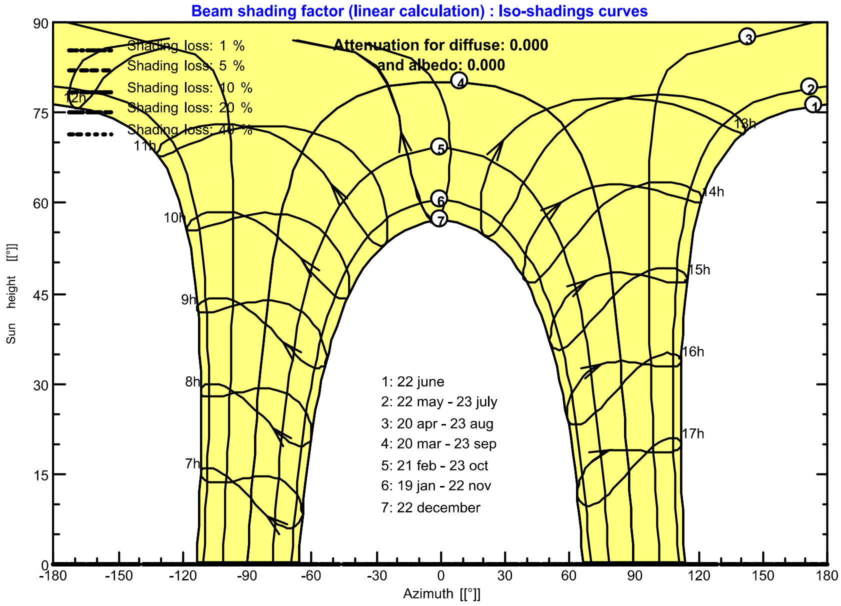
Simulation for the first year of operation

Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	0°	Axis Azimuth	0°
PV modules	Model	JKM 335PP-72-2016	Pnom	335 Wp
PV Array	Nb. of modules	277500	Pnom total	**92963 kWp**
Inverter	Model	R15015TL	Pnom	1410 kW ac
Inverter pack	Nb. of units	55.0	Pnom total	**77550 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



Grid-Connected System: Main results

Project : **EN2530-Pooneryn-SolarGIS-SYN**

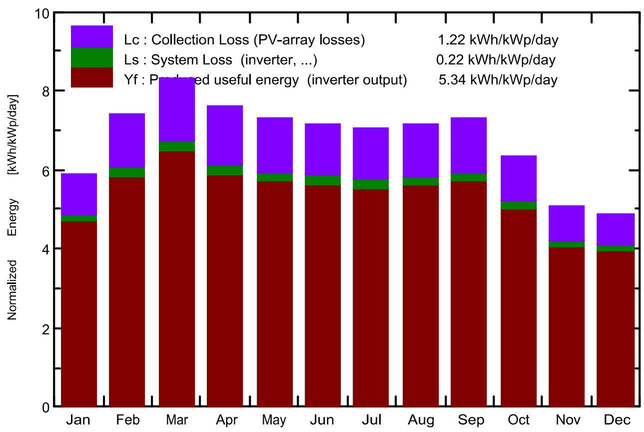
Simulation variant : **77.55MVA - 4 Pitch - 1.29 - Trackers - Jinko**

Simulation for the first year of operation

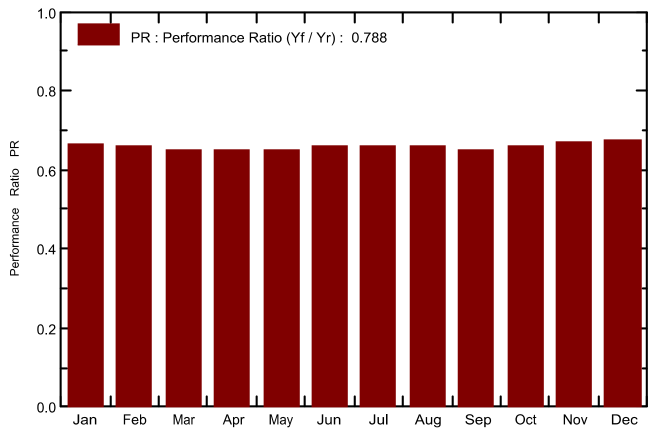
Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	0°	Axis Azimuth	0°
PV modules	Model	JKM 335PP-72-2016	Pnom	335 Wp
PV Array	Nb. of modules	277500	Pnom total	**92963 kWp**
Inverter	Model	R15015TL	Pnom	1410 kW ac
Inverter pack	Nb. of units	55.0	Pnom total	**77550 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**181308 MWh/year**	Specific prod.	1950 kWh/kWp/year
	Performance Ratio PR	78.83 %		

Normalized productions (per installed kWp): Nominal power 92963 kWp



Performance Ratio PR



77.55MVA - 4 Pitch - 1.29 - Trackers - Jinko

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	153.0	70.00	26.00	182.5	171.8	14102	13541	0.798
February	167.0	63.00	26.80	206.8	195.7	15836	15201	0.791
March	207.0	73.00	28.20	257.6	244.2	19447	18660	0.779
April	186.0	72.00	29.70	228.0	215.9	17162	16475	0.777
May	188.0	87.00	30.00	226.9	213.9	17158	16489	0.782
June	178.0	81.00	29.40	214.1	201.8	16359	15728	0.790
July	182.0	86.00	29.00	218.0	205.2	16635	15991	0.789
August	184.0	86.00	28.90	220.8	207.9	16844	16190	0.789
September	181.0	77.00	28.80	219.1	207.0	16584	15920	0.782
October	164.0	74.00	28.10	196.6	185.4	15013	14417	0.789
November	129.0	68.00	27.10	152.0	142.5	11768	11305	0.800
December	129.0	69.00	26.30	151.9	142.0	11846	11390	0.807
Year	2048.0	906.00	28.20	2474.1	2333.2	188754	181308	0.788

Legends:	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

Grid-Connected System: Loss diagram

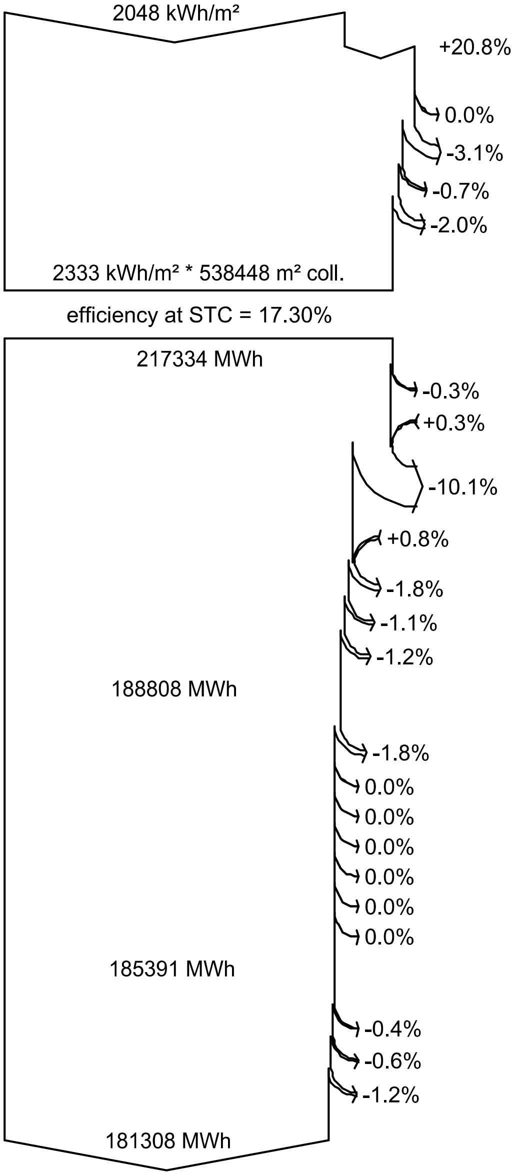
Project : **EN2530-Pooneryn-SolarGIS-SYN**

Simulation variant : **77.55MVA - 4 Pitch - 1.29 - Trackers - Jinko**

Simulation for the first year of operation

Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	0°	Axis Azimuth	0°
PV modules	Model	JKM 335PP-72-2016	Pnom	335 Wp
PV Array	Nb. of modules	277500	Pnom total	**92963 kWp**
Inverter	Model	R15015TL	Pnom	1410 kW ac
Inverter pack	Nb. of units	55.0	Pnom total	**77550 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



2048 kWh/m²	**Horizontal global irradiation**
+20.8%	**Global incident in coll. plane**
0.0%	Global incident below threshold
-3.1%	Near Shadings: irradiance loss
-0.7%	IAM factor on global
-2.0%	Soiling loss factor
2333 kWh/m² * 538448 m² coll.	**Effective irradiance on collectors**
efficiency at STC = 17.30%	PV conversion
217334 MWh	**Array nominal energy (at STC effic.)**
-0.3%	Module Degradation Loss (for year #1)
+0.3%	PV loss due to irradiance level
-10.1%	PV loss due to temperature
+0.8%	Module quality loss
-1.8%	LID - Light induced degradation
-1.1%	Mismatch loss, modules and strings
-1.2%	Ohmic wiring loss
188808 MWh	**Array virtual energy at MPP**
-1.8%	Inverter Loss during operation (efficiency)
0.0%	Inverter Loss over nominal inv. power
0.0%	Inverter Loss due to max. input current
0.0%	Inverter Loss over nominal inv. voltage
0.0%	Inverter Loss due to power threshold
0.0%	Inverter Loss due to voltage threshold
0.0%	Night consumption
185391 MWh	**Available Energy at Inverter Output**
-0.4%	Auxiliaries (fans, other)
-0.6%	AC ohmic loss
-1.2%	External transfo loss
181308 MWh	**Energy injected into grid**

Grid-Connected System: Simulation parameters

Project :	**EN2530-Pooneryn-SolarGIS-SYN**			
Geographical Site	**EN2530-Pooneryn-SolarGIS-SYN**		Country	**Sri Lanka**
Situation	Latitude	9.53° N	Longitude	80.17° E
Time defined as	Legal Time	Time zone UT+5.5	Altitude	6 m
	Albedo	0.20		
Meteo data:	**EN2530-Pooneryn-SolarGIS-SYN**	SolarGIS Monthly aver. , period not spec. - Synthetic		

Simulation variant :	**77.55MVA - 4 Pitch - 1.29 - 15º -FirstSolar**	
	Simulation date	04/05/18 09h35
	Simulation for the	**first year of operation**

Simulation parameters	System type	**Tracking system**		
Tracking plane, tilted Axis	Axis Tilt	0°	Axis Azimuth	0°
Rotation Limitations	Minimum Phi	-60°	Maximum Phi	60°
Trackers configuration	Nb. of trackers	2459	Identical arrays	
	Tracker Spacing	4.00 m	Collector width	2.00 m
Shading limit angles	Phi limits	+/- 59.8°	Ground cov. Ratio (GCR)	50.0 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			

PV Array Characteristics

PV module CdTe	Model	**FS-6420_prelim_Dec16**		
Custom parameters definition	Manufacturer	First Solar Preliminary		
Number of PV modules	In series	6 modules	In parallel	36885 strings
Total number of PV modules	Nb. modules	221310	Unit Nom. Power	420 Wp
Array global power	Nominal (STC)	**92950 kWp**	At operating cond.	86672 kWp (50°C)
Array operating characteristics (50°C)	U mpp	966 V	I mpp	89684 A
Total area	Module area	**544423 m²**	Cell area	535128 m²
Inverter	Model	**R15015TL**		
Custom parameters definition	Manufacturer	FIMER SPA		
Characteristics	Operating Voltage	850-1320 V	Unit Nom. Power	1410 kWac
Inverter pack	Nb. of inverters	55 units	Total Power	77550 kWac
			Pnom ratio	1.20

PV Array loss factors

Array Soiling Losses			Loss Fraction	2.0 %
Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	0.18 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	0.0 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Module average degradation	Year no	1	Loss factor	0.5 %/year
Mismatch due to degradation	Imp RMS dispersion	0.4 %/year	Vmp RMS dispersion	0.4 %/year

Incidence effect (IAM): User defined IAM profile

0°	30°	50°	60°	65°	70°	75°	80°	90°
1.000	1.000	0.990	0.960	0.940	0.890	0.820	0.690	0.000

Grid-Connected System: Simulation parameters

System loss factors				
AC wire loss inverter to transfo	Inverter voltage	550 Vac tri		
	Wires: 3x30000.0 mm²	53 m	Loss Fraction	1.0 % at STC
External transformer	Iron loss (24H connexion)	91495 W	Loss Fraction	0.1 % at STC
	Resistive/Inductive losses	0.0 mOhm	Loss Fraction	1.2 % at STC
User's needs :	Unlimited load (grid)			
Auxiliaries loss	Proportionnal to Power	4.0 W/kW	... from Power thresh.	0.0 kW

Grid-Connected System: Near shading definition

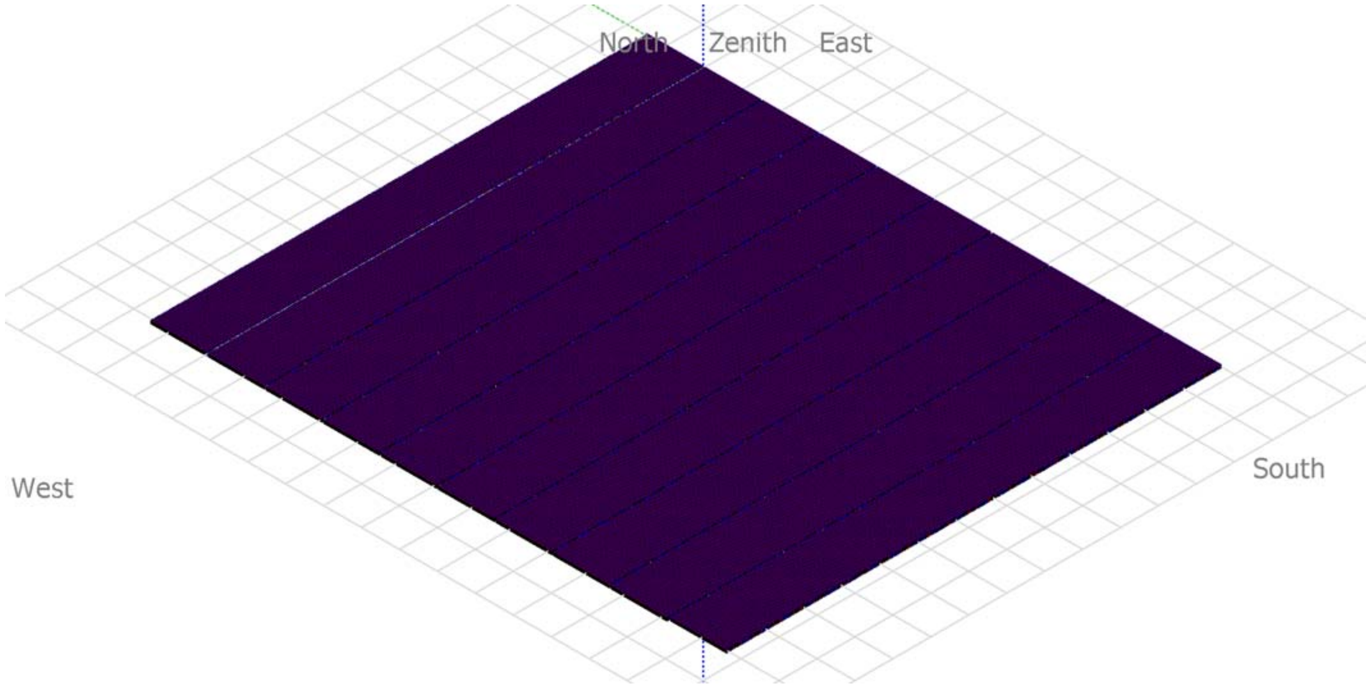
Project : **EN2530-Pooneryn-SolarGIS-SYN**

Simulation variant : **77.55MVA - 4 Pitch - 1.29 - 15º -FirstSolar**

Simulation for the first year of operation

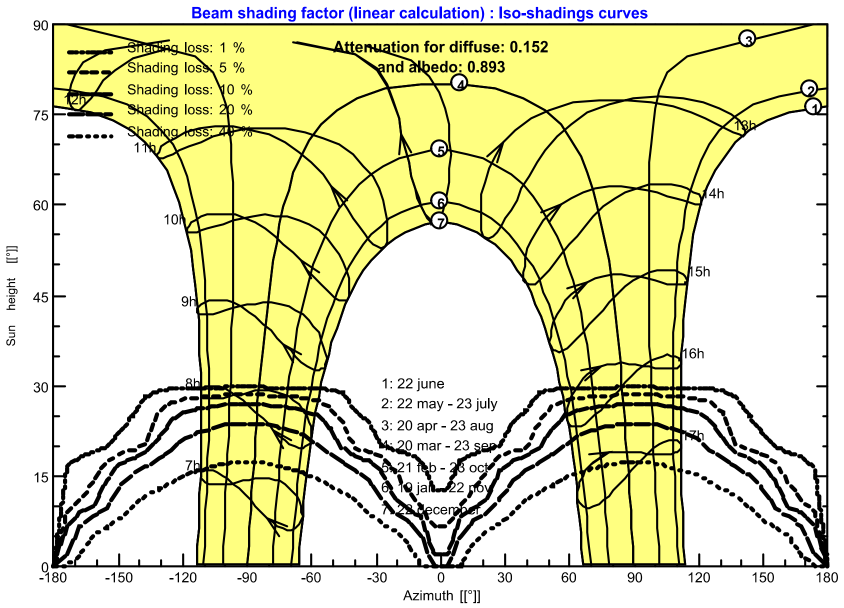
Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	0°	Axis Azimuth	0°
PV modules	Model	FS-6420_prelim_Dec16	Pnom	420 Wp
PV Array	Nb. of modules	221310	Pnom total	**92950 kWp**
Inverter	Model	R15015TL	Pnom	1410 kW ac
Inverter pack	Nb. of units	55.0	Pnom total	**77550 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

EN2530-Pooneryn-SolarGIS-SYN



Grid-Connected System: Main results

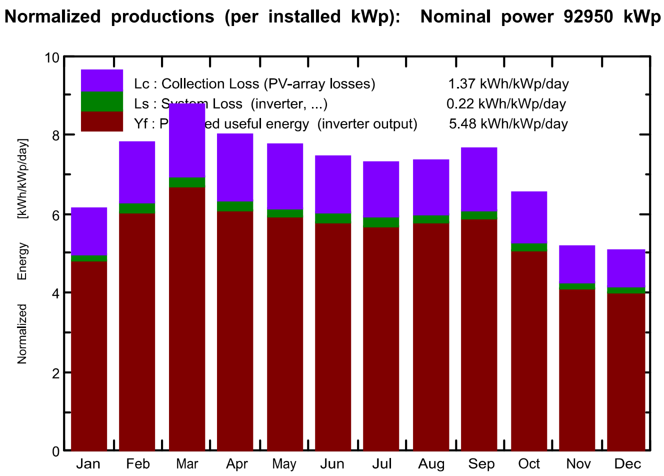
Project : **EN2530-Pooneryn-SolarGIS-SYN**

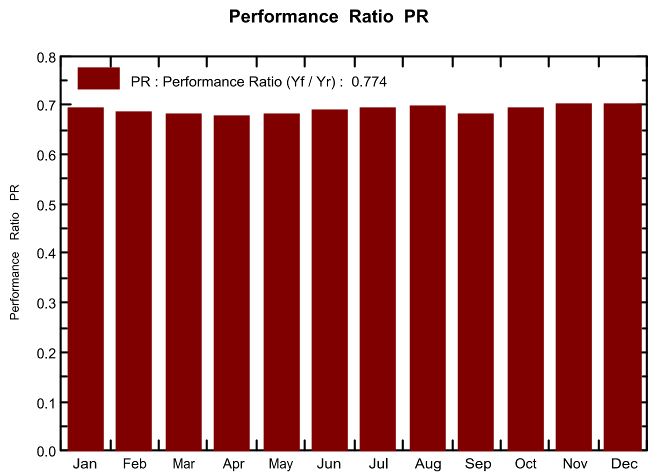
Simulation variant : **77.55MVA - 4 Pitch - 1.29 - 15º -FirstSolar**

Simulation for the first year of operation

Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	0°	Axis Azimuth	0°
PV modules	Model	FS-6420_prelim_Dec16	Pnom	420 Wp
PV Array	Nb. of modules	221310	Pnom total	**92950 kWp**
Inverter	Model	R15015TL	Pnom	1410 kW ac
Inverter pack	Nb. of units	55.0	Pnom total	**77550 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**185933 MWh/year**	Specific prod.	2000 kWh/kWp/year
	Performance Ratio PR	77.45 %		





77.55MVA - 4 Pitch - 1.29 - 15º -FirstSolar

Balances and main results

	GlobHor kWh/m²	**DiffHor** kWh/m²	**T Amb** °C	**GlobInc** kWh/m²	**GlobEff** kWh/m²	**EArray** MWh	**E_Grid** MWh	**PR**
January	153.0	70.00	26.00	190.5	170.1	14390	13825	0.781
February	167.0	63.00	26.80	218.5	194.5	16336	15688	0.773
March	207.0	73.00	28.20	271.1	242.6	20052	19248	0.764
April	186.0	72.00	29.70	240.0	214.3	17691	16990	0.761
May	188.0	87.00	30.00	239.8	212.3	17727	17043	0.765
June	178.0	81.00	29.40	224.2	200.2	16834	16194	0.777
July	182.0	86.00	29.00	226.0	202.9	17064	16411	0.781
August	184.0	86.00	28.90	228.3	205.3	17260	16597	0.782
September	181.0	77.00	28.80	229.5	205.0	17016	16340	0.766
October	164.0	74.00	28.10	202.1	182.8	15273	14672	0.781
November	129.0	68.00	27.10	156.1	140.2	11882	11422	0.787
December	129.0	69.00	26.30	156.9	140.2	11951	11502	0.789
Year	2048.0	906.00	28.20	2582.9	2310.4	193477	185933	0.774

Legends:				
	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

Grid-Connected System: Loss diagram

Project : **EN2530-Pooneryn-SolarGIS-SYN**

Simulation variant : **77.55MVA - 4 Pitch - 1.29 - 15º -FirstSolar**

Simulation for the first year of operation

Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	0°	Axis Azimuth	0°
PV modules	Model	FS-6420_prelim_Dec16	Pnom	420 Wp
PV Array	Nb. of modules	221310	Pnom total	**92950 kWp**
Inverter	Model	R15015TL	Pnom	1410 kW ac
Inverter pack	Nb. of units	55.0	Pnom total	**77550 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year