Technical Assistance Consultant's Report
Final Report: Part 2 (Wind and Solar Resource Assessment)

Project No. 43576-012
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SRI LANKA: Clean Energy and Network Efficiency Improvement Project

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Colombo, Sri Lanka

For Ministry of Power and Energy
Sustainable Energy Authority of Sri Lanka

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Asian Development Bank

List of Abbreviations

°C	Degree Centigrade
3D	Three Dimensional
ADB	Asian Development Bank
AGL	Above Ground Level
AOD	Aerosol Optical Depth
ASCII	American Standard Code for Information Interchange
AWS	Automatic Weather Station
CDF	Cumulative Distribution Function
CEB	Ceylon Electricity Board
CFDC	Cumulative Frequency Distribution Curves
CFSR	Climate Forecast System Re-analysis
CSP	Concentrating solar power
DAkkS	Deutsche Akkreditierungsstelle GmnH
DHI	Diffuse Horizontal Irradiance
DLR	German Aerospace Centre
DNI	Direct Normal Irradiance
DoM	Department of Meteorology
FGW	Fördergesellschaft Windenergie
FITNAH	Flow over Irregular Terrain with Natural and Anthropogenic Heat Sources
GE:Net	Ge:Net GmbH
GEO-NET	GEO-NET Umweltconsulting GmbH
GHI	Global Horizontal Irradiance
GoSL	Government of Sri Lanka
ha	Hectare
hPa	hetro Pascal
Hz	Hertz
IEC	International Electrotechnical Commission
km	Kilometre
kWh	kilowatt hour
m	meter
m/s	Meter per second
m^2	Square meter
MCP	Measure-Correlate-Predict
MERRA	Modern-Era Retrospective Analysis for Research And Application
mm	millimetre
MoPE	Ministry of Power and Energy
MoU	Memorandum of Understanding
MW	Mega Watt
MWh	Mega Watt hour
NASA	National Aeronautics and Space Administration
NCAR	National Centre for Atmospheric Research
NCDC	National Climatic Data Centre
NCEP	National Centres for Environmental Predictions
NE	North East
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
NW	North Western
PV	Photovoltaic
RMA	Resource Management Associates (Pvt) Ltd
RTNEPH	Real Time Nephanalysis
SD	Sunshine Duration
SLSEA	Sri Lanka Sustainable Energy Authority
SOLEMI	Solar Energy Mining
sq. km	Square kilometre
SRTM	Shuttle Radar Topographical Mission
SW	South West
SWERA	Solar and Wind Energy Resource Assessment
SZA	Sun Zenith Angle
TA	Technical Assistance
TMY	Typical Meteorological Year
TOR	Term of Reference
UNEP	United Nations Environmental Programme

UoJ	University of Jaffna
UTM	Universal Transverse Mercator
VDI	Association of German engineers
W	Watt
W/m^2	Watts per square metre
WMM	Wind Met Mast
WMO	World Meteorological Organization

EXECUTIVE SUMMARY

Wind Resource Assessment

Government of Sri Lanka (GoSL) is planning to develop wind resources in the Mannar Island as part of its effort to reach the policy target of producing 20% of country's electrical energy requirement by 2020 from renewable energy sources. This requires, among other things, high quality wind data that represents the wind conditions in the area considered for wind power development.

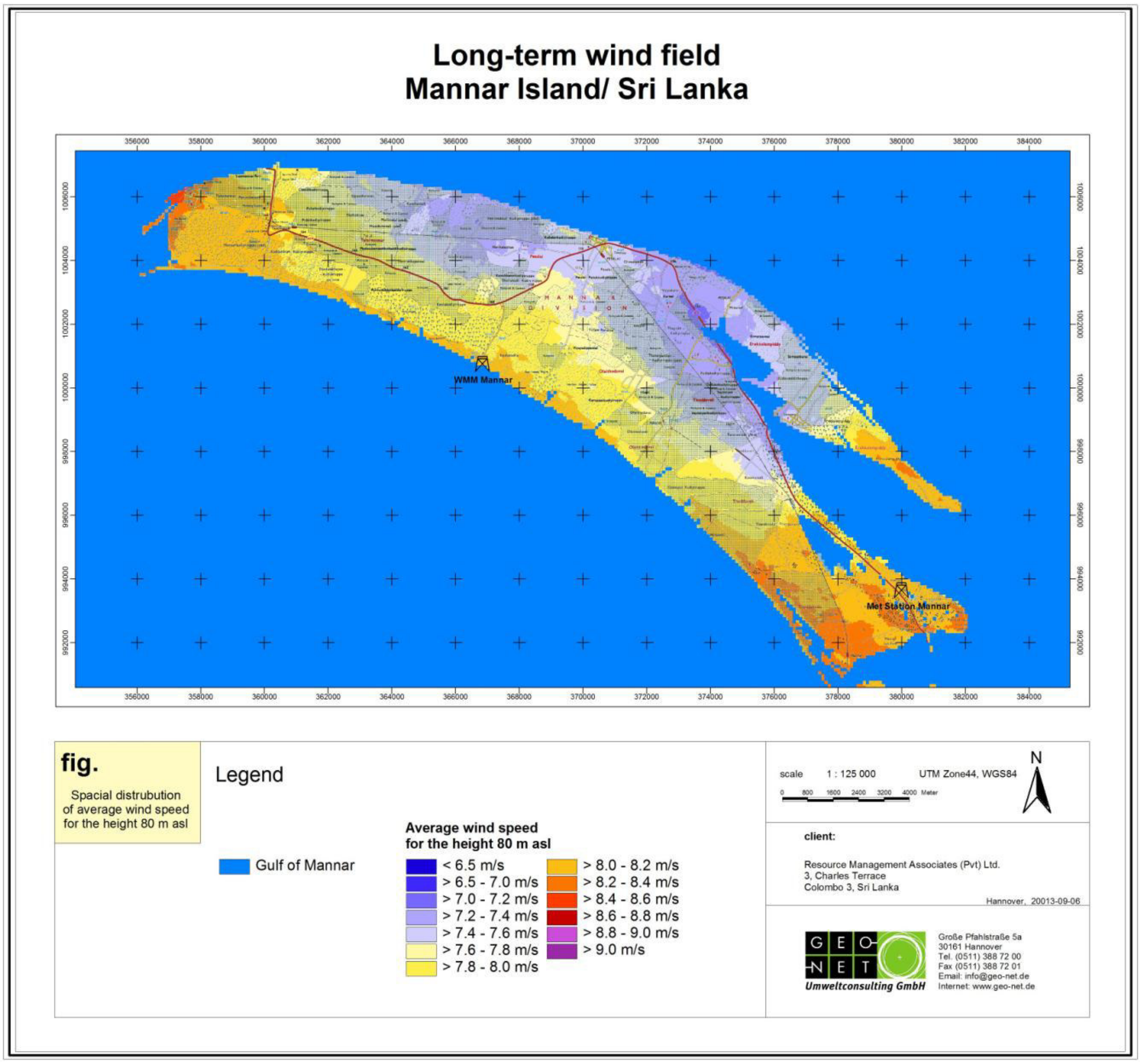
Wind data for the Mannar Island is available from (a) Department of Meteorology (DoM) as routine wind observations, (b) Ceylon Electricity Board (CEB) for the period from 2002-2003 and (c) Sri Lanka Sustainable Energy Authority (SLSEA) since 2010. But, none of these sources are able to provide internationally acceptable high-quality data that is required for executing bankable feasibility studies on multi-megawatt wind projects that SLSEA is planning.

Asian Development Bank (ADB) offered to the GoSL to provide technical support for this wind development initiative through part 2 of the TA - 7837 SRI: Clean Energy and Network Efficiency Improvement Project. For this purpose, ADB contracted Resource Management Associates (Pvt) Ltd (RMA), working in partnership with GEO-NET Umweltconsulting GmbH (GEO-NET) in Germany. The study involved the analysis of the wind potential in the Mannar Island, preparing a high-quality wind map through wind field modelling work using global weather data sets and validating the results with data gathered from an on-site wind mast and producing a long-term wind data set for the site for the period 1992-2012.

Wind field modelling of the flow conditions in the model area was conducted grid based and realised by application of the three dimensional, non-hydrostatic meso-scale model - *Flow over Irregular Terrain with Natural and Anthropogenic Heat Sources* (FITNAH), developed by Prof. Dr. G. Groß. FITNAH complies and exceeds the minimum requirements for meso-scaled models as determined in the VDI guideline 3783 -1992, and has been successfully implemented for years by the German Weather Service for surveys.

The model area for the calculation of the wind field has a size of 35 km x 35 km (Mannar Island). The single grid cells have a mesh size of 50 m x 50 m. The land use structures are obtained by digitize topographical maps and the information derived from on-site inspection. The relief structure was obtained from the Shuttle Radar Topographic Mission (SRTM) elevation model of the National Aeronautics and Space Administration (NASA) space shuttle mission 2000 (USGS 2004).

Based on the analysis results and information presented in Chapter 7, a long-term extrapolation of the short-term measurements was done. The results of the long-term extrapolated short-term measurements will be site specific compared with the result of the FITNAH 1-D and FITNAH 3-D wind field and wind potential simulation (see the wind map and Table on data validation on next page).



Comparison of Average Wind Speed of the Wind Met Mast (WMM) sites (Measured and Long-Term Transformed) and of the Results of the FITNAH-Simulation

Measurement Mast	**WMM Mannar (Nadukkuda)**			
Height of wind measurement	20 m	40 m	60 m	80 m
Measurement period	2012-06-01 till 2013-07-31 (till 2013-05-31 1year)			
availability	~99.5 %	~99.5 %	~99.5 %	~99.5 %
Average wind speed	7.59 m/s (7.15 m/s)	8.22 m/s (7.80 m/s)	8.54 m/s (8.14 m/s)	8.85 m/s (8.44 m/s)
Long-term transformation based on MERRA (reference period 1992-2012)				8.06 m/s
Long-term transformation based on CFSR (reference period 1992-2012)				8.10 m/s
Long-term transformation based on AWS Mannar (reference period 2010-2012)				8.28 m/s
FITNAH-simulation (reference period 1992-2012)				**8.08 m/s**

Considering the estimated uncertainty of the measurement, of the long-term data and of the procedure the comparison between the long term transformed wind speeds at the measuring sites to the results of the FITNAH simulation indicates good results.

Solar Resource Assessment

The aim of the present study is to produce TMY (Typical Meteorological Year) data which takes into account uneven distributed cloud cover over Sri Lanka. Initially the proposed methodology was to use of METSTAT model and use Real Time Nephanalysis (RTNEPH) Cloud Database, Aerosol optical depth (AOD) data and precipitable water and others as inputs to the METSTAT Model, This was later changed to an approach calling for alternative data source employing the German Aerospace Center (Deutsches Zentrum für Luft und Raumfahrt, DLR) that offers high quality time series data of ground-irradiance with its product SOLEMI (Solar Energy Mining), which already considers the influence of clouds and aerosol particles. This kind of data is used worldwide for evaluation of solar resources and meets international standards. This data contains broadband Direct Normal Irradiation (DNI) + Global Horizontal Irradiation (GHI) for defined locations. In the study several sites in Sri Lanka for which data is available for 11 years starting from the year 2000 were also used.

Resource data used in this study is based on three data sources: A local, high quality solar measurement in Kilinochchi, data from local weather stations as long term data source and SOLEMI data as a long term and independent data source. The measurement site Kilinochchi is located in the northern plains of the island at an elevation 48 m above sea level. The exact coordinates are Easting 44P 433972, Northing 1029301 (UTM WGS84). The measurement station is equipped with solar sensors and an additional meteorological mast with 4 m height.

With results of the present study using the above resources, it is possible to characterize the solar climate in Sri Lanka with a high precision and on the current state of technology. For regions where a TMY was established using time series of SOLEMI data it was possible to check the validity of ground based measurements for sun shine duration data. Since two independent approaches were used, it could be shown that both approaches reach comparable results that could be used for development of long term correlations of solar radiation.

It is observed that the platform laid down by the government to accommodate net-metered and grid connected Non Conventional Renewable Energy based electricity generation as per the Government policy has encouraged the solar based electricity system developers. The preliminary estimations carried out in this study on the amount of electricity generation employing best practiced technologies using ground level measured data shows that the said estimations are 12% lower than those predicted by employing SOLEMI based TMY data for this location for the period of March to September 2013. This highlights an important preliminary conclusion indicating that the electricity generation estimated employing measured ground level data would lead to more meaningful, accurate and informed decisions in view of solar based projects.

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1 INTRODUCTION

The Asian Development Bank contracted RMA, working in partnership with GEO-NET in Germany to conduct wind and solar resource assessment in the Mannar Island and Hambantota region respectively. The assignment constitutes part 2 of the TA - 7837 SRI: Clean Energy and Network Efficiency Improvement Project (43576 – 012) offered to the GoSL. The Contract of this assignment (Contract No. 100297-S41789) was signed on 07th December 2011 and Notice to Proceed was issued on 13 December 2011.

Inception and interim reports on this assignment were submitted on 19 January 2013 and 5 July 2013 respectively. Draft final report was submitted separately for the wind and solar parts of the study on 27 September 2013 and 8 October 2013 respectively for which ADB has sent valuable comments. This final report incorporates responses to ADB comments with revisions and additional information where necessary. The final report accompanies a separate technical report consisting of two parts (a) Wind Measurement Campaign and (b) Wind Met Mast (WMM) and Measurement Equipment. We are also submitting a Compact Disk (CD) containing soft copies of following data:

1. Long-term hourly wind speed and direction data derived from the wind field modelling process for Nadukkuda (the site of wind measurement) the period 1992-2012
2. Typical Meteorological Year (TMY) data for ten locations[1] in Sri Lanka that were derived using the database called Solar Energy Mining (SOLEMI) developed and maintained by the German Aerospace Centre (DLR)

[1] The ten locations represent the meteorological stations where solar data is routinely collected

2 BACKGROUND

As envisaged in the National Energy Policy of Sri Lanka, GoSL is planning to accelerate development of renewable energy with special emphasis on wind and solar energy. SLSEA is entrusted with the planning and creating enabling environment for renewable energy development. Specifically, SLSEA is planning to develop 100MW of wind power in the Mannar Island and 10MW of solar power in the Hambantota region.

SLSEA prepared and submitted a concept paper on this project to the Board of Management for approval through the Board Paper 36/2009 on 17th July 2009. This paper was presented to the Ministry of Power & Energy as an alternative strategy to develop the wind resources in the island of Mannar. The Ministry of Power & Energy accepted the concept and presented a Cabinet Paper on 29th July 2011 (Cabinet Paper 34/2011/PE). Considering the proposal and observations made by other line agencies, the Cabinet of Ministers, through the Decision CP No.06/1858/222/057 of 18th October 2011 conveyed thus;

- approval in principle to develop wind as a renewable energy resource
- approval of the establishment of energy parks as a means of reducing cost of providing infrastructure
- legislation to ensure investments by the private sector is forthcoming for the project be formulated by CEB
- an environmental impact assessment be carried out before commencing any development activities in the proposed region

Giving due consideration to these proposals, observations and decisions SEA prepared the document titled " A proposal on Developing a 100MW Wind Energy Park in Mannar" elaborating on the implementation strategy.

3 THE ASSIGNMENT

As a fundamental pre-requisite of the wind and solar energy development strategy, SLSEA is conducting wind resource assessment studies in the Mannar Island and solar radiation measurements in the newly established Solar Energy Park in Hambantota. GoSL and the SLSEA have recognized that these efforts need to be complemented with high-quality wind and solar measurements[2] complying with international standards. As bankable feasibility studies on large-scale wind and solar project need long term data, the need for development of a reliable long-term wind and solar database was also considered an urgent need.

In response to this need, the ADB has offered to the GoSL to provide technical support to upgrade the on-going wind and solar measurement activities. On completion of the assignment, it is expected that the SLSEA (as the implementation agency of this assignment) would be in possession of a reliable long-term database on wind and solar resources in Mannar and Hambantota areas respectively which could be used to prepare bankable feasibility reports on the proposed wind and solar power plants.

Terms of Reference (TOR) of the assignment is presented in Annex 1

[2] Solar measurement station was later installed at the Faculty of Engineering of the University of Jaffna sited in Kilinochchi

4 INSTITUTIONAL ARRANGEMENTS

4.1 RMA-GEONET

RMA is a leading consulting company in the energy sector in Sri Lanka that undertakes assignments on various energy related disciplines both locally and overseas. Based on specific requirements of the assignment RMA seeks external inputs for their work. In this particular assignment, RMA selected GEO-NET as the technical partner for wind and solar climate modelling work which constitutes the key task in generating long-term wind and solar statistics. GEO-NET is accredited according to DIN EN ISO/IEC 17025:2005 for wind and energy yield assessments, wind potential studies, wind measurements and wind analysis. RMA is the Lead Consultant in this assignment with GEO-NET acting as the Technical Consultant.

4.2 RMA-SLSEA

RMA has to work in close collaboration with SLSEA which is the ultimate beneficiary of the assignment. Working arrangement between RMA and SLSEA was discussed in detail at the kick-off meeting held at the SLSEA office on 7th December 2011.

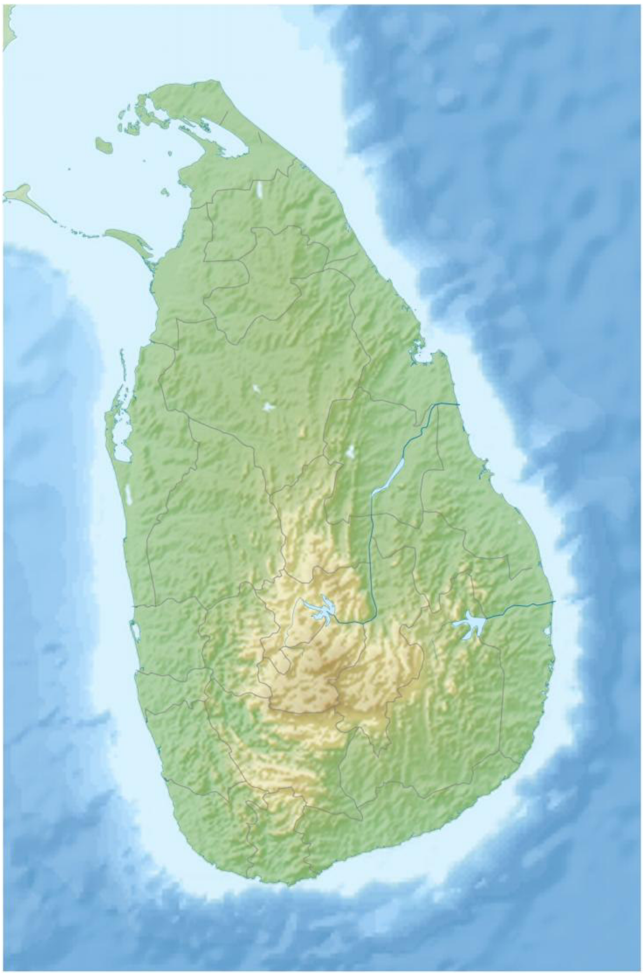
Main issue that was raised at the meeting was on the procedure for procurement of wind and solar measuring instruments. According to the agreement with ADB, procurement of wind and solar measuring equipment was entrusted to RMA mainly to expedite the process to enable timely completion of the assignment. According SLSEA, government regulations do not allow payment of duties & taxes on wind and solar measuring equipment unless SLSEA is allowed to take over the goods as their assets once the measuring systems are installed. Also, SLSEA must be the consignee of goods though sourcing will be done by RMA.

SLSEA appointed Ajith Alwis –Director, Economic Affairs as RMA's counterpart in view of his long experience in wind resource studies. Mutually agreed division of responsibilities between RMA and SLSEA is presented in Annex 2.

5 GEOGRAPHY AND CLIMATE OF SRI LANKA

Sri Lanka is an island located in the Indian Ocean, southwest of the Bay of Bengal, between 5° 55' to 9° 51' North latitude and between 79° 42' to 81° 53' East longitude. The Island lies on the Indian tectonic plate, a minor plate within the Indo-Australian Plate, and is separated from the Indian subcontinent by the Gulf of Mannar and the Palk Strait. The island measures about 415km from north to south, and 220km from east to west, with a total land area of about 65,600 square km. It has more than 1340km of coastline.

Figure 1 - Map Depicting the Relief of Sri Lanka



Extensive faulting and erosion over time have produced a wide range of topographic features in the country. Three zones are distinguishable by elevation: the Central Highlands, the plains, and the coastal belt (Figure 1). The south-central part of Sri Lanka is characterized by the rugged terrain of the Central Highlands. The core of this area is a high plateau, running north-south which includes Sri Lanka's highest mountain peak – Pidurutalagala 2,524m. At the plateau's southern end, mountain ranges extend to the west and east forming a wall of mountains about 100km in length.

Flanking the high central ridges are two lower plateaus. To the north, separated from the main body of mountains and plateaus by broad valleys, lies the Knuckles Massif: steep escarpments, deep gorges, and peaks rising to more than 1,800m. South of Adam's Peak lies the parallel ridges of the Rakwana Hills with several peaks over 1,400m. The land

descends from the Central Highlands to a series of escarpments and ledges at 400m to 500m above sea level before sloping down toward the coastal plains.

Most of the island's surface consists of plains between 30m and 200m above sea level. In the southwest, ridges and valleys rise gradually to merge with the Central Highlands, giving a dissected appearance to the plain. The transition from the plain to the Central Highlands is abrupt in the southeast, and the mountains appear to rise up like a wall. In the east and the north, the plain is flat, dissected by long, narrow ridges of granite running from the Central Highlands. A coastal belt about thirty meters above sea level surrounds the island.

The climate of the island could be characterized as tropical and is influenced by the contrasting Asian monsoon wind regimes; the South West (SW) monsoon winds which occur during summer in the Northern Hemisphere and the North East (NE) monsoon winds which occur during northern winter. Island's rain climate is largely influenced by these monsoon winds and is marked by four seasons. The first is from mid-May to October, when SW winds bring moisture from the Indian Ocean and unload heavy rains on the mountain slope in the south western sector of the island. During this period the leeward slopes in the east and northeast receive little rain. The second season occurs in October and November, the inter-monsoonal months. During this season, periodic squalls occur and sometimes tropical cyclones bring overcast skies and rains to the southwest, northeast, and eastern parts of the island. During the third season, December to March, monsoon winds come from the northeast, bringing moisture from the Bay of Bengal and depositing across the northern, eastern, south eastern regions. Another inter-monsoonal period occurs from March until mid-May, with light, variable winds and evening thundershowers. Humidity is typically higher in the southwest and mountainous areas and depends on the seasonal patterns of rainfall. Thus, the climate of Sri Lanka could summarise as follows:

Northeast Monsoon	December to February
First Inter-monsoon Season	March to April
Southwest Monsoon	May to September
Second Inter-monsoon Season	October to November

The mean temperature ranges from a low of 16 °C in Nuwara Eliya in the Central Highlands (where frost may occur for several days in the winter) to a high of 32°C in Trincomalee on the northeast coast (where temperatures may reach 38 °C). Day and night temperatures may vary by 4 to 7 °C. January is the coolest month, especially in the highlands, where overnight temperatures may fall to 5°C. April, the hottest period, precedes the summer monsoon rains. Humidity is typically higher in the southwest and mountainous areas and depends on the seasonal patterns of rainfall.

6 WIND RESOURCE STUDY

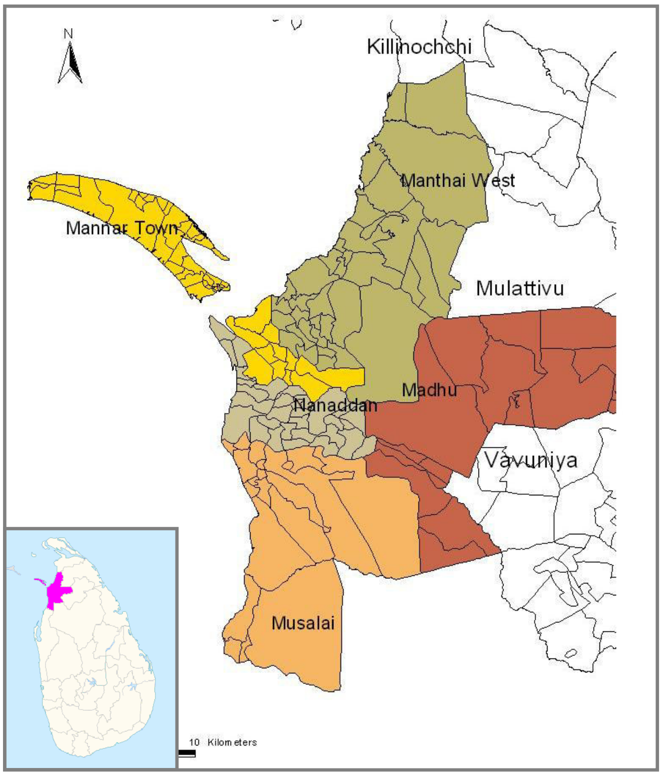
6.1 Objective of the Study

Main objective of the study is to prepare a detailed wind map of the Mannar Island and calculate long-term time series wind data for a representative location in the island so that the database could be used in bankable feasibility studies of future large-scale wind projects in Mannar.

6.2 Profile of the Mannar District

Mannar district is located in north-western part of Sri Lanka. The district covers 2,002sq.km, approximately 3% of the total land area of Sri Lanka. Mannar district is divided into 5 Divisional Secretary's Divisions, namely, Madhu, Mannar, Manthai West, Musalai and Nanaddan (Figure 2). The Divisional Secretary Divisions are further sub-divided into 153 Grama Niladhari Divisions. Population in the district was 103,688 in 2007.

Figure 2 - Mannar District



Geographically the bulk of Mannar is on the mainland within the arid and dry zone. High temperatures and low rainfall characterize the climate. The monthly temperatures range between 26.5°C and 30.0°C with highs normally recorded between May and August. Mannar receives nearly 60% of its rainfall during the northeast monsoon, which lasts from October through December. The land area is relatively flat and sits at low elevations. Towards the interior the terrain is gently undulating, favouring the storage of rainwater in tanks that provide the majority of the irrigation for the district’s arable land. The primary economic activities in Mannar are crop cultivation (mainly paddy), fisheries and animal

husbandry. Employment opportunities in the district are highly seasonal, and there are no institutional facilities for tertiary education.
Agriculture is one of the key economic sectors in the district providing livelihoods for over 15,000 families, approximately 67% of the population. Out of a land area of 200,206ha, the total cultivable land is 37,160ha (19%). Over 65% is under forest cover. The pattern of agriculture practiced is dependent on climate and tradition. The average rainfall in the district is 960mm per year, the majority of which occurs during the northeast monsoon from October to March.

Fishing is a major contributor to the local economy of Mannar District. It provides the principal source of livelihood for a large portion of the population, particularly in Mannar and Musali Divisions, where over 50% and nearly 40% of families respectively rely heavily on fishing activities. Over 8,700 families in 52 villages are involved in fishing.

The district has a marine coastline of 163km, fresh water area of 4,867ha and a brackish water area of 3,828ha. The marine fishing area in the district stretches from Thavenpiddy to the north to Mullikulam in the east and Talaimannar to the south. In addition, although the majority of anchorage facilities are damaged or destroyed, there are 29 separate, small fishing harbours spread around the coastline.

6.3 Review of Past / Ongoing Resource Studies

The review was based on discussions held with relevant officials of SLSEA, study of SLSEA's wind databases, discussions with the climate data branch of the DoM and visit to the met station in Mannar.

6.3.1 Routine Wind Observations

Routine wind observations are carried out by DoM which is a government department established in 1948. Its main functions are (a) provision of meteorological, climatological & limited astronomical services, (b) provision of early warning services with regard to meteorological hazards and tsunami and (c) contribute to technical activities on climate change.

DoM operates a network of 22 metrological stations where routine observations are made on key climate parameters such as rainfall, atmospheric pressure, temperature, visibility, cloud, wind speed & direction and dew point. One of these stations is situated in the Mannar Island. Data collection at this station is carried out at three-hourly intervals; 0530, 0830, 1130, 1430, 1730, 2030, 2330, 0230. Wind run is recorded using a mechanical cup-counter type anemometers (make: Casella) at 6m above ground level. Wind direction is observed using a wind vane mounted on a vertical axle and recorded in descriptive form, e.g. West, south West, South....etc. The general view of this met station is shown in Figure 3.

Figure 3 - **General View of the Mannar Met Station**

History of the station spans over 60 years. Evidently, exposure of the stations to prevailing wind has diminished over the years due to landscape changes occurring around the station with time. Therefore, DoM has shifted the met station to a less crowded location and the station has been operating at this location since 5th June 2007.

Since November 2009, DoM has been operating an AWS at the Mannar met station in addition to its conventional instrumentation set. However, due to satellite communication problems AWS has not been transmitting data regularly. A brief note on the Mannar Island met station is presented in Annex 3.

Due to low height of measurement, 3-hourly data collection frequency, absence of an instrument calibration system and poor instrument exposure, wind data from the met station has limited use for wind energy applications. At best their use would be limited to study of long-term wind pattern. Climate data from DoM databases are available for purchase at nominal prices quoted in the official web site of DoM (www.meteo.gov.lk).

6.3.2 Wind Measurements by Ceylon Electricity Board

The first systematic wind resource assessment in the Mannar region aimed at capturing wind resource data useful for wind power generation was conducted by CEB in 2002. A wind mast to capture wind resource data at three different heights; 40m, 20m, 10m above ground level (AGL) was erected under this study in the coastal village of Nadukkuda which is situated at the edge of the southern coast of Mannar Island. This wind measuring station had been in operation or more than a year until it was abandoned due to the conflict situation prevalent at that time. CEB has provided this data set (for the period from 17th September 2002 to 17th September 2003) to RMA.

6.3.3 Wind Masts Operated by SLSEA

As part of preparatory work on the proposed 100MW wind park, SLSEA has been collecting wind data at three locations in the Mannar region, namely, Nadukkuda, Nanaddan and Silawathurai since 15th March 2011. These 50m high wind masts (Figure 4) record time-series 10-minute average wind speed, maximum & minimum wind speed in the interval, standard deviation in the interval, 10-minute wind direction, 10-minute average temperature and 10-minute average solar radiation.

Figure 4 - Wind Mast Operated by SLSEA

Sensors of this wind mast have been purchased from NRG Systems while the mast and data logger were produced locally. Absence of any test reports from the local manufacturer for data loggers makes the quality of data from these masts questionable. Stay wires and anchoring accessories of these masts are heavily corroded which would seriously affect the durability of the masts. SLSEA has provided raw data available from the three wind masts for the period March 2011 to September 2011 to RMA.

6.4 Assessment of Available Wind Data

GEO-NET started working on the wind potential study in Mannar Island with the analysis and assessment of available upper-air and surface wind data, as well as with a first preliminary wind field simulation with the meso scale model FITNAH 3-D based on geostrophic wind data from the 850 hPA level of the National Oceanic and Atmospheric Administration (NOAA). This analysis and assessments indicate, that the various available surface wind data sources for Mannar Island are not of good quality and in the end none of

the surface wind data sources are able for use to verify the model outputs based on geostrophic wind data with an adequate uncertainty for a feasibility study on the planned wind power project Mannar Island.

6.5 Siting of the Proposed Wind Met Mast

In view of the limitations of available wind data for the present study, it was decided to set up a high-quality on-site wind measurement system according to IEC (61400-12-1:2005) and the accredited procedure for wind measurements. The objective of this measurement was to get high-quality short-term local surface wind data upon generally acknowledged and state-of-the-art methods, which allow a reliable conclusion of the geostrophic and reanalysed wind data quality, which are able for the long-term extrapolation and to verify the model outputs. In consultation with the SASEA, it was decided to install the wind met mast (WMM) in Nadukkuda replacing SLSEA's own mast that was not functioning properly.

6.6 Procurement of Wind Mast Equipment

Based on existing regulations on procurement, ADB authorised RMA to adopt a simple procurement procedure (shopping - calling minimum of three quotations from suppliers offering goods conforming to same standards). Based on the advice of GEO-NET, following suppliers were short-listed for this procurement:

a) Ammonit Measurement GmbH, rangelstrasse 100, D-10997 Berlin, Germany (Ammonit)
b) Ge:Net GmbH, Am Rollberg 1, 38678 Claisthal-Zellerfeld, Germany (GE:Net)
c) KINTECH Engineering, Hernan Cortes, 10 dpdo Esc.A 1 Izda, Zaragoza 50004, Spain (KINTECH Engineering)
d) STE Global, CIF B50993054 Calle Calvo Sotelo, 12 Villanueva de Gallego, 50830 Zaragoza, Spain (STE Global)

All four suppliers responded to the "call for quotation" by 15 January 2012.

Quotations were evaluated jointly by RMA and GEO-NET in terms of (a) conformity to specifications, (b) supplier's experience & reputation, (c) completeness of the offer and (d) the price. Based on this evaluation, RMA recommended to ADB the offer from Ge:Net GmbH as the preferred source of wind measuring equipment. Approval from ADB for the selected supplier was sent on 14 February 2012. Agreement for the full scope of goods & services, i.e. equipment supply and installation, was signed with Ge:Net GmbH on 6 April 2012. This system was installed and operated from June 2012 to July 2013. Installation report and monthly station log with data quality check and analysis are presented in a combined report[3] accompanying this final report.

[3] 5_11_029_ WMC-Mannar Island-Sri Lanka_FR_rev00

6.7 Applied Procedure, Methodology and Model

This section presents how the high-quality on-site measurement at the site Nadukkuda was used for verifying the quality of the reanalysis wind data, how the long-term extrapolation was done, how the long-term time-series wind data set at the measuring site Nadukkuda was produced and how this stationary information was used to simulated the long-term wind field in the study area. A very important component of all this assessments is the uncertainty analysis at the end of the report.

6.7.1 Long-term Time-series

The simulation of the long-term time-series with FITNAH 1-D at the wind measuring site Nadukkuda for 80 m AGL is in the simplified sense a simulation model supported MCP-method (measure-correlate-predict). Based on the reanalysis time-series different simulations with adapted model-parameters (roughness, stability etc.) for the overlapping short-term measurement period were done. The results were compared with the observed wind speed and wind direction at the measurement site Nadukkuda. The model parameters of the run with the best fit to the observations were used to simulate the long-term time-series. Therewith a transfer of the long-term reanalysis data to the stationary, local conditions was conducted.

6.7.2 Long-term Wind Field

Based on the simulated long-term time-series at the site Nadukkuda a spatial transfer of the stationary wind conditions with the model FITNAH 3-D was made. FITNAH is a meso-scale, three-dimensional non-hydrostatic climate and stream flow model for the calculation of wind fields and the spatial characteristics of climate parameters (e.g. cold air streaming, temperature fields).

The simulation of the flow conditions in the model area is conducted grid based and realised by application of the three dimensional, non-hydrostatic meso-scale model FITNAH. FITNAH complies and exceeds the minimum requirements for meso-scaled models as determined in the VDI guideline 3783 (1992), and has been successfully implemented for years by the German Weather Service for surveys.

The basic structure of the model FITNAH consists of the equations for the conservation of momentum (Navier Stokes equation of motion), the law of conservation of mass (continuity equation) and the conservation of energy (1st main clause of thermodynamics). Due to the consideration of the *Coriolis* force in this set of equations, the change of wind direction with the height, which can be observed in the atmospheric boundary layer, is computed. The calculation of the meteorological variables is carried out on a numeric-iterative approach for each grid point of the computing lattice.

The basis for the different calculations is information regarding the spacious, middle synoptic weather conditions, for which the local wind conditions in different heights above ground are to be calculated at a site. As a representative meteorological situation, the wind conditions at a height of 1500-2000m AGL of NOAA are typically used (geostrophic

wind, upper wind), because the flow regime is unaffected at this level. The used official NOAA/National Centres for Environmental Predictions (NCEP) data is available in a worldwide constant, relatively close meshed grid network (mesh size 2.5 degrees). The modification of the wind field at ground level and in the entire atmospheric boundary layer is calculated by the three-dimensional, non-hydrostatic meso-scale model FITNAH. The direction and the velocity of the wind flow within the free atmosphere (geostrophic wind, upper wind) are considered in the simulations as well as the characteristics of air mass. For the wind field simulations conducted in this context, vertical temperature stratification according to the standard atmosphere (easily stable) is used.

In the course of the model calculation 50 horizontal, surface-adapted calculation layers are arranged above each other. The distance selected is very small at ground level (5m to 10m). With increasing height over ground, the distance increases gradually until it reaches the upper boundary of the calculation grid at a maximum of 2000m. This configuration considers the fact that the vertical deviations of the meteorological variables are particularly large at ground level, while at higher altitudes and further distance to the ground level only small variations are usually observed.

The grid points at the bottom of the calculation planes are assigned a mean height over ground and various parameters for land usage. The various land usage types, based on long-term experience and terrain knowledge, are characterized by the parameters obstacle height, permeability coefficient, roughness length and anthropogenic heat release. The accuracy of this input data is subject to the computing grid. In particular the effects of larger, usually compact obstacles, e.g. building complexes or forests must find a realistic consideration on the distribution of meteorological variables within the wind field simulation. The introduction of the parameter of an increased surface roughness usually provides no satisfying results. Not until the consideration of e.g. forest height and density as well as building height and construction density, the 3D-model FITNAH is able to calculate the typical deceleration of the average flow as well as the significant increase of gustiness due to the existence of forests and settlements.

While simulating the local wind-flow, a wind stream with different velocities, one for each of three defined wind speed distribution classes is applied from 12 different directions over the investigation area. Due to the diversity of possible annual weather conditions the numeric simulation has to be restricted to typical meteorological situations. In this case, the computations with a speed of 5 m/s are representative for the wind speed distribution class of 0-7.5 m/s, computations with 10 m/s for the wind speed distribution class of 7.5-12.5 m/s and computations with 15 m/s represent the wind speed distribution class of speeds greater than 12.5 m/s. The resulting 36 flow fields are weighed according to their frequency in the subsequent evaluation. The respective factors pertinent to weighting are extracted from the dual-parameter distribution of the upper wind (frequency distribution of wind velocity for the respective wind direction sectors).

After the model calculation is done, site- and hub height specific wind statistics for each grid point within the 3D computing lattice are on hand. Since the procedure for the evaluation of these statistics is very extensive, the wind statistic is only picked out for

necessary locations and hub heights in the model area. The location-specific wind statistics refer to the next convenient grid point of the model calculation that is most representative for the site conditions. In principle the vertical computing layers are arranged in such a way that all heights above ground relevant for the wind converter sites are covered. If a regarded height, for which a wind statistic should be compiled, lies between two computing layers, the wind speed will be interpolated linearly in individual cases. The location- and hub height specific wind statistic contains all important simulation results, which are needed for the calculation of energy yield, e.g. frequency distribution of the wind velocity, wind direction distribution, wind force distribution and atmospheric pressure. The simulated atmospheric pressure refers to the average long-term air temperature at the regarded location and is computed for the specific hub height above sea level.

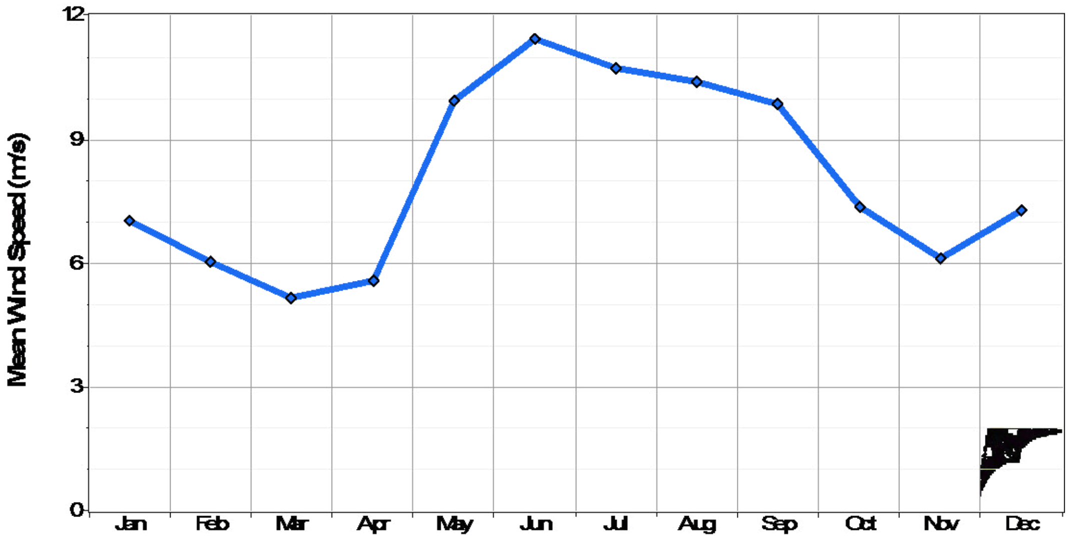
For the entire computing lattice and each grid point and for any height above ground, an average value of the simulated wind velocity, gustiness and environment turbulence is evaluated. Based on this evaluation an area-wide wind field for the model area can be produced and represented.

The model area for the calculation of the wind field has a size of 35km x 35km (Mannar Island). The single grid cells have a mesh size of 50m x 50m. The land uses structures are obtained by digitize topographical maps and the information from exemplary on-site inspection. The relief structure was obtained by the SRTM elevation model of the NASA space shuttle mission 2000 (USGS 2004).

6.8 Wind Potential

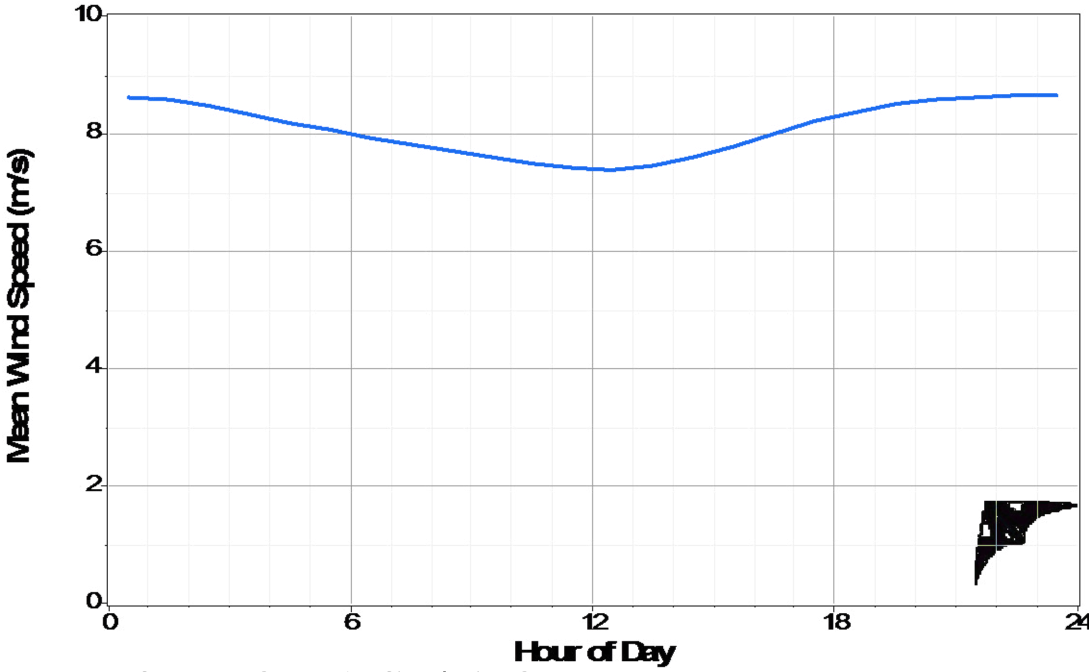
The simulated, stationary and hub height specific long-term-time-series for the site Nadukkuda on Mannar Island based on the FITNAH 1-D simulation is shown as an overview in Figure 5 to Figure 8. The simulated average long-term annual average wind speed is 8.08m/s in 80 m height.

Figure 5 - Monthly Wind Speed Distribution for the Nadukkuda Site



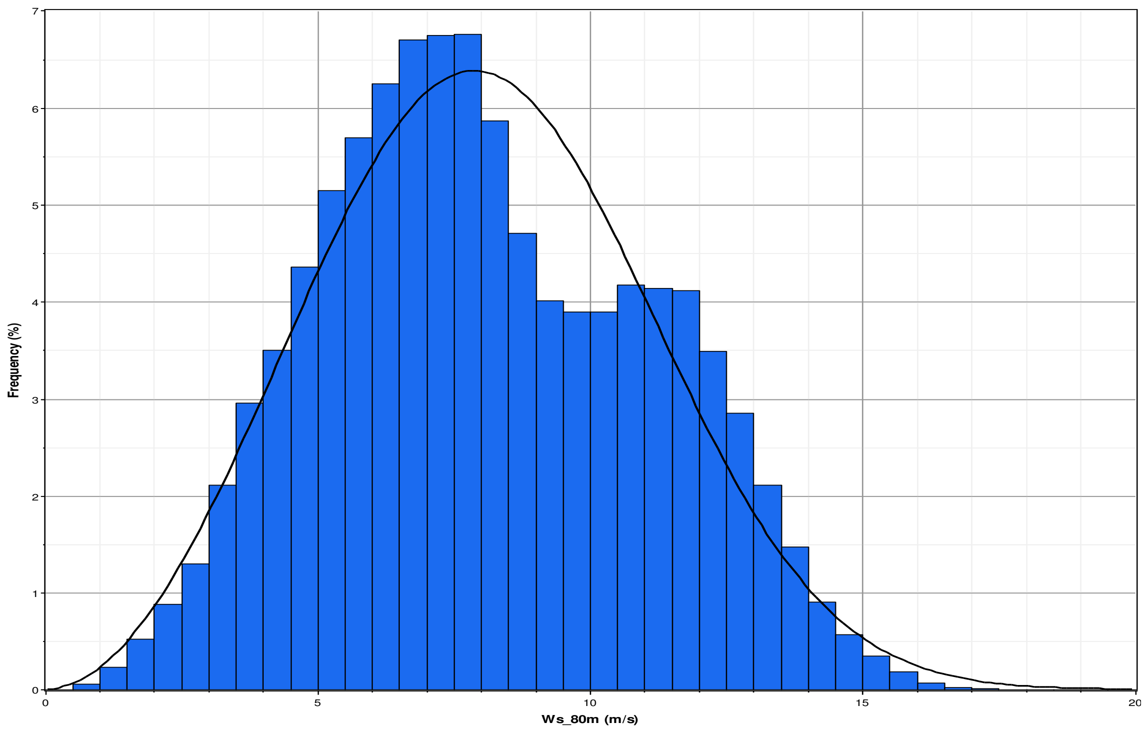
Source: 1-D-FITNAH-Simulation Data

Figure 6 - Diurnal Wind Speed Distribution for the Nadukkuda Site



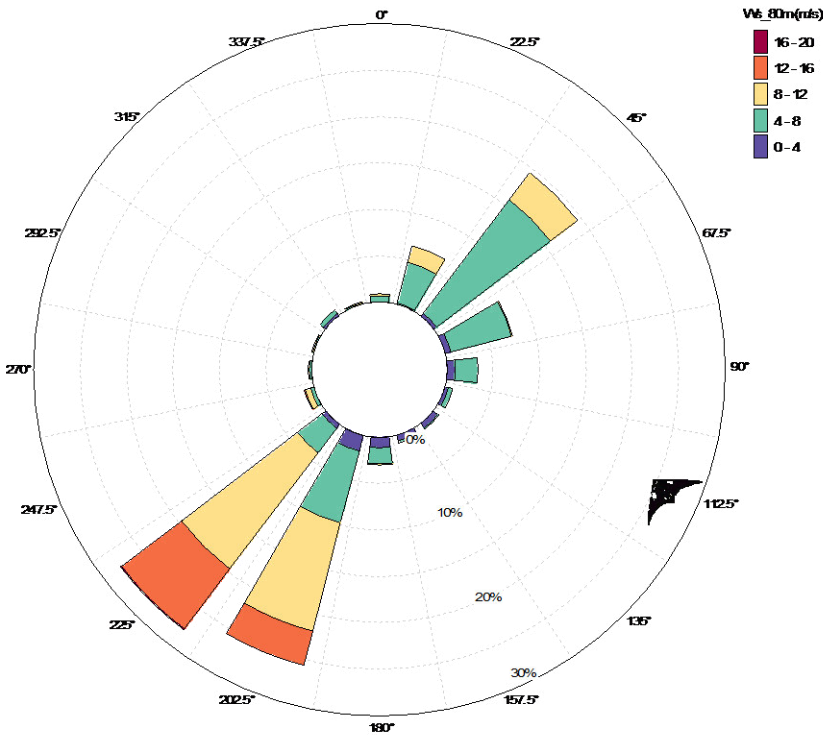
Source: 1-D-FITNAH-Simulation Data

Figure 7 - Wind Speed Distribution for the Nadukkuda Site



Source: 1-D-FITNAH-Simulation Data

Figure 8 - Wind Direction Distribution for the Nadukkuda Site



Source: 1-D-FITNAH-Simulation Data

The simulated, location- and hub height specific, long-term expected wind potential for the Mannar Island based on the 3D wind field simulation is shown as overview in Annual average wind speed data presented in Figure 9 has been transformed into wind power density (W/m^2) in Figure 10.

Figure 9 - Overview Mannar Island: Simulated Wind Field for the Height of 80m AGL.

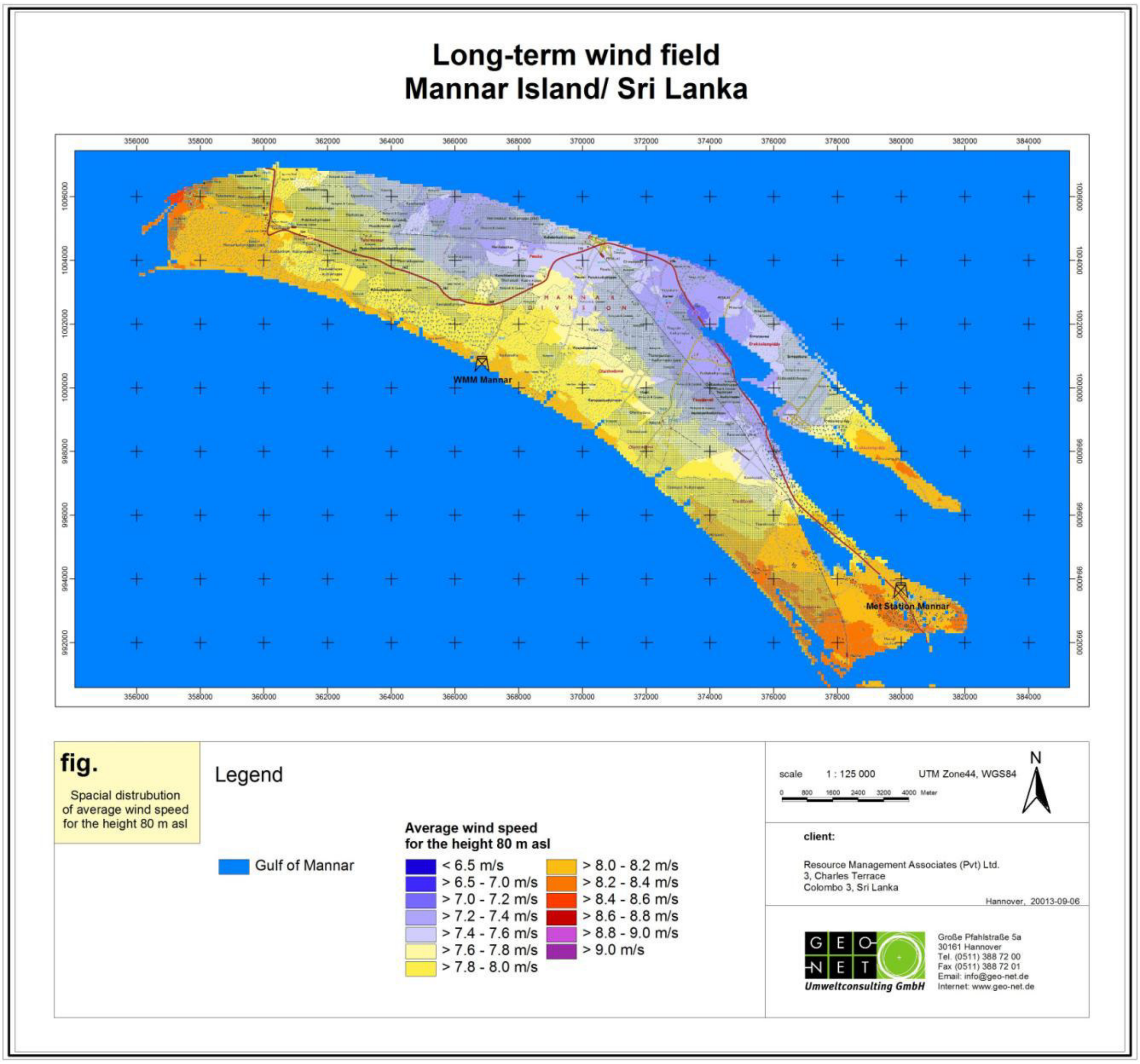
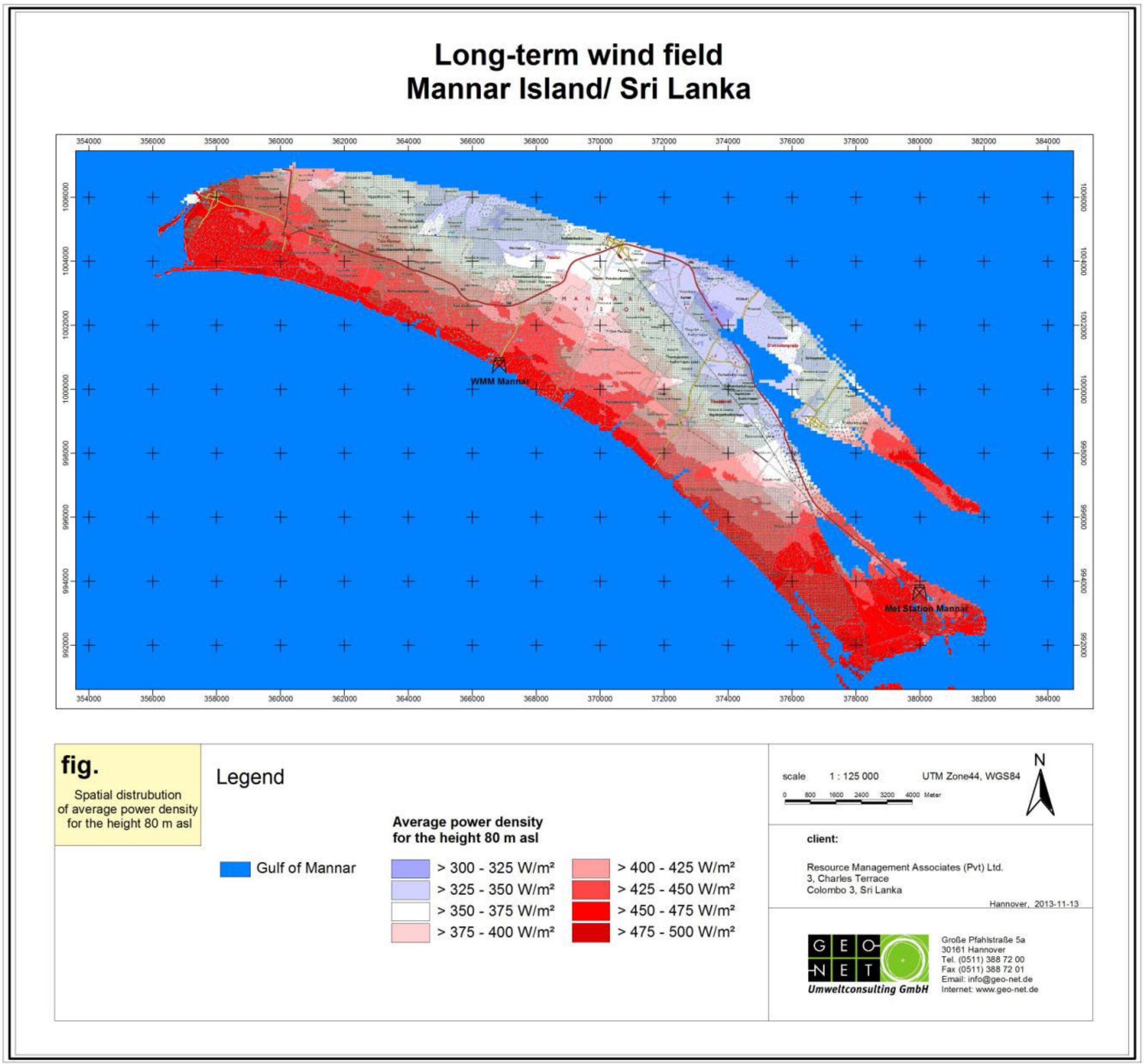


Figure 10 - Spatial Distribution of Wind Power Density across Mannar Island



6.9 Long-Term Correlation and Validation of the Results

Furthermore, for the investigation of wind potential at the considered measurement site and Mannar Island area a long-term correlation will be elaborated (10 years or more if possible). This can be achieved by comparing wind measurements and/or data from other wind converters with long-term observations. The representativeness (spatial and temporal correlation) of the comparative site has to be evaluated for the location under investigation.

6.9.1 Description of Comparative Measurement

Short-term Wind Data

The analysis and assessment of the short-term on-site wind measurement at the site Nadukkuda is documented in detail in the separate report "5_11_026_WMC-Mannar Island-Sri Lanka_FR_rev00_20130814" (accompanying the final report)

Long-term Wind Data

In this case the two reanalysis products - Modern-Era Retrospective Analysis for Research and Application (MERRA) and Climate Forecast System Reanalysis (CFSR) were used:

- Long-term time series of MERRA-Reanalysis 50m wind speed and wind direction at grid point 9.0°N 79.33°E for the period 1992-01-01 to 2013-07-31.
- Long-term time series of CFSR Reanalysis 50m wind speed and wind direction at grid point 9.0°N 79.33°E for the period 1992-01-01 to 2013-07-31 (SANDER, 2013).

Aside the observations at the met station Mannar were viewed:

- Long-term manual observations of average wind conditions at the met station in Mannar; period 2001/01/01 – 2013/07/31 (daily average wind speed data; Department of Meteorology, Colombo, Sri Lanka - obtained by RMA 2013)
- Observations of average wind conditions at the met station in Mannar (new Automatic Weather Station - AWS), period 2010/01/01 - 2013/07/31 (daily average wind speed, National Climatic Data Centre (NCDC)

6.9.2 Quality of Comparative Measurement

All comparative measurements have been verified and analysed according to the standard procedure of the Födergesellschaft Windenergie (FGW 2011) and IEC norm 61400-12-1. All data used for this procedure was quality checked and also checked for consistency before appliance. Data, which appeared incorrect due to malfunction or bad recording devices, were not used for the analysis.

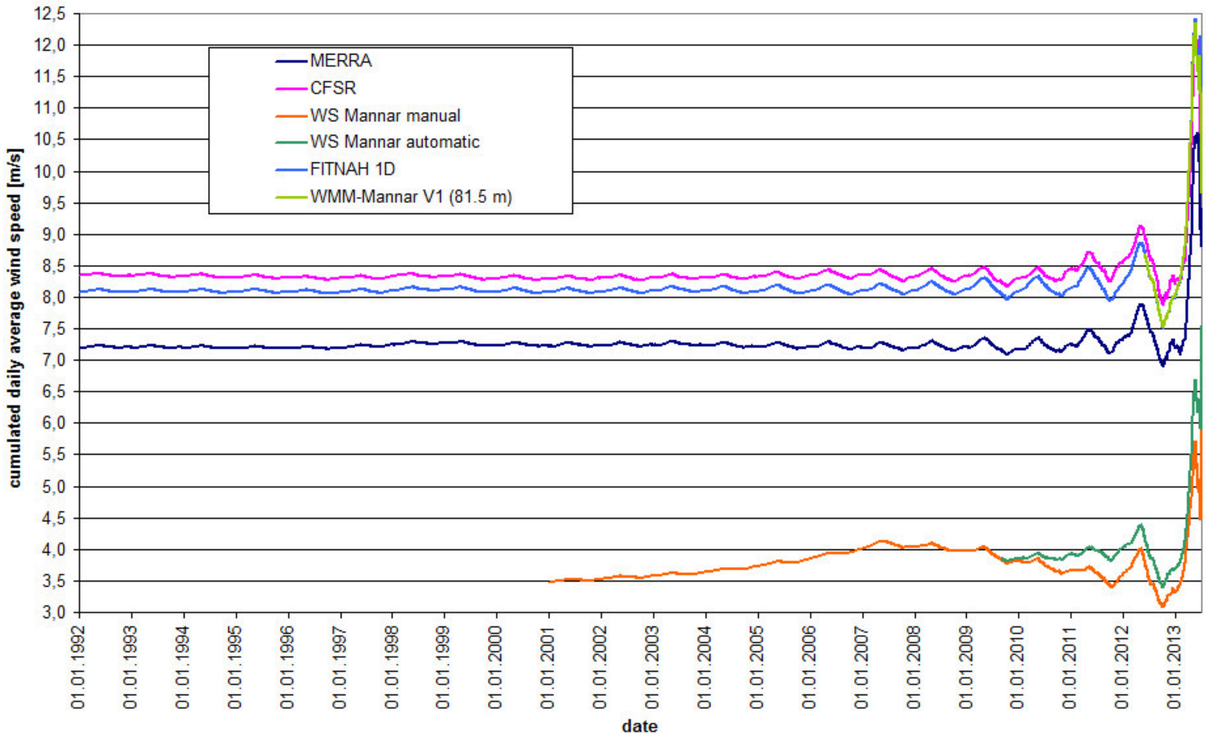
The quality of long-term data depends on the method of recording. In contrast to high quality wind measurements, observations at met stations or modelled long-term meteorological data are only used to determine long-term trend. This means for example that the resolution of the measurement or modelling is normally not high (every 1, 3 or 6 hours) and the measurement sensors are mostly checked but not calibrated.

In case the method of recording is consistent (sensors, resolution, observation site) the quality is good enough for the long-term extrapolation of short-term measurements and so for classifying and verifying the calculation results of the 1-D and 3-D long-term wind potential simulation.

Figure 11 shows the result of the consistency check for the available long-term data useable for the Mannar Island investigation area. The figure shows a strong trend in the course of the cumulated daily average wind speed at the manual met station Mannar before June 2007. The reason for that strong trend was the relocation of the measurement

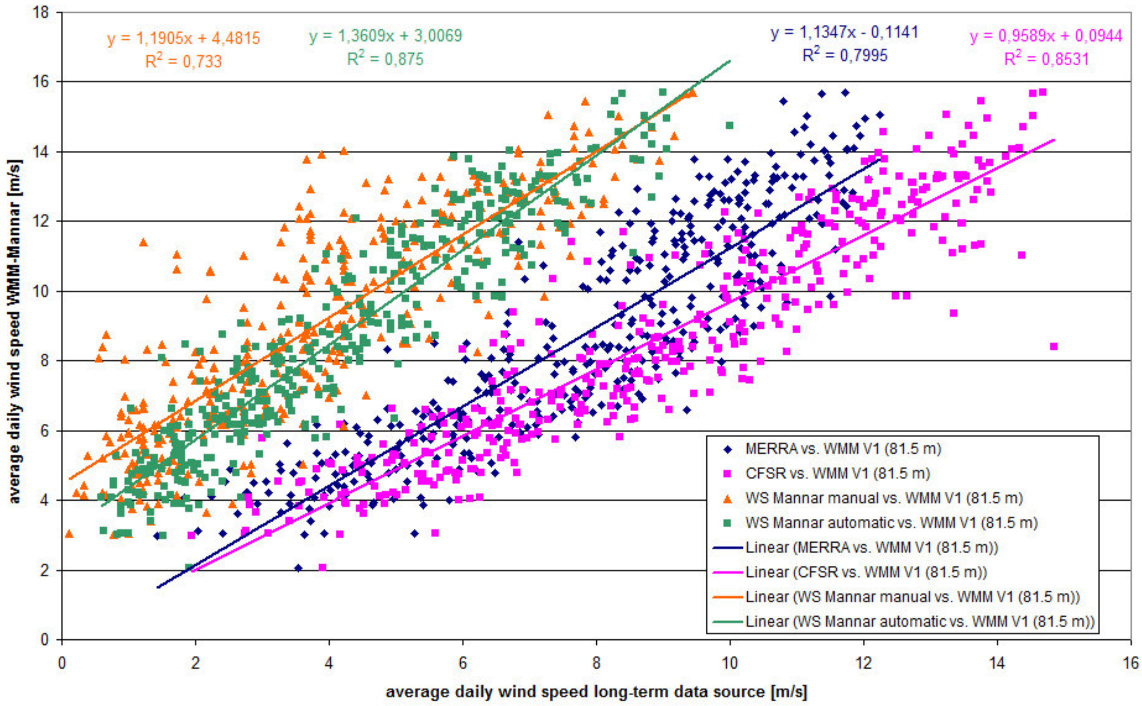
site to the present site on 5th of June 2007. From June 2007 until middle of 2011 the course of the cumulated daily average wind speed shows also a trend. From middle of 2011 the course of the cumulated average wind speed seems consistent. This statement will be supported in comparison with the consistent course of the MERRA, CFSR and the data of the automatic weather (AWS) station in Mannar. The figure shows as well the course of the cumulated daily average wind speed simulated with FITNAH 1-D at the site WMM Nadukkuda.

Figure 11 - Consistency Test Long-term Data



The correlation between the long-term time-series and the short-term time-series is determined by a linear regression between the concurrent time series of measurement and reanalysis data (AWS data). The correlations found for the one year measurement period are very good for both reanalysis and AWS and for all measurement heights (see Figure 12). The coefficient of determination values r^2 is close to 0.8, which is above common average.

Figure 12 - Correlation between the Daily Average Wind Speeds of the Long-term Data Sets and the Short-Term Data at the Measurement Site WMM Mannar



6.9.3 Results from Comparative Measurement

Based on the results of analysis and information presented in Chapter 7, a long-term extrapolation of the short-term measurements was done. The results of the long-term extrapolated short-term measurements will be site specific compared with the result of the FITNAH 1-D and FITNAH 3-D wind field and wind potential simulation (see Table 1).

Table 1- Comparison of Average Wind Speed of the WMM Sites (Measured and long-term Transformed) and of the Results of the FITNAH-Simulation

Measurement Mast	**WMM Mannar (Nadukkuda)**			
Height of wind measurement	20 m	40 m	60 m	80 m
Measurement period	2012-06-01 till 2013-07-31 (till 2013-05-31 1year)			
availability	~99.5 %	~99.5 %	~99.5 %	~99.5 %
Average wind speed	7.59 m/s (7.15 m/s)	8.22 m/s (7.80 m/s)	8.54 m/s (8.14 m/s)	8.85 m/s (8.44 m/s)
Long-term transformation based on MERRA (reference period 1992-2012)				8.06 m/s
Long-term transformation based on CFSR (reference period 1992-2012)				8.10 m/s
Long-term transformation based on AWS Mannar (reference period 2010-2012)				8.28 m/s
FITNAH-simulation (reference period 1992-2012)				**8.08 m/s**

Considering the estimated uncertainty of the measurement, of the long-term data and of the procedure the comparison between the long term transformed wind speeds at the measuring sites to the results of the FITNAH simulation indicates good results.

In the following the results will be also viewed from the energy side. For this purpose the observations at the measurement site WMM Mannar were calculated in monthly energy output exemplarily for the WTG-type RE power MM-82. Based on the MERRA Reanalysis time-series a monthly energy-yield-index was calculated with an in-house-method for the period 1992-2013 based on the reference period 1992-2012. Table 2 show the results of this analysis.

Table 2 Comparison of Energy Production Derived from Long-Term Reference Data with Data from the FITNAH-Simulation

Month	Monthly energy yield REpower MM-82 with 80.0 m hub height based on WMM Mannar (kWh)	Monthly Energy-Yield-Index based on MERRA Reanalysis (reference period 1992 - 2012) (%)
June 2012	1.311.083	188
July 2012	952.492	158
August 2012	1.239.142	180
September 2012	1.069.617	144
October 2012	433.683	62
November 2012	328.767	53
December 2012	463.475	106
January 2013	398.325	108
February 2013	322.425	60
March 2013	192.667	39
April 2013	338.200	37
May 2013	1.119.200	147
June 2013	1.226.075	190
July 2013	1.053.467	174
Long-term annual average energy yield based on linear regression between MERRA-Index and monthly energy yield for the example WTG at the site WMM Mannar	7.560.550 kWh/a	
Long-term annual average energy yield based on FITNAH 1-D / 3-D simulation for the example WTG at the site WMM Mannar	7.580.000 kWh/a	

6.10 Overall Uncertainty of the Results

The relevant main uncertainty components that have to be taken into account are depending on the subjected result. For the prognosis of the annual average wind speed and wind direction the following components have to be taken into account:

- Wind data basis: subcomponents are the uncertainty of the on-site measurement and the uncertainty of the long-term extrapolation (consistency, homogeneity, representativeness and projection of the long-term data source)
- Modelling: subcomponents are the model input data (topography, model specific adoptions and adaptations)

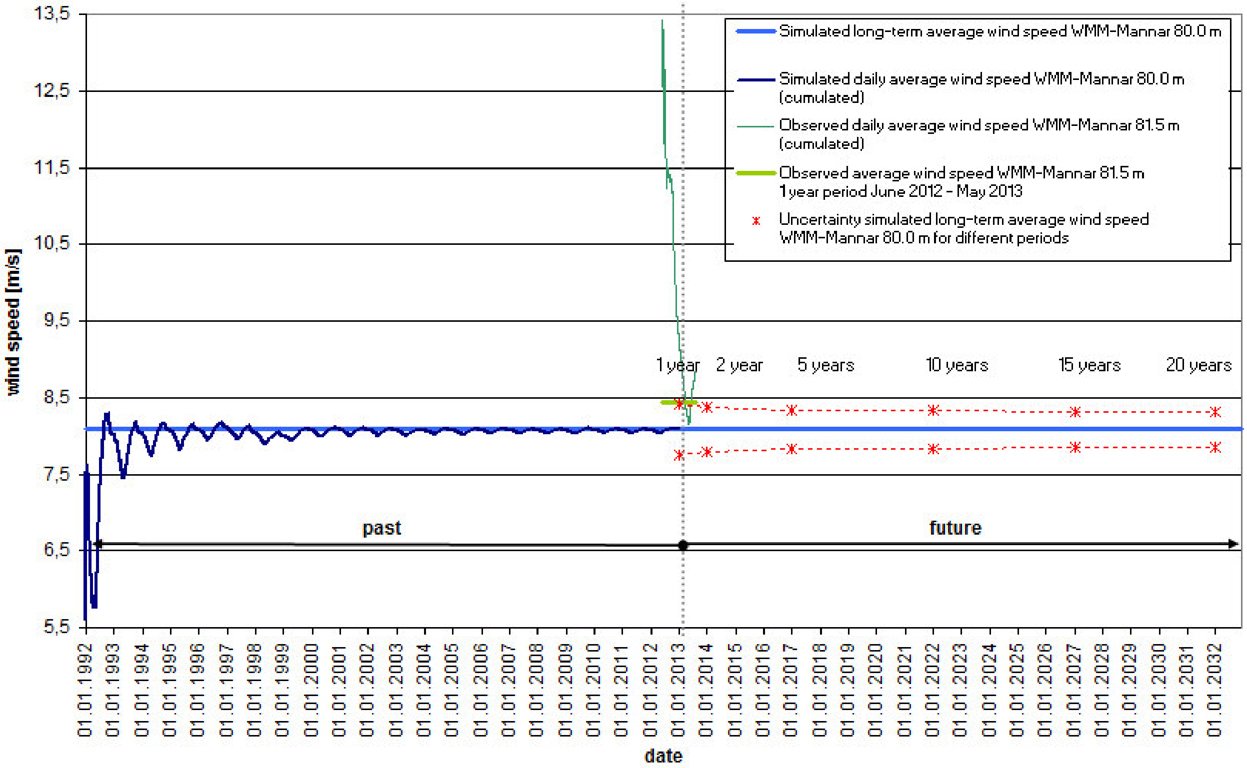
For the prognosis of the annual average energy yield the following components have to be added:

- Park efficiency: subcomponents are the uncertainty of the model adoptions, ct-curve etc.

- Technical WTG parameter: subcomponents are the uncertainty of the power curve (measured – calculated, transfer of the power curve to the analysed site etc.)

The simulated 20years time-series as reference of the expected stationary long-term average wind speed/wind potential for 80.0 m above ground at the site of the WMM Mannar for the future 20 years has an uncertainty of 3%. The uncertainty increases with shorter prediction periods (see Figure 13).

Figure 13 - Prognosis Based on Past Data and Uncertainty of Future Periods



The prognosis of the annual average energy yield for a 20years operation period for the example WTG REpower MM-82 with 80.0 m hub height at the site WMM Mannar has an uncertainty of 8.8 %.

The uncertainty of the spatial distribution of the long-term average wind speed (wind field for Mannar Island) increase with the distance from the on-site measurement. Along the SW cost in the field of the beach area the uncertainty will be estimated close to 3 %. Because of bad topographic data the uncertainty of the wind field simulation will increase upcountry and on the NW coast up to 7 %.

6.11 Capacity Building Activities

Training of staff in SLSEA is an important task for continuity of the work initiated under the present TA. Item 2(x) in the TOR explicitly refers to training as a part of the project outputs. For this purpose views of SLSEA were obtained on the desired scope of training. Based on these views, training was conducted in two forms, (a) classroom lectures on the selection of wind measuring sites and appropriate measuring equipment and (b) on-the-job training on assembly, installation and commissioning of wind masts.

6.11.1 Classroom Training

Learning Objective: On completion of training, it is expected that the trainees would have the basic exposure to select a site for wind resource assessment and specify appropriate wind measuring equipment for the purpose

Curriculum

<u>Part 1</u> Overview about the general requirements for the determination of wind potential and energy yields according to international accepted and national guidelines (MEASNET, FGW TR6 etc.)

<u>Part 2</u> Detail representation of the international norm IEC 61400-12-1 and international accepted guidelines (MEASNET etc.) concerning on-site wind measurements. This will cover:

- Selection of wind measuring sites
- Proper way to erect a tower (tubular, lattice tower, booms, instruments, calibration etc.)
- Data management and security (documentation of measuring, archiving data, assuring quality, consistency checking etc.)
- Uncertainty analyses
- Examples and discussion

<u>Part 3</u> Detail representation international accepted and national guidelines concerning wind and energy yield expertises

- Input data (topographic and meteorological)
- Short term and long-term resource data
- Long-term extrapolation
- Validation
- Micro-siting (include requirements)
- Yield calculation (include requirements)
- Uncertainty analyses
- Examples and discussion

Teaching Methodology

Teaching methodology of this training course was based on PowerPoint presentations with reference to useful web sites. Participants interacted actively with the resource person and the session lasted about 3 hours. Altogether three staff members of SLSEA (Suriyakumara, Jayatunga and Padmadeva) were trained during these sessions. Classroom training was conducted on 28 May 2012 In Mannar and training on installation and maintenance was conducted as on-the-job training from 24-30 May 2012, i.e. during the period of WMM installation and commissioning.

Figure 14 - Ingo Wendt Conducting the Classroom Training Session

6.11.2 Field-level Training

Learning Objective: On completion of training, it is expected that the trainees would be able to use and maintain meteorological sensors, data logger, remote data acquisition system and the wind mast.

Proposed Curriculum:

- Components of the wind mast and their functions
- Calibration certificates
- Stages of wind mast assembly & erection, potential dangers and safety measures
- Demonstration on the use of climbing safety harness
- Witness assembly of wind mast and gin-pole – participate by helping the assembly work
- Introduction to data logger and its key functions, settings, remote data retrieval process

Training Methodology

Training methodology was based on hands-on-work, verbal explanations, reference to drawings / sketches / catalogues

Figure 15 - Field-level Training through Direct Participation in the Installation Process

7 SOLAR RESOURCE STUDY

7.1 Background

On 1 March 2012, RMA invited offers from five international suppliers for supply of instruments and equipment for a complete solar measuring station. Three of them responded to the call for quotations. Proposed solar measuring station was to be sited in the Solar Energy Park of SLSEA in Hambantota. However, in late March 2012, ADB requested RMA to re-focus the study to cater to the design needs of rooftop solar Photovoltaic (PV) systems. Both SLSEA and RMA believe that commercialisation of rooftop solar PV, if ever they become cost-competitive with grid electricity, might start first with urban customers. Therefore, it was decided that the solar measurement programme needs to be located ideally within the Greater Colombo Area. The idea was debated further at the meeting held in the MOPE on 17 May 2012 with the participation of SLSEA and ADB officials. Views expressed at this meeting are summarised below:

1. Proposed solar measuring station is designed to collect high-quality solar radiation data that could be used for design of large-scale solar power plants – both solar PV and solar thermal power plants.
2. Such high-quality data is generally not required for design and analysis of small-scale (typically less than 100kW) solar PV plants that would find a market in rooftop applications
3. Large-scale solar PV and thermal plants, if and when they become commercially attractive, will be sited in sparsely populated regions having substantial solar energy potential – e.g. Northern districts
4. In view of above considerations, it was agreed that the proposed solar measuring station need to be sited in the Northern region. Taking into account logistical considerations and long-term sustainability of the solar measurement programme, it was agreed to site the proposed solar measurement station in the University of Jaffna (UoJ) subject to confirmation by the university authorities.

Setting up the solar measuring station in UoJ would guarantee continuity of measuring work beyond the project period and generate long-term high-quality data that is lacking in any of the local solar measuring stations. This is an essential element in internationally accepted studies/analysis, in particular in the domains of solar energy and building energy systems. Proposed solar measurement station with secondary standard instruments could also contribute to solar energy and related research at UoJ as well as to upgrade academic modules on solar energy at undergraduate / postgraduate levels.

Solar radiation measuring equipment procured under the current TA will become the property SLSEA. The collaborative arrangements for the solar measuring station was finalised through a Memorandum of Understanding (MoU) signed between SLSEA and UoJ.

7.2 Objective of the Study

The objective of the solar resource study is to produce Typical Meteorological Year (TMY) data which takes into account uneven distributed cloud cover over Sri Lanka. During the first draft of the methodology in the interim report it was considered to use a METSTAT model and use Real Time Nephanalysis (RTNEPH) Cloud Database, Aerosol optical depth (AOD) data and precipitable water and others as inputs to the METSTAT Model. As a result, long term data for irradiance on the ground would be generated.

7.3 Study Methodology

In order to plan solar power projects the annual solar potential must be calculated. For integration of solar energy into electrical grids also the monthly production of solar energy must be predictable for different climate zones in Sri Lanka. As a first Step in this process the long term correlated potential of solar irradiance usable for further planning must be known on annual and monthly basis. Time series products of hourly Solar Direct Normal Irradiation (DNI) and Global Horizontal Irradiation (GHI) for selected locations in Sri Lanka were already produced in earlier studies. The approaches of reviewed studies did not take into account uneven distribution of cloud cover over Sri Lanka.

This approach suggested in the ToR and the Inception report was closely related to the approach used in 2003 by the National Renewable Energy Laboratory (NREL) in the US. The main difference is that recent high resolution satellite data for cloud cover would be used to generate ground based irradiation data.

However, data sources for high resolution satellite data of cloud cover required for the approach described could not be identified. Instead of high-resolution cloud cover data which would have to be evaluated and processed in a complicated, time-consuming and cost-intensive procedure, other data sources and approaches were found. The German Aerospace Center (Deutsches Zentrum für Luft und Raumfahrt, DLR) offers high quality time series data of ground- irradiance, which already considers the influence of clouds and aerosol particles. This kind of data is used worldwide for evaluation of solar resources and meets international standards. These data are based on the Meteosat satellite images and are processed by DLR on request for defined locations. Data contain broadband Direct Normal Irradiation (DNI) + Global Horizontal Irradiation (GHI) for defined locations. For some of the sites in Sri Lanka listed in Table 3 (see last column), data is available for 11 years starting from the year 2000.

Because SOLEMI irradiation data are processed using a different approach than used in the NREL study, it offers the possibility to compare independent generated TMY data for the selected locations to each other, proof results of the first study and therewith increase the quality of the study significantly.

7.4 Solar Resource Estimation

Requirements for solar resource assessment differ with the planned type of energy conversion system. PV system generally converts global irradiation (direct and diffuse).

Attention to the ratio of diffuse and direct irradiation has to be concerned if the modules are not fixed but tracking the path of the sun. Concentrating solar power (CSP) facilities can only convert direct irradiation. Thus resource assessment for CSP focuses on direct irradiation.

7.4.1 Data Sources

Data sources for irradiation parameters are direct in-situ measurements, i.e. measurements with pyranometers or pyrheliometers directly at the location of interest. Measurements of standard parameters like global irradiation are performed at operational weather network station and more elaborate measurements are done at research facilities. These networks are sparse and are not necessarily located at site of interest for solar energy applications.

Interpolation of solar measurement data is complicated due to the high spatial variability of clouds, atmospheric turbidity, water vapour and other parameters which affect irradiation at the ground. Elaborate models are employed to determine irradiation from input data like temperature, humidity, cloud cover, cloud type, aerosol optical depth and others. On the other hand, these models can produce gridded datasets and to some extent time series for large areas.

7.4.2 Available Data

There are numerous commercial providers of solar resource data. Some open access data are provided in the frame of the Solar and Wind Resource Assessment (SWERA) initiated by the United Nations Environmental Programme (UNEP). SWERA provides a GIS based web interface which allows for selecting geographical regions and displaying and analyzing available data. A short overview of SWERA datasets and capabilities is given below.

The Solar and Wind Resource Assessment (SWERA) initiated by UNEP is a collection of different data sources which can be accessed via a GIS based web interface. It allows searching for data in geographical regions and displays gridded data as map overlays and other data as graphs (Figure 16 to Figure 18). SWERA also provides all data used to generate the visualizations.

For Sri Lanka different gridded data sets of irradiation parameters are available. For example DLR provides monthly sums of GHI with 10 x 10 km resolution for the years 2000, 2002 and 2003. All data can be downloaded as text and shape files.

The available data sets give a first impression of regional and to a lesser extent temporal distribution of some irradiation parameters. It is not sufficient for detailed resource assessment and qualified decision for solar energy projects.

Figure 16 - Sample of SWERA Web Interface Showing DLR Data.

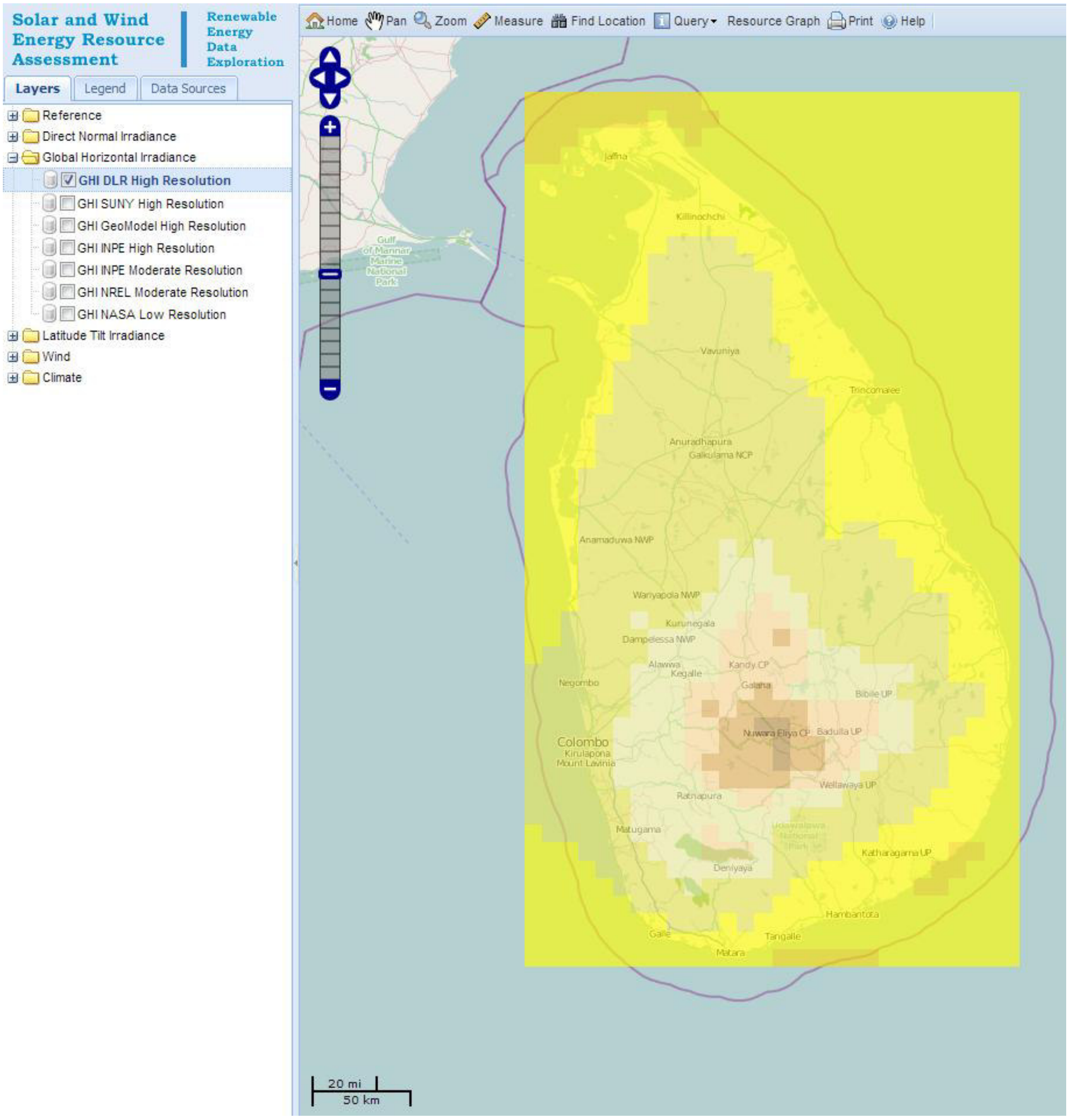


Figure 17 - Sample of SWERA Web Interface Showing NREL Data.

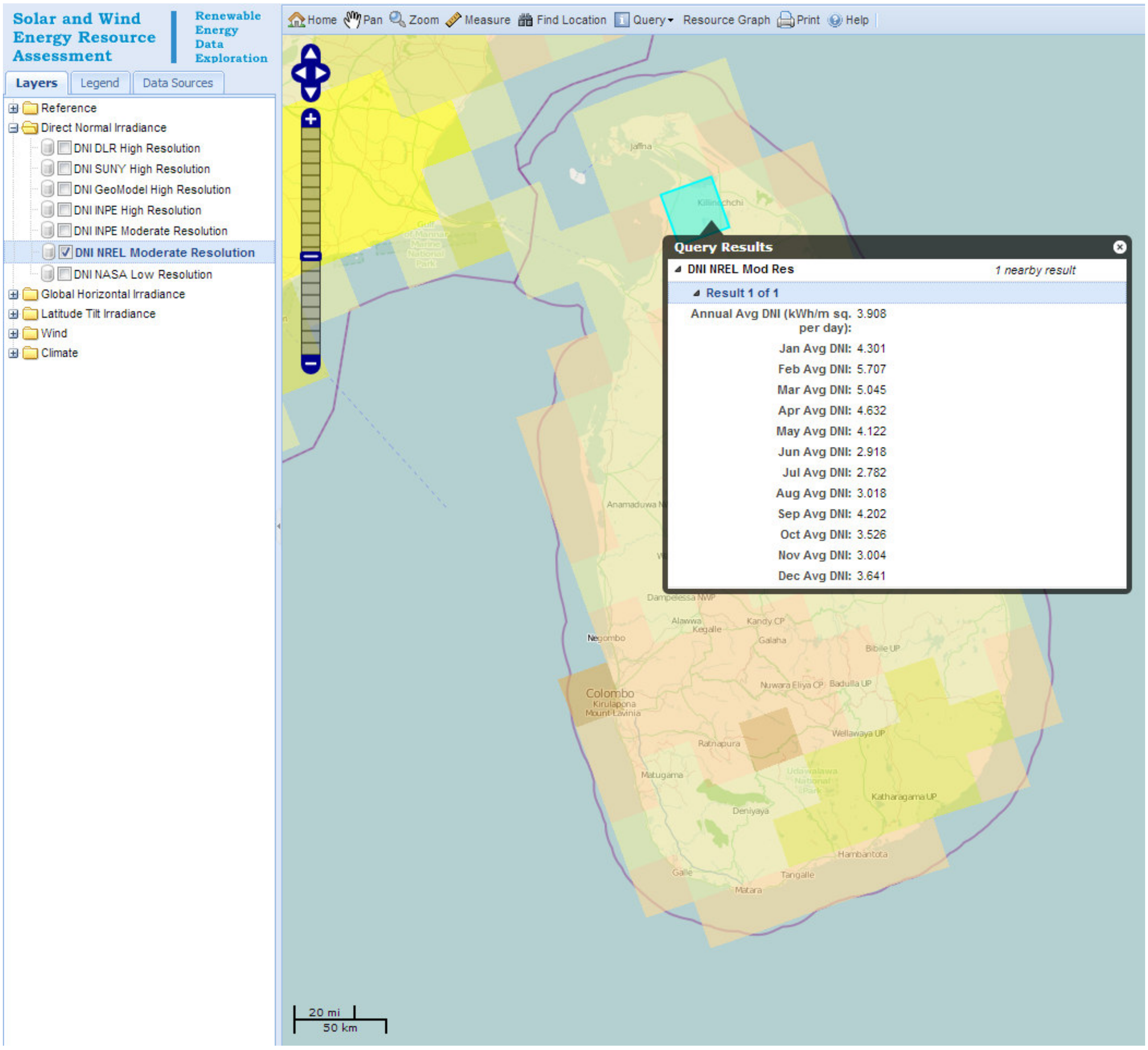
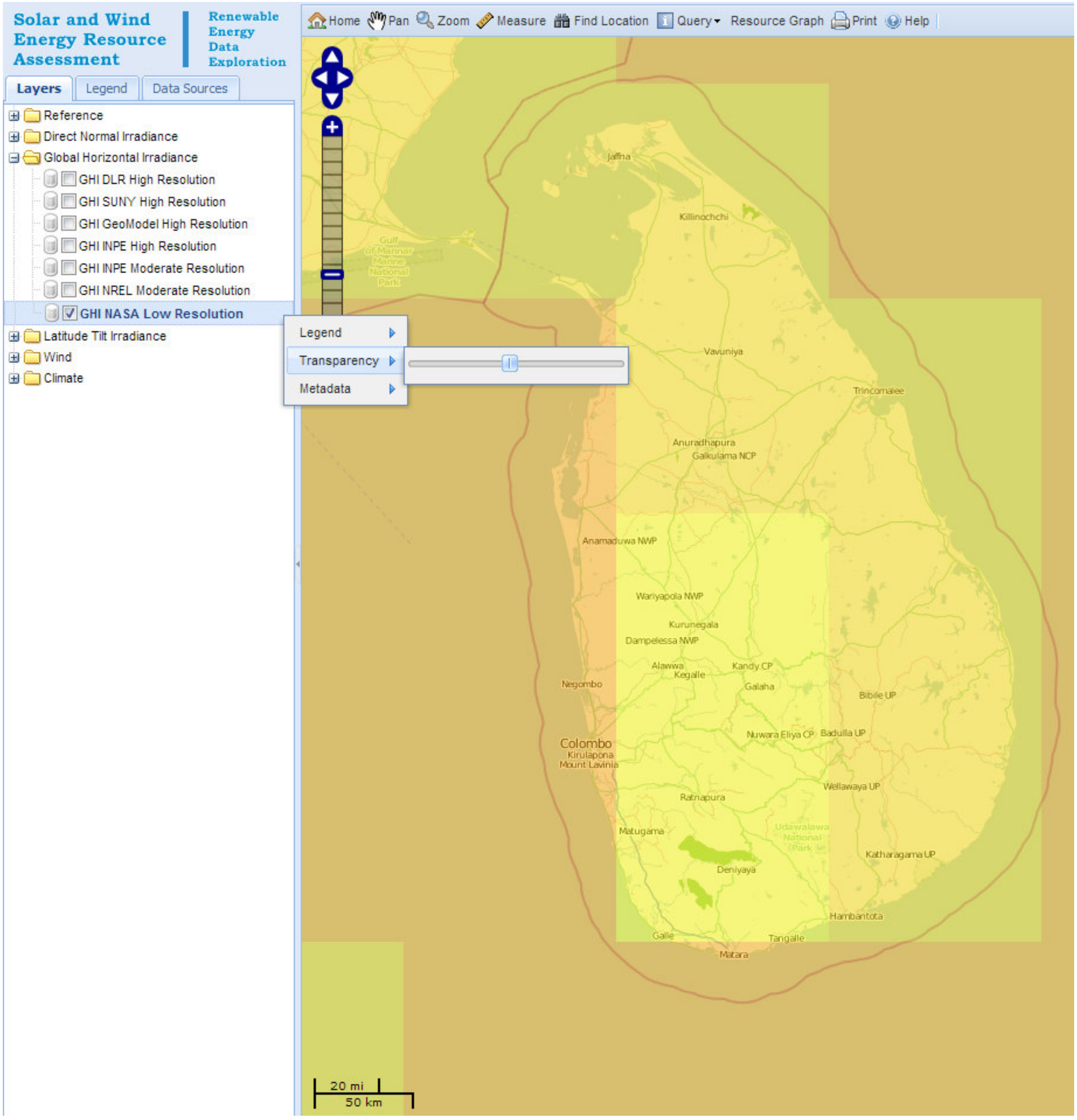


Figure 18 - Sample of SWERA Web Interface Showing NASA Data.



7.4.3 Review of Existing Evaluations

Few investigations of solar irradiation exist for Sri Lanka. Except for global datasets like those available via SWERA, two distinct investigations are reported; Samuel, 1991; NREL 2003.

Samuel[4] used observations of sunshine duration to estimate global irradiation for 22 stations across Sri Lanka. His method was to calculate factors for the modified Angström formula and put in the ratio of sunshine duration and length of the day for the stations. He did not have the possibility to validate his findings as no suitable measurements of global irradiation were available at that time. From a contemporary point of view, his method is quite uncertain, but it gave a rough picture of the regional difference of solar radiation across Sri Lanka.

[4] Faculty of Engineering, University of Peradeniya, Sri Lanka

Samuels's findings are presented in Table 3; the unit of global radiation energy is converted from Joule to Watt hours. For some of the employed stations, SOLEMI data is available and these are presented in Table 3 for comparison.

Table 3 - Results of Samuel, 1991

Station	Altitude(m)	S/Z	Samuel H (MJ m^{-1} d^{-1})	Samuel H (kWh m^{-2} a^{-1})	SOLEMI H (kWh m^{-2} a^{-1})
Agalawatta	65,5	0,42	15,56	1578	
Alutharama	96,0	0,51	17,25	1749	
Angunakolapalessa	23,0	0,62	19,20	1947	
Bandarawela	1290,0	0,44	15,97	1619	1858
Batalagoda	128,0	0,54	17,76	1801	
Batticaloa	2,7	0,63	19,34	1961	2226
Bombuwela	3,0	0,55	17,97	1822	
Colombo	7,3	0,61	19,00	1926	2155
Hanguranketta	731,5	0,50	17,08	1732	
Kankusanturai	14,6	0,65	19,60	1987	
Kantalai	225,0	0,62	19,12	1939	
Lunuwila	30,0	0,58	18,46	1872	
Mahailluppallama	137,0	0,66	19,89	2017	2181
Maradankadawela	137,0	0,56	18,08	1833	
Matale	357,0	0,45	16,15	1637	
Peradeniya	476,4	0,53	17,60	1784	
Ratnapura	39,6	0,49	16,92	1716	1924
Sita Eliya	1860,0	0,45	16,16	1638	
Talawakelle	1220,0	0,49	16,91	1714	
Thirunelvelly	4,0	0,62	19,05	1931	
Trincomalee	3,0	0,65	19,67	1994	
Vanathavillu	6,0	0,62	19,12	1939	

The National Renewable Energy Laboratory (NREL) which is subordinated to the U.S. Department of Energy prepared a solar resource assessment for Sri Lanka and the Maldives (NREL, 2003) in the year 2003. Its result consists of a gridded dataset with medium resolution (40km x 40km) of DNI and the solar resource on a fixed flat-plate collector oriented south at latitude tilt. Additionally typical meteorological year (TMY) time series were processed for 9 stations in Sri Lanka. NREL applied a radiative transfer model (METSTAT) with various input data sources.

Due to the grid size of 40x40km for cloud cover data and the time-resolution of observations used (3 hours) the results of this study may not take into account the impact of an uneven distribution of clouds over Sri Lanka with appropriate precision.

7.5 Data Used in the Present Study

This resource assessment report is based mainly on three data sources: A local, high quality solar measurement in Kilinochchi, data from local weather stations as long term data source and SOLEMI data as a long term and independent data source.

7.5.1 Measurement at Kilinochchi

A solar measurement station was installed near the city of Kilinochchi in the Northern Province during March 2013. It is located in a rural area at an elevation of 48 m above sea level. Details on the measurement site and equipment are given below.

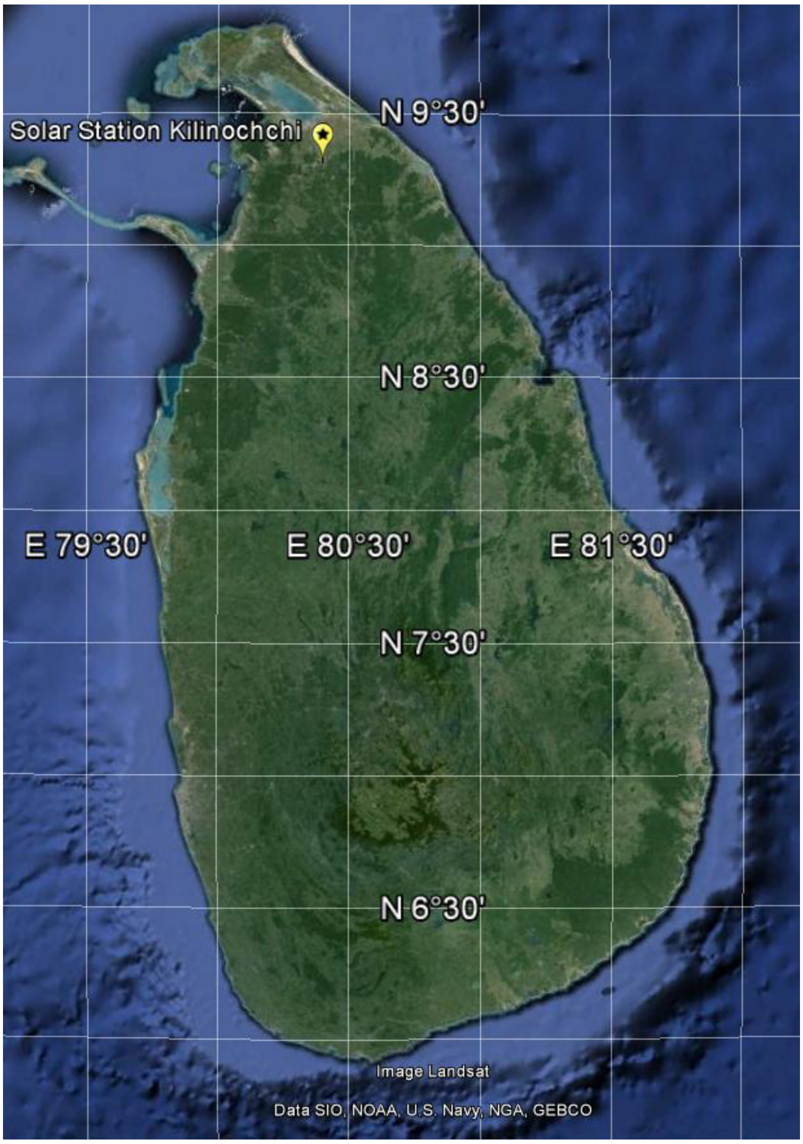
Location of the Station

The measurement site is located in the northern plains of the island at an elevation 48 m above sea level. The exact coordinates are Easting 44P 433972, Northing 1029301 (UTM WGS84). The site is surrounded by vegetated areas with shrubs and small trees. In southern direction lies a settlement with few scattered buildings. Pictures of the surroundings are shown in Figure 19 and Figure 20 and the geographical position is shown in Figure 21. The area does not have significant orographic features. Shadowing effects due to trees are not expected to be of relevant magnitude, as the sun crosses the horizon at steep angles.

Figure 19 - Solar Measurement Station Kilinochchi - View to East and North

Figure 20 - Solar Measurement Station Kilinochchi - View to South and West

Figure 21 - Location of Solar Measurement Station Kilinochchi.



Instrumentation

The measurement station is equipped with solar sensors and an additional meteorological mast with 4 m height. The solar measurement consist of two pyranometers of type Kipp & Zonen CMP11 (Figure 22) mounted on a solar tracker of type Kipp & Zonen SOLYS 2 (Figure 24). The sun tracker holds a shading ball which is masking the direct radiation from one of the pyranometers. The sun tracker position is controlled by a sun detector.

The solar equipment is mounted on a concrete foundation at 3 m height above the ground. The foundation also houses the logger and batteries contained in steel cabinets and two solar panels for energy supply are attached facing south (Figure 25).

Figure 22 - Pyranometer, Kipp & Zonen CMP11

Figure 23 - Silicon Sensor IMT Solar Si-13TC-K

Figure 24 - Sun Tracker Kipp & Zonen SOLYS 2

The meteorological mast is 4 m high and placed several meters from the solar equipment in eastern direction. Anemometer and wind vane (Figure 27) are mounted on a boom oriented in north-south direction, with the anemometer facing south. The mast also holds a silicon irradiance sensor and the combined thermo-hygro sensor. Details on the sensors and equipment are given in Table 4 and Table 5.

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Figure 25 - Assembly of Solar Measuring Station Kilinochchi

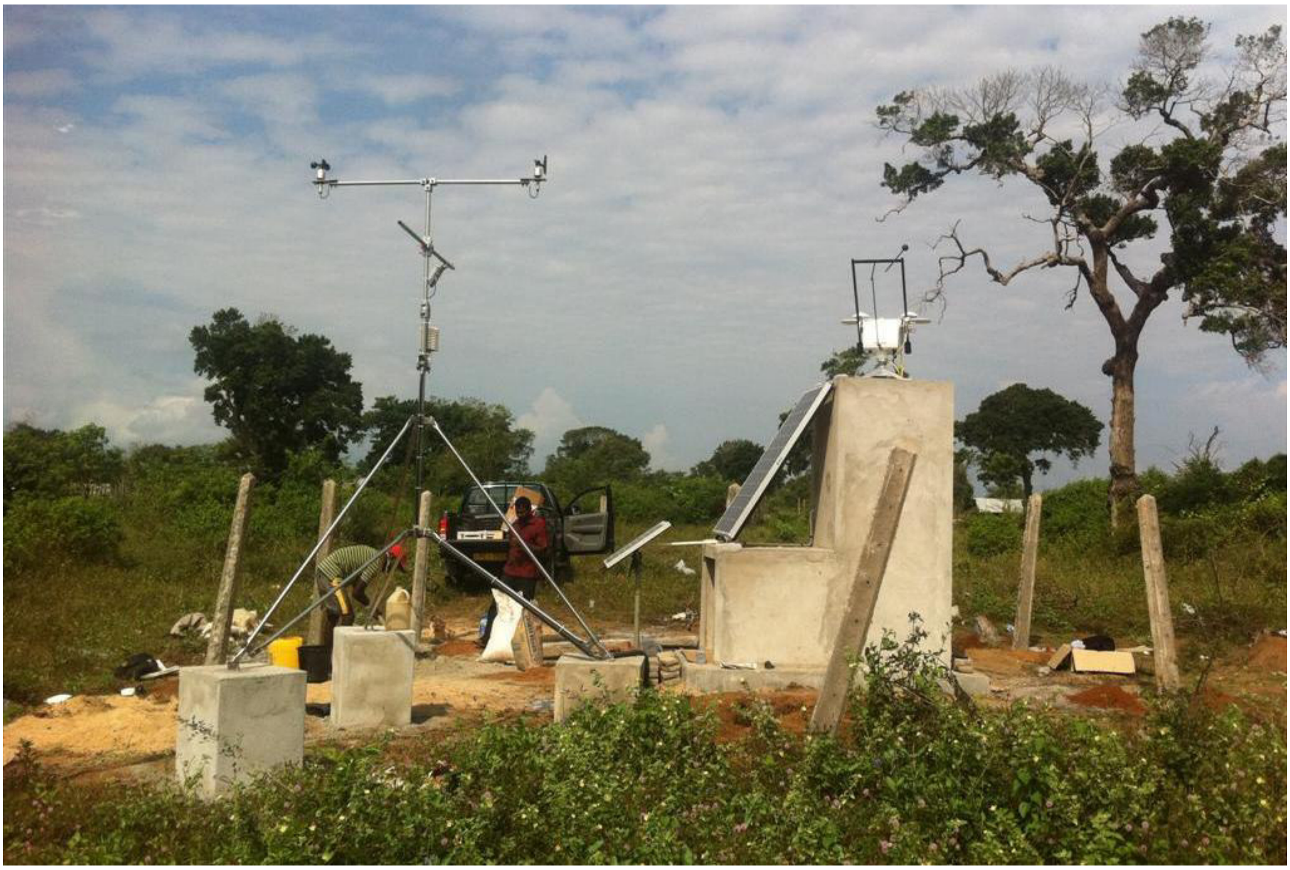

Figure 26 - Foundation with Steel Cabinet for Data Logger and Power Supply

Data acquisition, storing and transmission are accomplished by an Ammonit Meteo-40M (Ammonit, 2013) data logger which is placed in a steel cabinet where also the barometer is placed.

Table 4 - Sensors at Solar Station Kilinochchi

Sensor	Type	Parameter	Position	Height above ground	Orientation / Tilt Angle
Pyranometer	Kipp&Zonen CMP11	Global Horizontal Irradiation	Sun Tracker	3 m	Sun tracked / Horizontal
Pyranometer	Kipp&Zonen CMP11	Diffuse Horizontal Radiation	Sun Tracker	3 m	Sun tracked / Horizontal
Silicon Sensor	IMT Solar Si-13TC-K Plug	Irradiation / Voltage	Met Mast	3.5 m	South / 30°
Sun Sensor	Kipp&Zonen	Sun Position	Sun Tracker	3 m	Sun tracked / Sun tracked
Anemometer	Thies Compact	Wind Speed	Met Mast	4 m	South / -
Wind Vane	Thies Compact TMR	Wind Direction	Met Mast	4 m	North / -
Barometer	Setra Model 276 800-1100	Air Pressure	Logger Cabinet	2 m	-
Thermometer	Galltec KPC1/5	Temperature	Met Mast	3 m	West / -
Hygrometer		Relative Humidity	Met Mast	3 m	West / -

Table 5 - Additional Equipment at Solar Station Kilinochchi

Device	Type
Sun Tracker	Kipp&Zonen SOLYS 2
Data Logger	Ammonit Meteo-40M

The Pyranomer CMP11 (Kipp&Zonen, 2013a) of Kipp&Zonen is of “High Quality” according to WMO classification and “secondary Standard” according to ISO. It has a fast response time of 1.7 seconds and is therefore well suited to measure fast changes in irradiation due to variable cloud conditions. The sun tracker SOLYS 2 (Kipp&Zonen, 2013b) is equipped with a sun sensor to control the alignment of the shading ball. This guarantees the prevention of errors due to incorrect tracking. The SOLYS 2 has an integrated GPS which is used to acquire precise time and therefore eliminates the chance of clock drift errors.

Figure 27 - Anemometer and Wind Vane at Solar Station Kilinochchi

Figure 28 - Thermo-Hygro-Sensor with Radiation Shield

Figure 29 - Barometer

Measured and Calculated Parameters

Directly measured solar parameters are global horizontal irradiation (GHI) acquired by the first pyranometer and diffuse horizontal irradiation (DHI) acquired by the second pyranometer which is shaded by the sun tracking mechanism. From GHI and DHI the direct normal irradiation (DNI) can be calculated by use of the solar zenith angle at the time of measurement. This calculation is not done online as the SZA is not available to the data logger.

The silicon radiation sensor (IMT, 2013) is comparable to a solar cell with a voltage output proportional to the incoming solar radiation. Another term for it is reference cell as this kind of sensor has the same characteristics as a photovoltaic cell which might be installed for power generation at the prospected site. The output signal in volts could be transformed to solar power with specific calibration coefficients.

Data Transmission and Checking

Data is transmitted from the data logger to Ammonit data server three times per day. Via the Ammonitor web frontend registered users can access raw data and numerous visualizations of time series and status information. Ammonitor can be modified to create regular reports and distribute it by e-mail in various formats (e.g. PDF).

For data checking and analysis the data are transmitted to GEO-NET every day. Data is checked for completeness and different objective tests (range, variability, correlation) are performed to ensure correct measurement. Subjective control by GEO-NET staff is performed at least thrice a week. Irregularities and suspect values are marked and special events are stated in the station log.

Maintenance Recommendations

To assure the correct operation and high quality data a list of recommendations for regular and occasional maintenance is given. The basic measures to ensure correct measurements are described by the World Meteorological Organization in its recommendations for operational meteorological observations and measurements (WMO, 2012).

As the correct calibration of pyranometers is crucial for irradiation measurement, regular recalibration is essential. Various methods of calibration are described in the WMO document, e.g. the on-site comparison to a standard instrument (travelling working

standard) or the exchange of the pyranometer with a calibrated one. It is recommended that calibration takes place at least after two years.

A simple comparison can be regularly performed between two pyranometers if GHI and DHI is measured. In case of completely overcast conditions, no direct irradiation is existent and both pyranometers should record identical values. This method requires on-site observation of cloud conditions and either direct observation of the measurement signal (not the average values) or sufficiently long persistence of overcast sky conditions.

More possibilities for data control appear with the operation of a pyrheliometer, which would additionally provide redundant measurement of DNI.
WMO recommends at least daily inspection and cleaning of the pyranometer domes to prevent errors due to soiling. If this is not feasible as the measurement station is placed at a remote location, cleaning should be done as frequent as possible and a correction of data for soiling errors should be attempted (Geuder and Quaschnig, 2006).

At inspection an occasional check of levelling (integrated bubble level) of the pyranometer should be performed. All connector and cable should be inspected for correct fixation and damages. The pyranometers contain a chamber for desiccant which has to be replaced regularly to prevent condensation of moisture inside the instrument. The Kipp&Zonen CMP11 is equipped with a desiccant cartridge which can be replaced. The desiccant has a color indication, orange indicates normal conditions, colorless indicates that the desiccant has to be replaced.

Data Access and Format
The data logger manufacturer Ammonit provides online access to the measurement via a web interface (Ammonitor, or.ammonit.com). The data can be displayed and downloaded in various formats. The report is delivered with the so far measured data as a text file (comma separated values, .csv). The data in the file is organized in lines an row (Figure 30). Each line represents one datum, which is given in the first two rows (date, time). Measured values are given in rows. The first line is a header line, which gives the order (name and unit) of the measured parameters.

The averaging time step is 10 minutes, based on a sampling rate of 1 Hz (one value per second). Averaging is done internally in the logger. The stored values per 10 minute interval are average, maximum, minimum and standard deviation.

Figure 30 - An Extract of the Described Data File.

```
datetime,Anemometer;wind_speed;Avg (m/s),Anemometer;wind_speed;Max (m/s),Anemometer;wind_speed;Min (m/s),Anemometer;wind_
2013-03-15 03:24:08,2.367,4.1944,1.1864,0.6368,352,97.656,22.5617,352,80.097,83.6024,75.8477,1.8037,352,28.3075,28.4826,2
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2013-03-15 07:20:00,2.4602,4.796,1.3368,0.6581,600,81.8942,19.2238,600,79.0541,82.3908,76.8487,1.1418,600,26.8911,27.091,
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```

7.5.2 SOLEMI Data

DLR offers high quality time series based data for ground-irradiance, which already take into account influence of clouds and aerosol particles. Data are processed from Satellite images taken by the geostationary Meteosat satellites. Scans of the infrared and visible channel serve as main inputs for processing of SOLEMI data.

SOLEMI used worldwide for evaluation of solar resource applications and meets international standards. Data contain broadband Direct Normal Irradiation (DNI) + Global Horizontal Irradiation (GHI) for defined locations. For sites in Sri Lanka listed in table 6 SOLEMI data sets starting in the year 2000 and ending in 2011 were purchased. SOLEMI data are not available for the time after 2011 because the Satellite Meteosat 6 which delivered data for the Sri Lanka was taken out of service.

7.5.3 Sunshine Duration

Sunshine duration is measured traditionally with the Campbell-Stokes recorder. It is a spherical lens which focuses a light beam onto a paper strip. If direct sunshine falls onto the lens, the beam is strong enough to burn a line into the paper. The sunshine duration is evaluated by measuring the length of the burned lines.

The signal of the Campbell-Stokes recorder cannot be directly transferred to an irradiation parameter. But comparison of different models in use showed that the registration corresponds to values of direct irradiation between about 100 and 150 W/m^2. Therefore the WMO defined that sunshine is registered if the value of direct normal irradiation exceeds 120 W/m^2.

Many different sensor types for measuring sunshine duration are now commercially available which refer to this definition.

7.6 Evaluation of Data

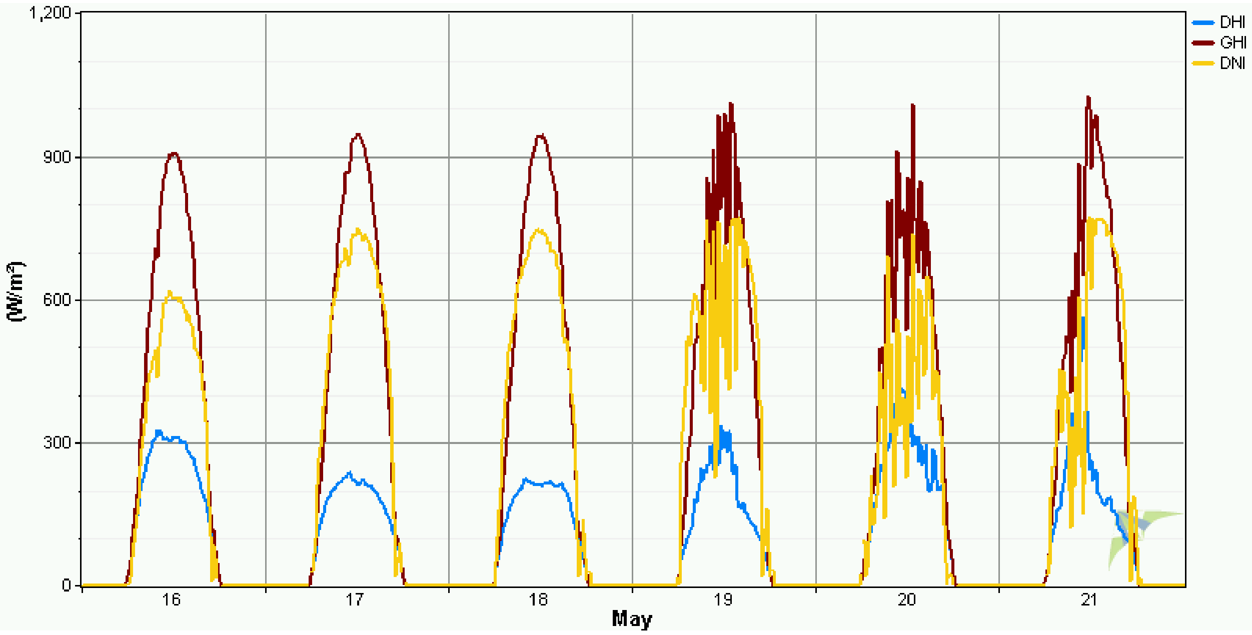
This section presents evaluations of the available data sources. It gives key figures on the relevant irradiation parameters like monthly sums and diurnal profiles. Data of the solar measurement station at Kilinochchi are only presented for months with full data coverage.

7.6.1 Solar Measurement at Kilinochchi

The measurement station at Kilinochchi is equipped with high precision irradiation sensors (measuring GHI and DHI) and additional meteorological sensors (wind, temperature, humidity, pressure). It delivers high quality data for an accurate determination of the local solar climate.

The station was brought into service on 15 March 2013. The data coverage is complete except for wind direction. From 17th March to 18th April no wind speed data are available due to a defective fuse. Missing data of wind speed and direction are not crucial for the evaluations below. Figure 31 depicts GHI, DHI and DNI for six consecutive days at the measurement station in Kilinochchi.

Figure 31 - Sample Time Series of GHI, DHI and DNI for Six Consecutive Days



To characterize the local conditions at least one year of measurement is necessary to cover the complete seasonal variation. Due to the high inter-annual variability of solar radiation long-term averages can only be calculated after several years of measurement.

Direct Normal Irradiation is that fraction of incoming solar radiation which would be detected by a sensor normal to the direction of direct sunlight. DNI is high, if the path is not obscured by clouds and if few radiation is scattered or absorbed by particles. DNI is not measured directly (pyrheliometer) at Kilinochchi, but it is calculated from measured DHI and GHI with the aid of the solar zenith angle (SZA). The employed relationship (WMO, 2012: Eq. 8.2) is:

$$DNI = (GHI - DHI) / \cos SZA$$

Table 6 - Monthly Sums of Irradiation Parameters

Parameter	May	June	July	August
GHI (kWh/m²)	177.5	171.9	168.3	179.2
DHI (kWh/m²)	84.3	92.4	87.4	78.0
DNI (kWh/m²)	119.8	102.8	103.0	129.4
SD (hours)	266 / 8.6 / 0 / 12	241 / 8.0 / 2 / 11	222 / 7.2 / 0, 11	264 / 8.5 / 1 / 12

Figure 32 - Monthly Mean Diurnal Cycle of GHI (Brown), DHI (Blue) and DNI (Yellow) at Measurement Station Kilinochchi

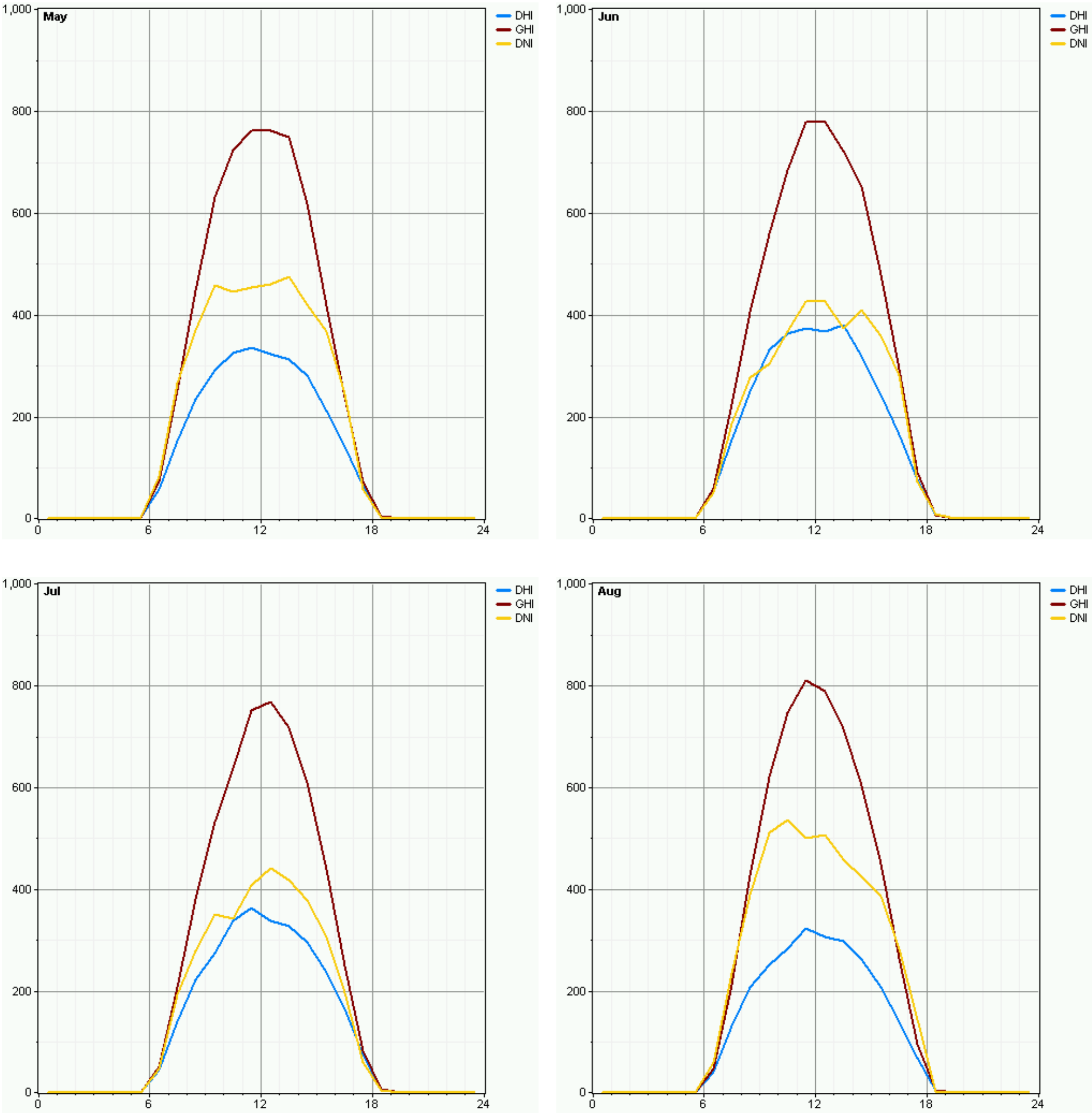


Table 7 - Monthly Values (mean. maximum. minimum) of Hourly Values of Meteorological Parameters

Parameter (mean / min / max)	May	June	July	August
Wind Speed (m/s)	**3.2** 0.0 7.4	**3.9** 1.2 7.2	**3.8** 0.0 7.5	**2.9** 0.0 7.4
Temperature (°C)	**28.9** 21.9 36.6	**28.7** 24.6 35.7	**28.5** 24.1 37.0	**28.2** 21.9 36.2
Relative Humidity (%)	**79.8** 31.8 100.0	**75.2** 43.1 95.4	**73.6** 33.0 94.8	**74.6** 41.0 99.3
Pressure (hPa)	**1003.0** 998.8 1006.1	**1002.6** 997.7 1007.3	**1002.8** 999.3 1007.5	**1003.7** 1000.2 1007.2

Figure 33 - Monthly Mean Diurnal Cycle of Wind Speed (V_avg, blue solid line) and Wind Direction (Dir_avg, green solid line) at Measurement Station Kilinochchi

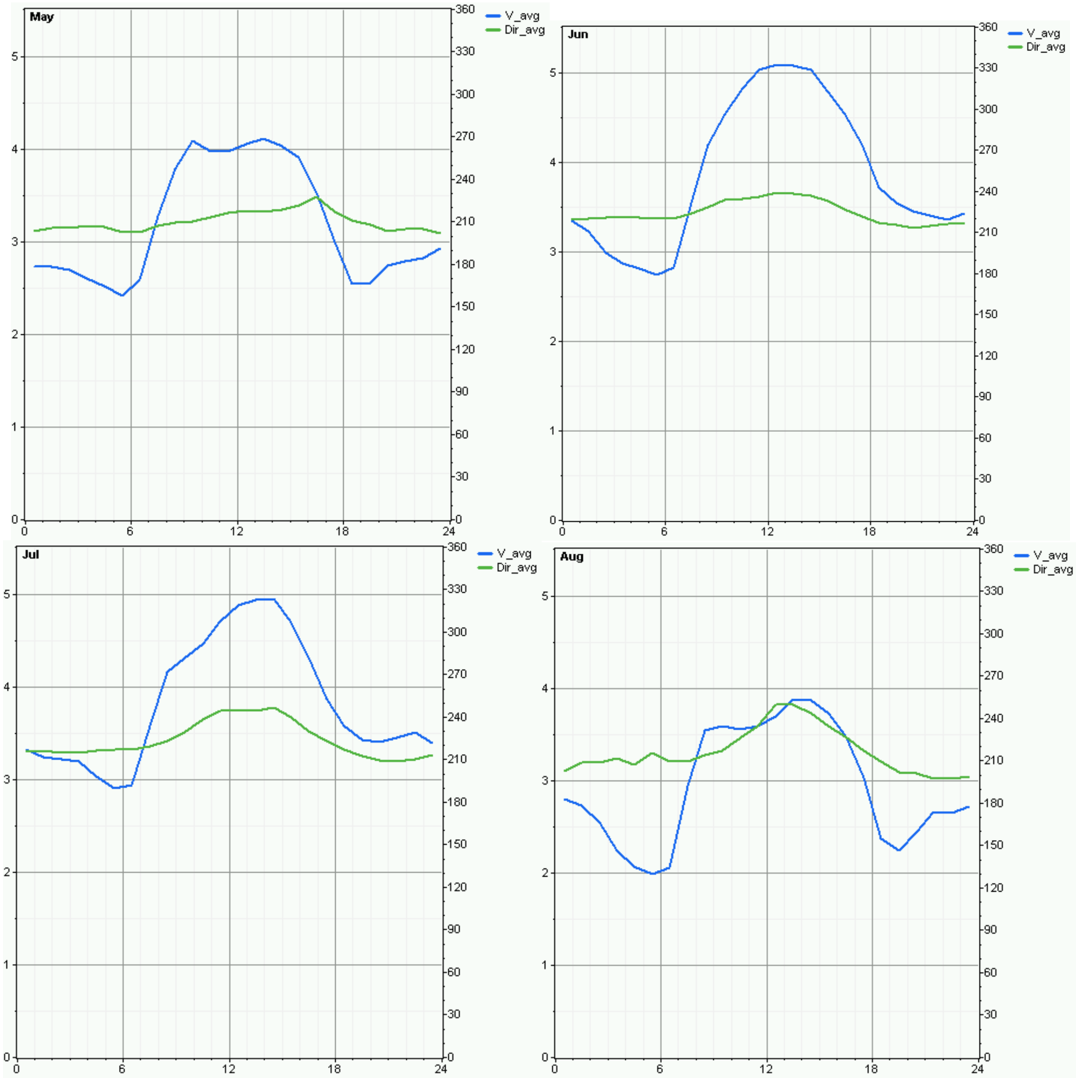


Figure 34 - Monthly Mean Diurnal Cycle of Temperature (T_avg, red solid line) and Relative Humidity (RH_avg, Yellow Solid Line) at Measurement Station Kilinochchi

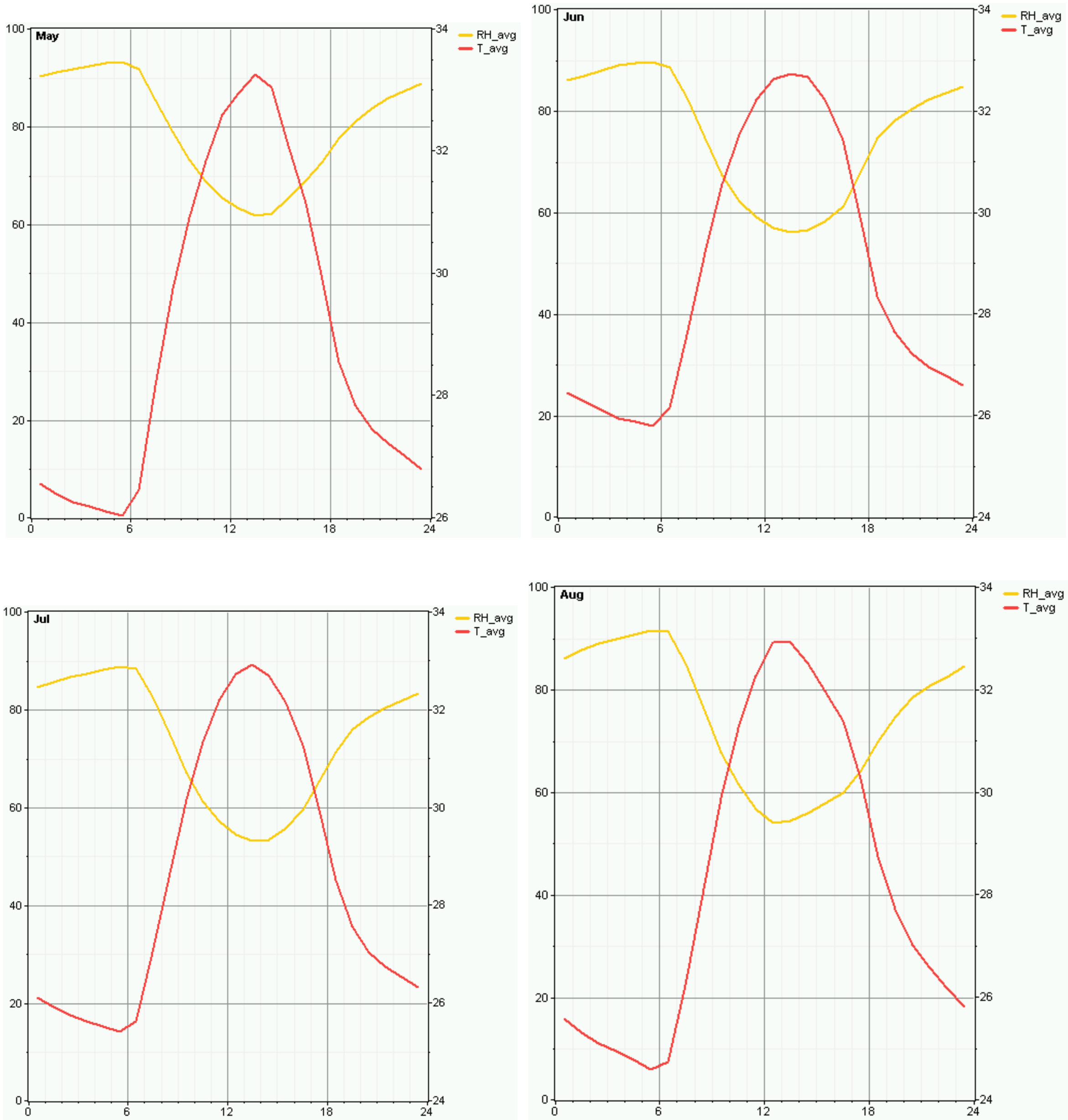


Figure 35 - Figure 37 show examples of individual days from the measurement. Figure 35 (17 August 2013) depicts mixed solar conditions. The correlation between GHI and DNI is obvious. Figure 36 shows a day with overall clear conditions - DNI is near optimum and DHI is low. A day with overcast conditions is depicted Figure 37 - GHI and DHI have the same level and the direct component is very low.

Figure 35 - Measurement Example of Typical Day with Mixed Conditions

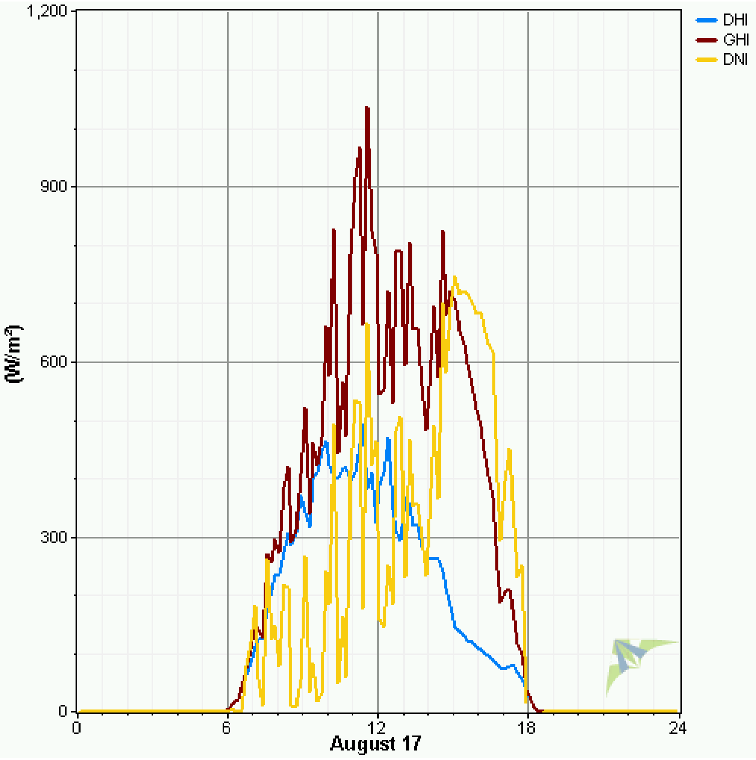


Figure 36 - Measurement Example of Typical day with Clear Conditions

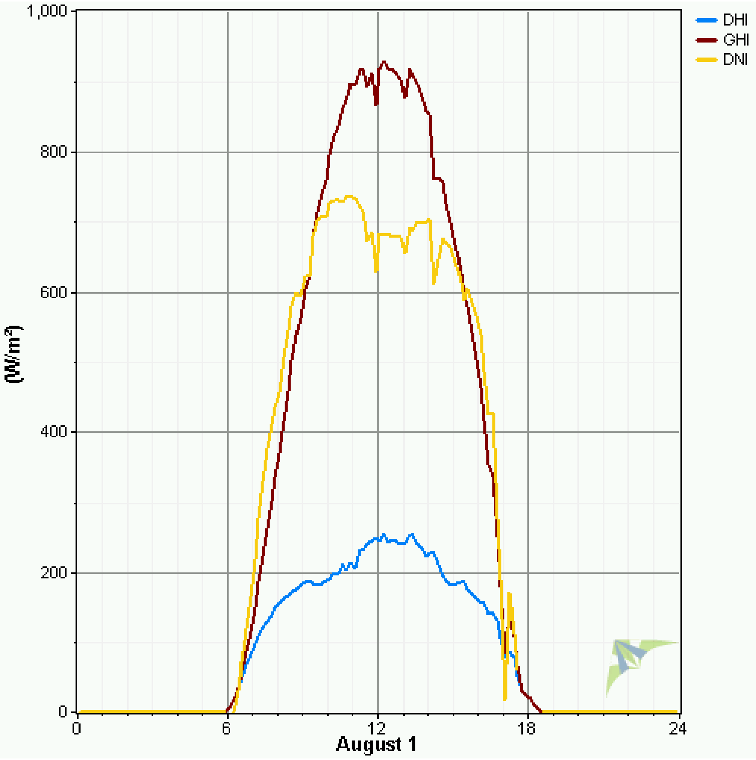
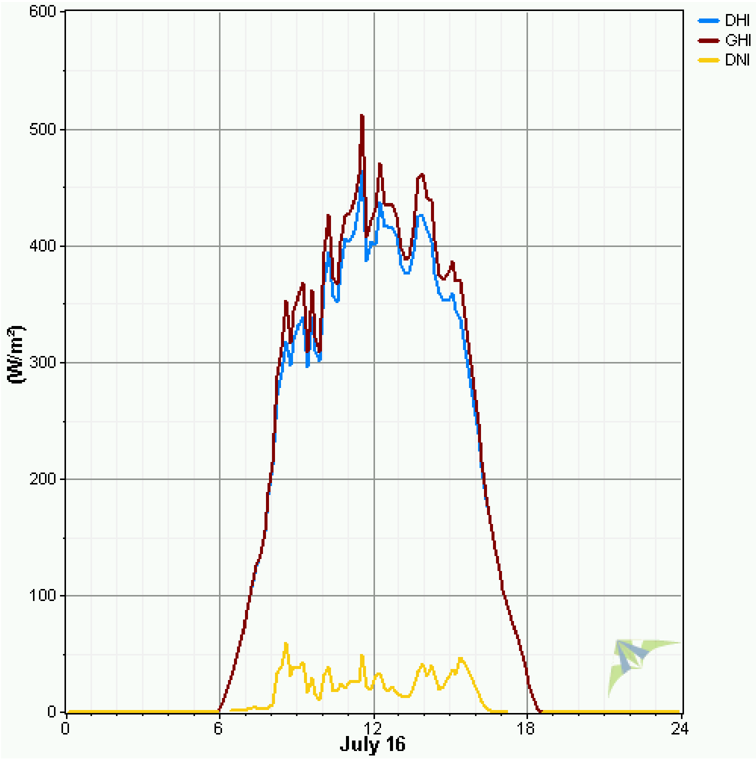


Figure 37 - Measurement Example of a Typical Day with Overcast Conditions



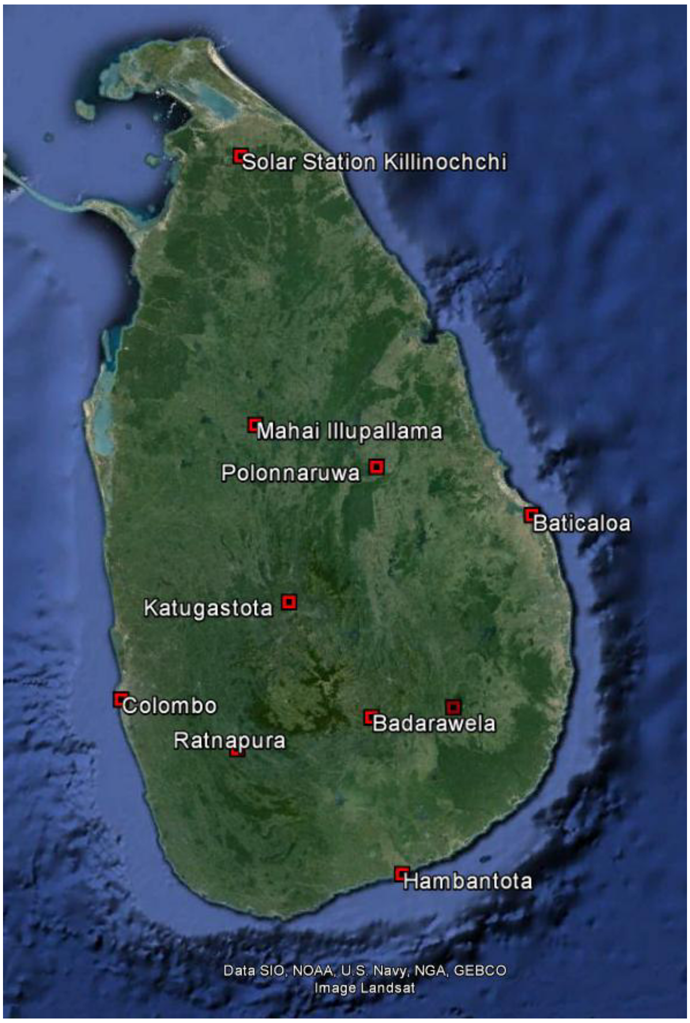
7.6.2 SOLEMI Data

SOLEMI time series were obtained for ten locations covering Sri Lanka, including the location of the solar measurement at Kilinochchi. Each time series is representative for a 1x1 km grid cell. The locations were chosen to be representative for the different conditions of Sri Lanka and to fit to the six stations where time series of sunshine duration data is available. The coordinates and heights are given in Table 8 and the geographical location is depicted in Figure 38.

Table 8 - Locations of SOLEMI Time Series

Location	Geographical Coordinates (WGS84)		Height a.s.l.	Time Span
	Latitude	Longitude		
Bandarawela	6.824	80.984	1180 m	2000 - 2011
Batticaloa	7.717	81.700	10 m	
Colombo	6.900	79.867	14 m	
Hambantota	6.125	81.120	13 m	
Katugastota	7.334	80.617	480 m	
Mahai Illupalama	8.117	80.467	120 m	
Station Kilinochchi	9.311	80.399	48 m	
Monaragala	6.867	81.348	160 m	
Polonnaruwa	7.931	81.007	50 m	
Ratnapura	6.683	80.386	50 m	

Figure 38 - Locations of SOLEMI Time Series



Yearly sums of the parameters GHI, DHI and DNI were calculated. The average, maximum and minimum for GHI and DNI are given in Table 9 and Table 10. Sums for individual years for the station at Kilinochchi can be extracted from Figure 41. Figures for all stations are presented in the detailed data set provided with the final report.

Table 9 - Yearly sums of Global Horizontal Irradiance GHI (kWh/m²) for the SOLEMI Data Points

Location	Average GHI	Maximum GHI	Minimum GHI
Bandarawela	1858 kWh/m²	1935 kWh/m²	1764 kWh/m²
Batticaloa	2226 kWh/m²	2169 kWh/m²	2259 kWh/m²
Colombo	2155 kWh/m²	2223 kWh/m²	2093 kWh/m²
Hambantota	2239 kWh/m²	2291 kWh/m²	2241 kWh/m²
Katugastota	1940 kWh/m²	1975 kWh/m²	1868 kWh/m²
Mahai Illupalama	2181 kWh/m²	2187 kWh/m²	2148 kWh/m²
Station Kilinochchi	2146 kWh/m²	2148 kWh/m²	2103 kWh/m²
Monaragala	2079 kWh/m²	2134 kWh/m²	2021 kWh/m²
Polonnaruwa	2161 kWh/m²	2209 kWh/m²	2165 kWh/m²
Ratnapura	1924 kWh/m²	1973 kWh/m²	1872 kWh/m²

Table 10 - Yearly Sums of Direct Normal Irradiance DNI (kWh/m^2) for the SOLEMI Data Points

Location	Average DNI	Maximum DNI	Minimum DNII
Bandarawela	1338 kWh/m^2	1336 kWh/m^2	1217 kWh/m^2
Batticaloa	1943 kWh/m^2	1944 kWh/m^2	1815 kWh/m^2
Colombo	1793 kWh/m^2	1911 kWh/m^2	1640 kWh/m^2
Hambantota	2002 kWh/m^2	2096 kWh/m^2	1997 kWh/m^2
Katugastota	1398 kWh/m^2	1481 kWh/m^2	1264 kWh/m^2
Mahai Illupalama	1735 kWh/m^2	1848 kWh/m^2	1642 kWh/m^2
Station Kilinochchi	1749 kWh/m^2	1851 kWh/m^2	1678 kWh/m^2
Monaragala	1642 kWh/m^2	1733 kWh/m^2	1507 kWh/m^2
Polonnaruwa	1802 kWh/m^2	1872 kWh/m^2	1706 kWh/m^2
Ratnapura	1354 kWh/m^2	1449 kWh/m^2	1268 kWh/m^2

Table 11 - Monthly sums of GHI of SOLEMI (2000 – 2011) and the measurement at Kilinochchi (2013) for the month May to August.

ear	May	June	July	August
2000	209,2 kWh/m^2	184,1 kWh/m^2	200,9 kWh/m^2	184,4 kWh/m^2
2001	220,6 kWh/m^2	182,3 kWh/m^2	182,2 kWh/m^2	207,8 kWh/m^2
2002	209,3 kWh/m^2	191,9 kWh/m^2	212,6 kWh/m^2	201,7 kWh/m^2
2003	184,2 kWh/m^2	209,3 kWh/m^2	178,3 kWh/m^2	181,5 kWh/m^2
2004	173,1 kWh/m^2	205,1 kWh/m^2	198,6 kWh/m^2	202,2 kWh/m^2
2005	212,8 kWh/m^2	194,0 kWh/m^2	192,4 kWh/m^2	212,9 kWh/m^2
2006	206,3 kWh/m^2	205,0 kWh/m^2	200,5 kWh/m^2	216,3 kWh/m^2
2007	213,5 kWh/m^2	158,7 kWh/m^2	186,9 kWh/m^2	200,1 kWh/m^2
2008	225,0 kWh/m^2	204,0 kWh/m^2	205,6 kWh/m^2	181,4 kWh/m^2
2009	199,5 kWh/m^2	210,7 kWh/m^2	199,9 kWh/m^2	197,5 kWh/m^2
2010	202,8 kWh/m^2	197,3 kWh/m^2	199,1 kWh/m^2	183,3 kWh/m^2
2011	218,4 kWh/m^2	203,1 kWh/m^2	201,3 kWh/m^2	197,0 kWh/m^2
Kilinochchi - May to Aug, 2013	177.5 kWh/m^2	171.9 kWh/m^2	168.3 kWh/m^2	179.2 kWh/m^2

Figure 39 - Monthly Irradiance Sums for Solar Measurement Station Kilinochchi

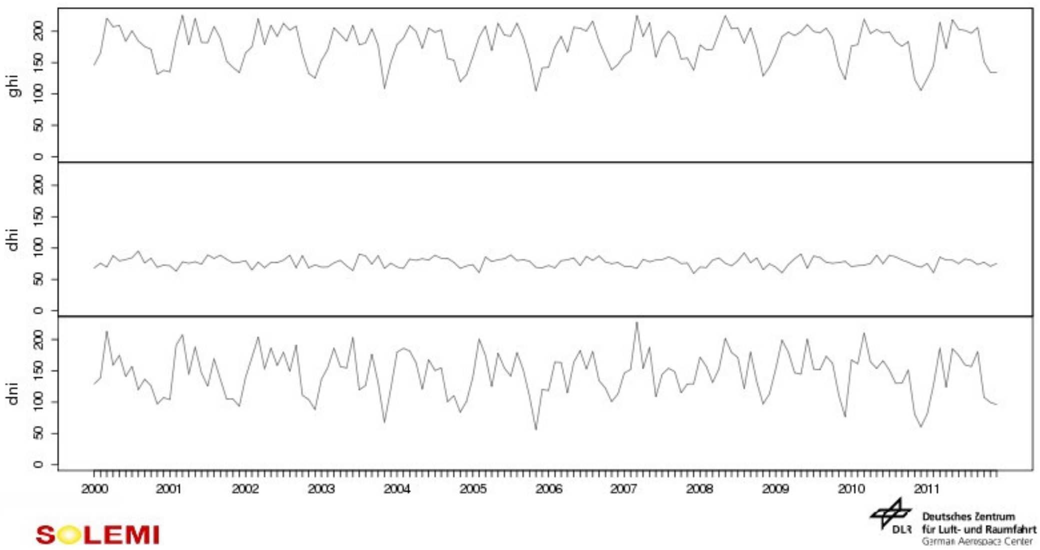


Figure 40 - Annual Cycle of Monthly Irradiance Sums for Solar Measurement Station Kilinochchi

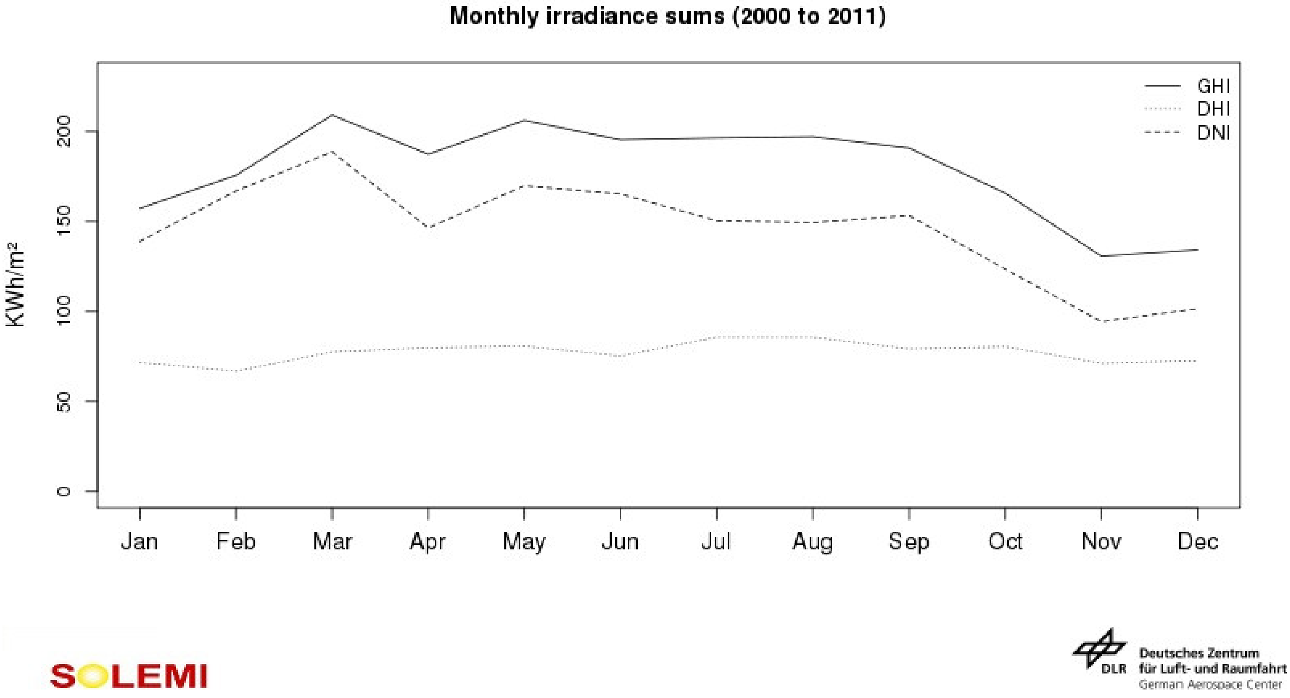


Figure 41 - Annual Irradiance Sums for Solar Measurement Station Kilinochchi

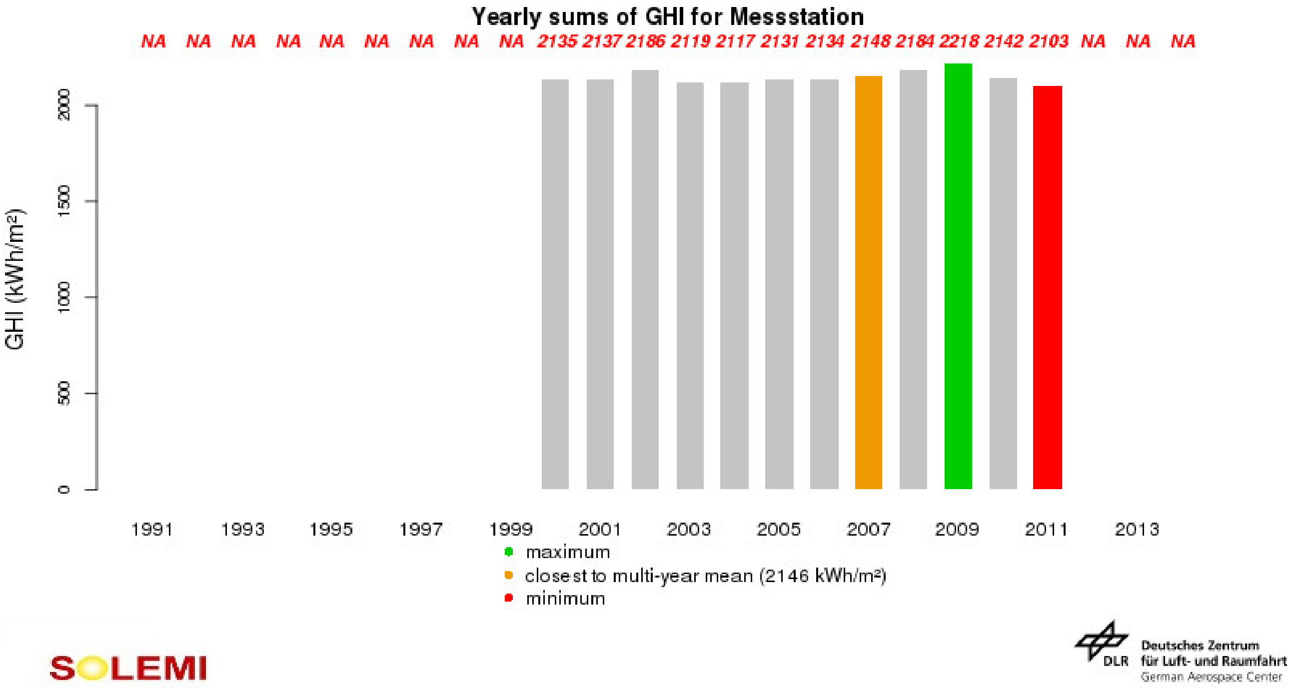


Figure 42 - Hourly Monthly Mean of Global Horizontal Irradiation (GHI) for Solar Measurement Station Kilinochchi

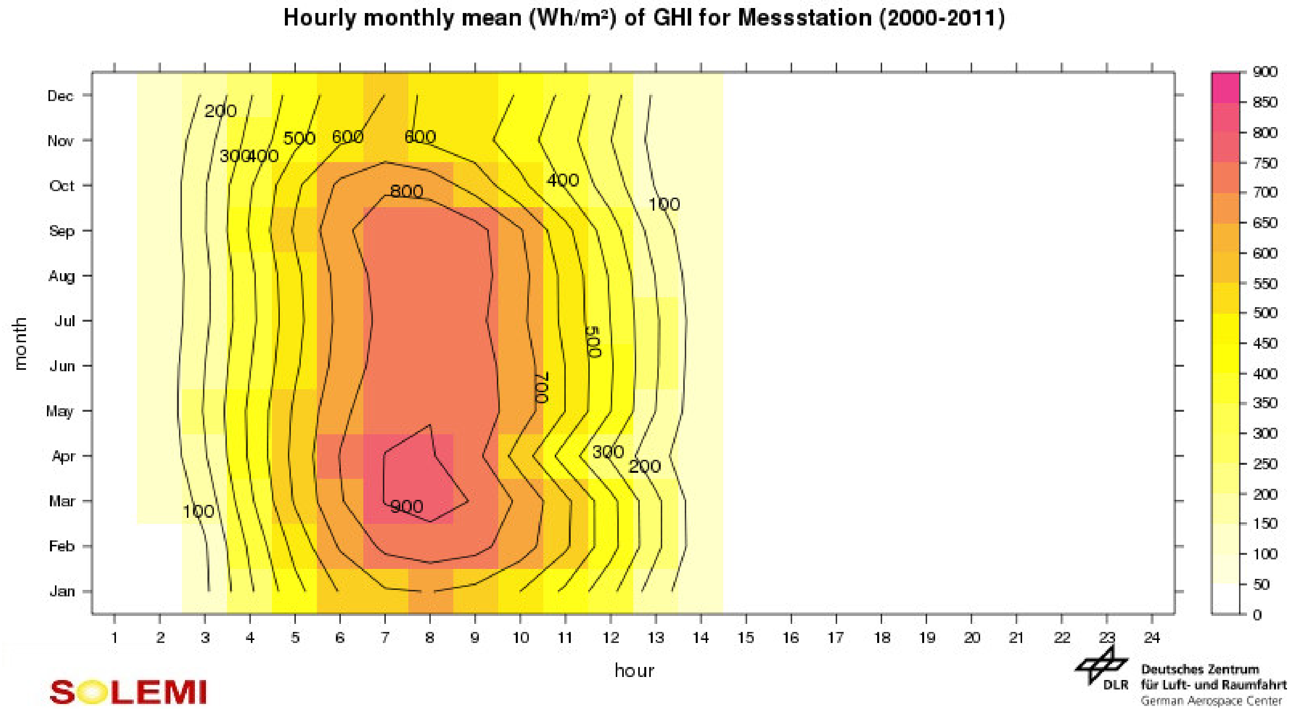


Figure 43 - Frequency Distribution of Global Horizontal Irradiation (GHI) for Solar Measurement Station Kilinochchi

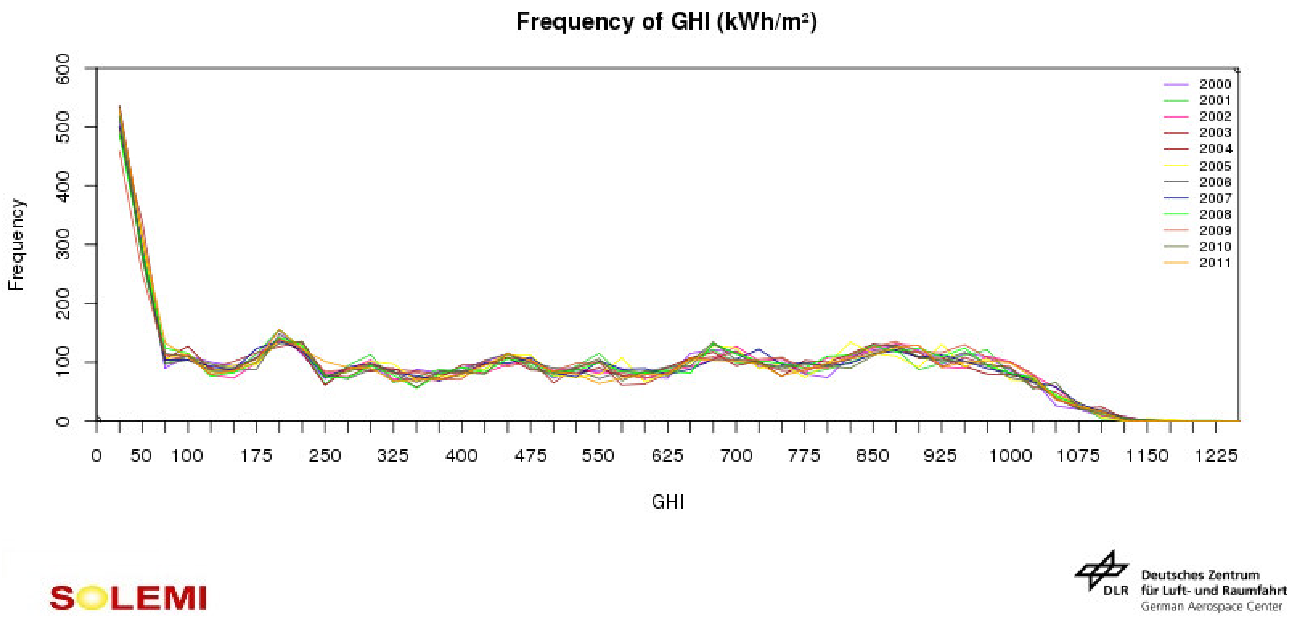


Figure 44 - Figure 45 show cumulative distribution functions (CDF) of GHI and DNI based on SOLEMI data. Shown are average CDF of daily irradiation sums for individual months. For the month May to August in which direct measurements are available, CDF of GHI is presented in Figure 46.

Figure 44 - Average Monthly Cumulative Frequency Distribution of Daily Sums Global Horizonatal Irradiation (GHI) from SOLEMI Data at Kilinochchi

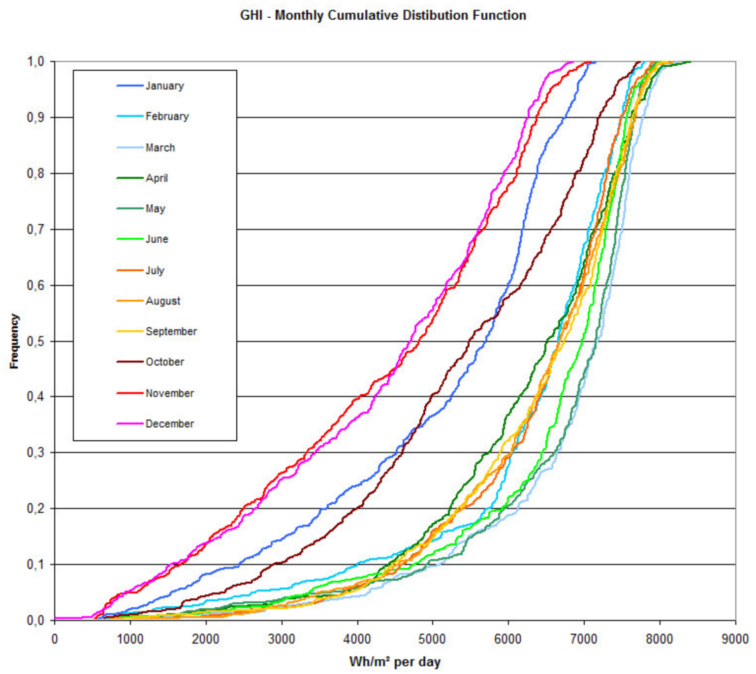


Figure 45 - Average Monthly Cumulative Frequency Distribution of Daily Sums Direct Normal Irradiation (DNI) from SOLEMI data at Kilinochchi

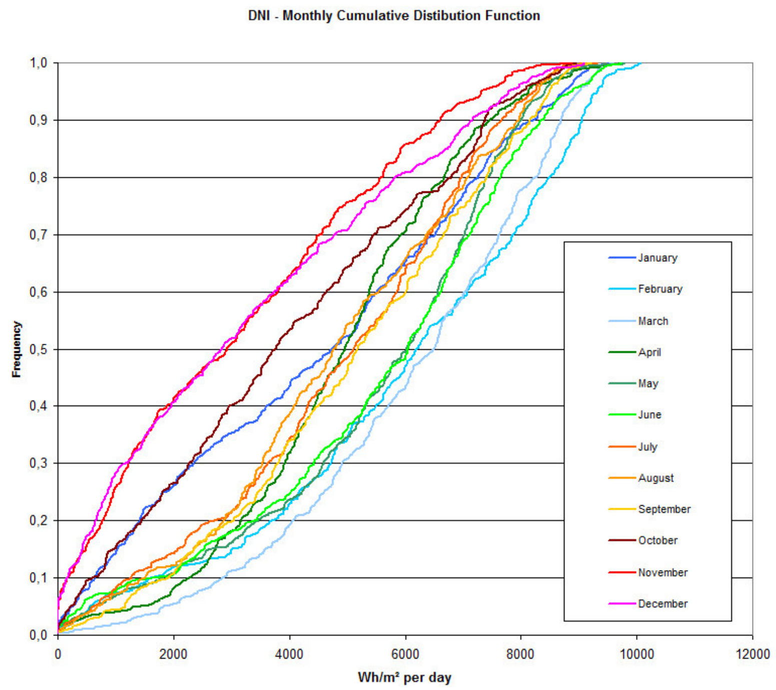
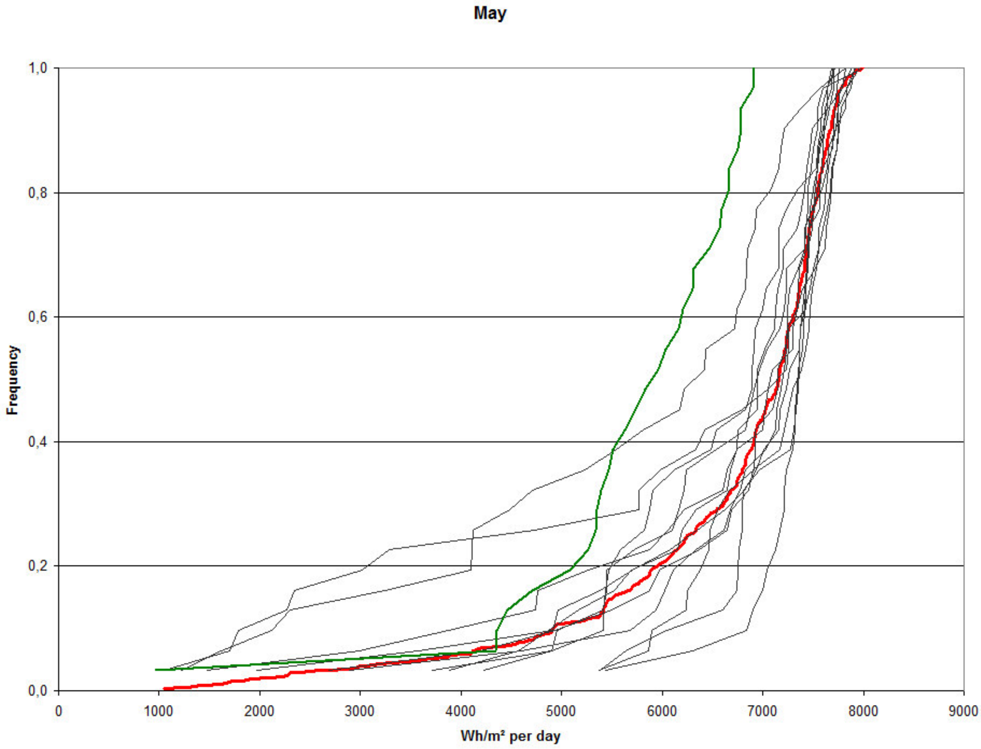
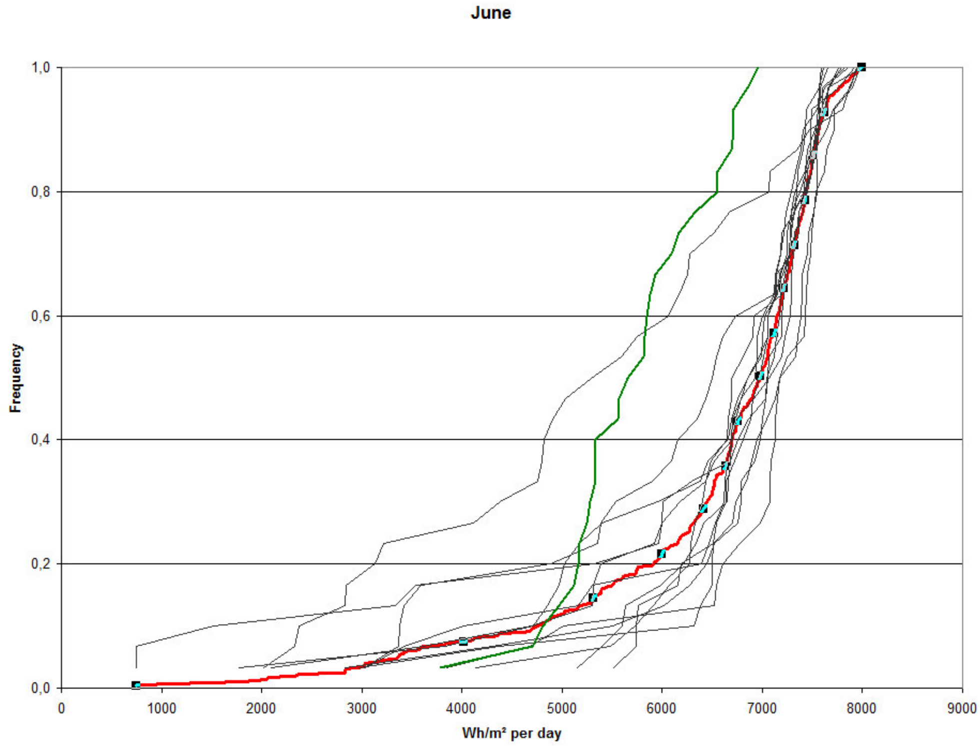
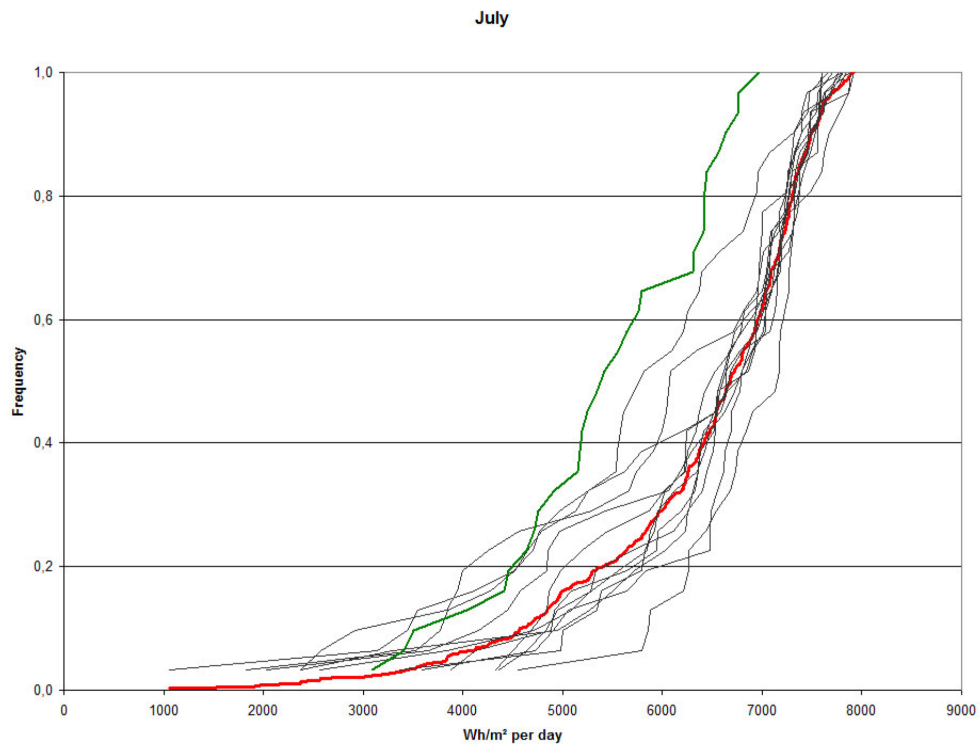


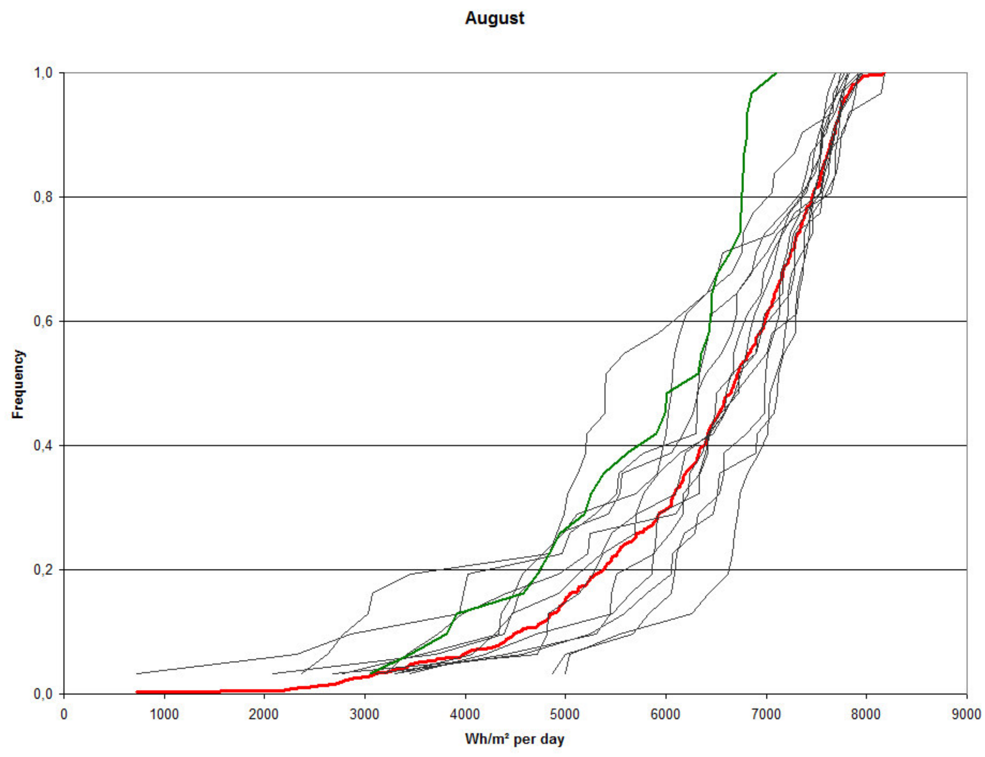
Figure 46 - Monthly (May - August) Cumulative Frequency Distribution of Daily Sums Global Horizontal Irradiation (GHI) from SOLEMI

(Red: average, black: individual years) and measured data (green) at Kilinochchi







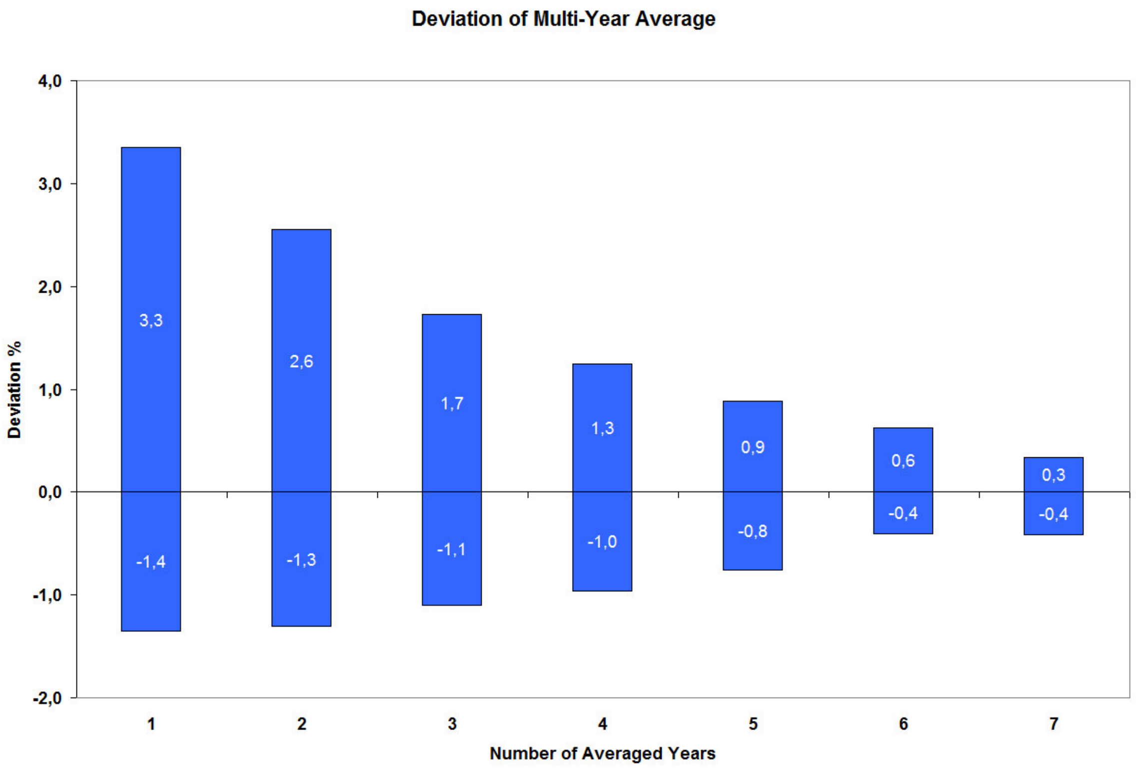


The Cumulative Frequency Distribution Curves (CFDC), provide an insight to solar radiation analysis in a general sense. Studies in solar radiation analysis have indicated that a direct comparison of them for different locations on monthly time scales could show how best the clearness indices of different locations could be linked to each other which is an important parameter in many radiation correlations established, how best general weather at locations could be compared thus providing the potential of making up for any deficient

radiation data for locations where less radiation information is available and in addition, to form the basis for many semi empirical solar system design methods such as the Utilizability method.

To get an estimation of inter-annual variability of irradiation, running means of annual sums of GHI with different numbers of averaged years are computed. This may reflect after how many years of measurement a representative long-term average is to be expected (see Figure 47). It can be shown in this case that the deviation of an individual year can be up to 3.3 % of the long-term average. After 5 years of measurement, the error of the measurement lies within one percent of the long-term value. It has to be recognized that the statistical significance of this estimation is low as the number of years is only 11 and a stable climatic average is assumed to be reached after about 30 years of measurement.

Figure 47 - Convergence of Multi-year Running Averages to Long-Term Average of GHI from SOLEMI at Kilinochchi



It has to be pointed out, that satellite data cannot replace in-situ measurements, as the temporal and spatial resolution cannot reach the representativeness of a ground based measurement. Satellite data cannot substitute measurements because certain applications deserve high temporal resolution, e.g. determination of rampage conditions due to fast changes in cloud cover which can occur on time scales of minutes or less.

7.7 Comparison of Sunshine Duration Observation and SOLEMI

Observations of sunshine duration were available from 6 stations in Sri Lanka. The measurement of sunshine duration at the given stations was done by a Campbell-Stokes recorder. Time series if daily sums are reported for the years 2000 to 2010. The stations Monaragala and Polonnaruwa have only records for the years 2009 and 2010. Annual cycles of monthly sums of sunshine hours are displayed in Figure 48 to Figure 53. Comparison with SOLEMI data show good agreement with the temporal characteristics but also an offset which changes significantly with time for most stations. Sources of error manifold, but highest uncertainty lies in the sensitivity of the Campbell-Stokes recorder and the evaluation of the recordings. It cannot be excluded that SOLEMI has varying uncertainty in regard to cloud properties in the course of the year.

Figure 48 - Annual cycle of Sunshine Duration, Comparison of SOLEMI and Observation at Bandarawela

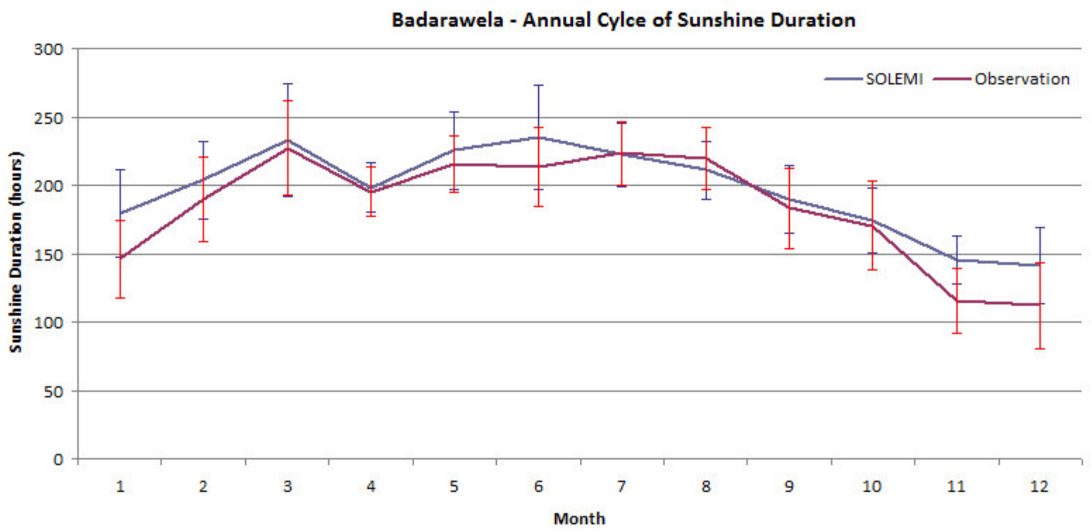


Figure 49 - Annual Cycle of Sunshine Duration, Comparison of SOLEMI and Observation at Katugastota

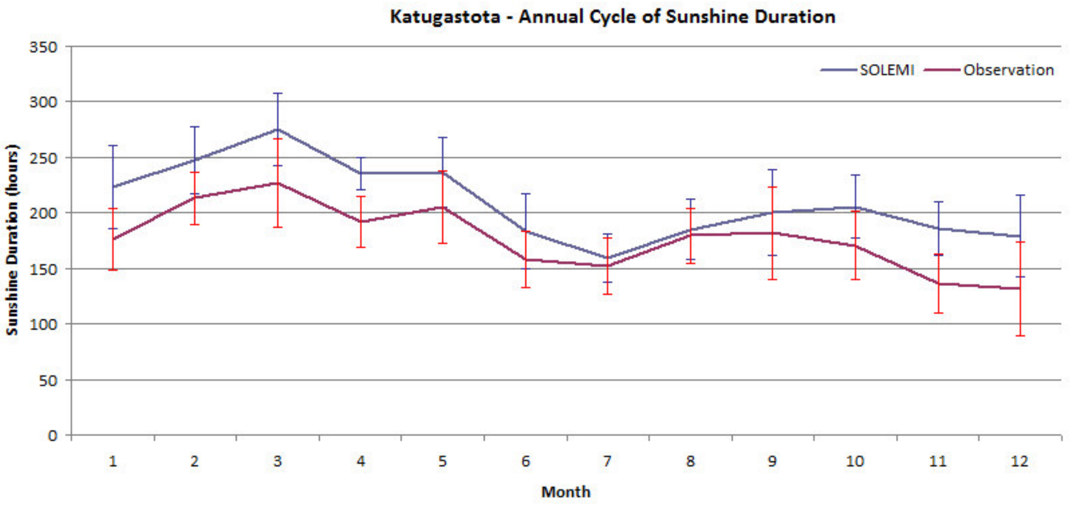


Figure 50 - Annual Cycle of Sunshine Duration, Comparison of SOLEMI and Observation at Mahailluppallama

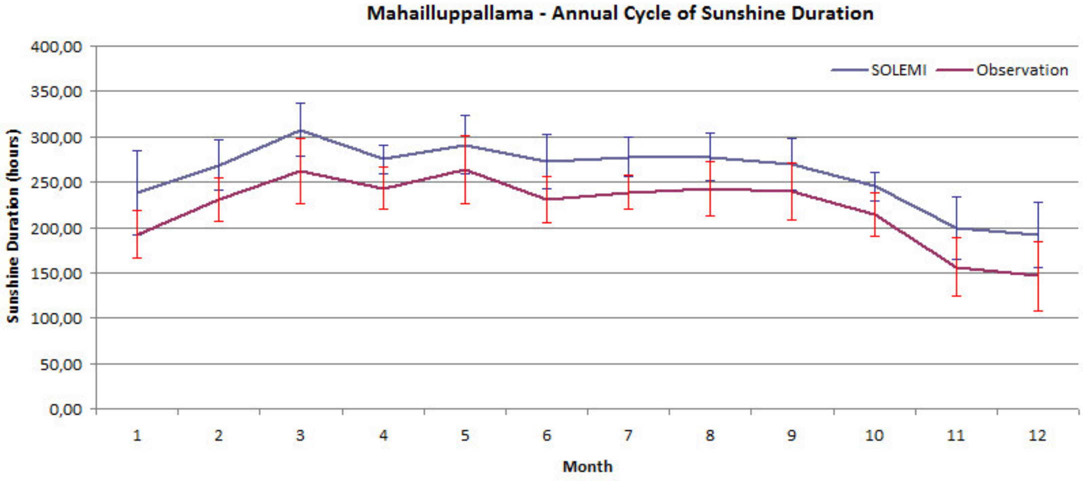


Figure 51 - Annual Cycle of Sunshine Duration, Comparison of SOLEMI and Observation at Monaragala

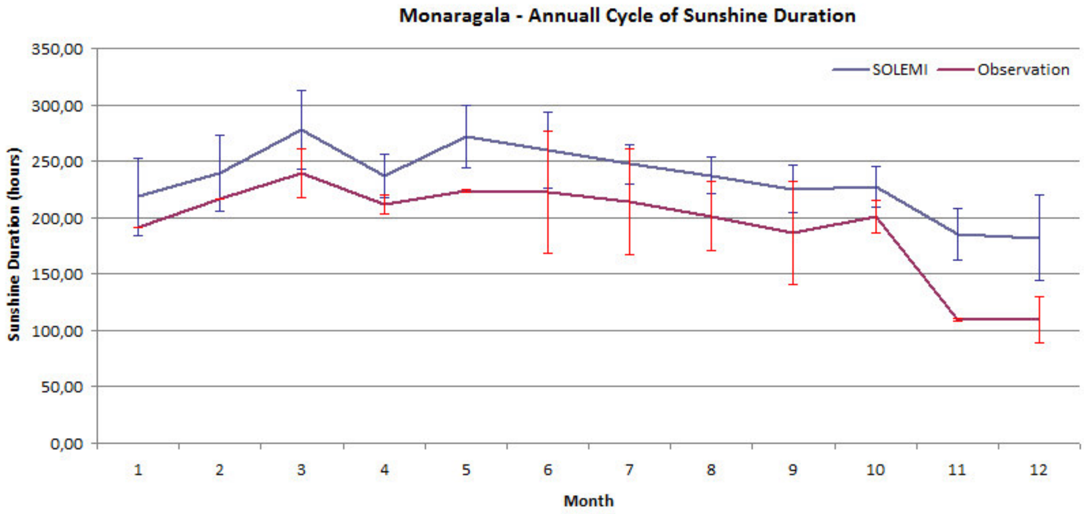


Figure 52 - Annual Cycle of Sunshine Duration, Comparison of SOLEMI and Observation at Polonnaruwa

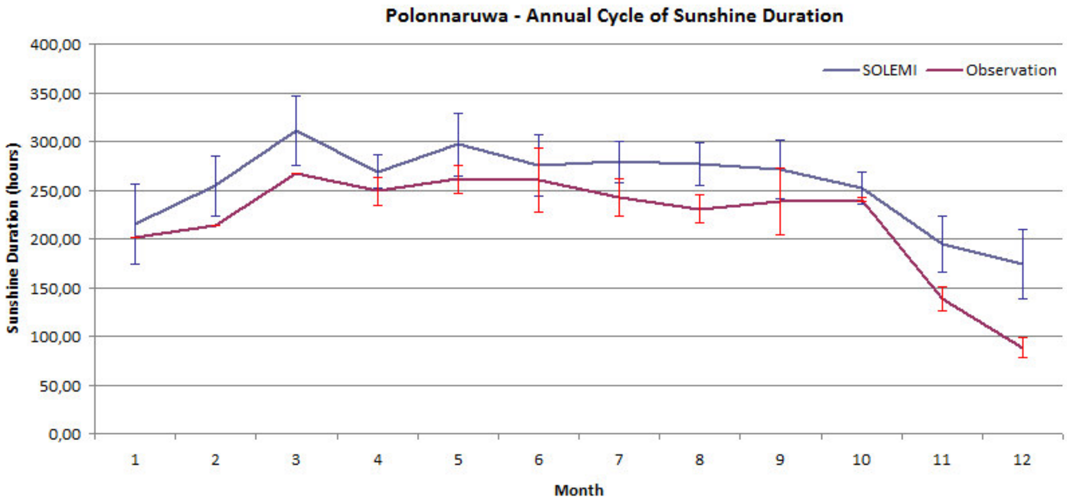
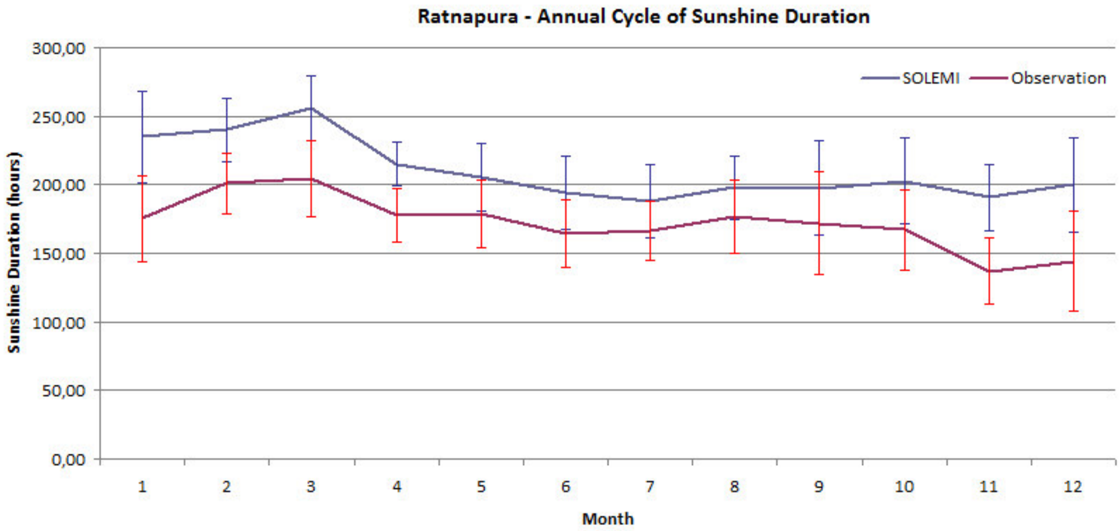


Figure 53 - Annual Cycle of Sunshine Duration, Comparison of SOLEMI and Observation at Ratnapura



7.8 Typical Meteorological Year

A Typical Meteorological Year is a representation of average conditions of meteorological parameters, especially GHI and DHI. It is a widely used input tool for modelling solar energy systems and solar properties of buildings.

Average conditions in this case do not refer to temporal averages but are meant as the most probable realisation of the meteorological parameters. A typical meteorological year is presented as a one year long time series of different parameters. The constructions bases on the so called Sandia method, developed at Sandia Laboratories.

The TMY time series is a concatenation of individual real months from the data base. The selection of the months bases on different parameters and is a processed in different steps. The NREL/Sandia method takes into account global horizontal irradiation, direct normal irradiation, temperature, humidity (dew point temperature) and wind speed. The TMY can contain more parameters, but these are strongly related to the radiative conditions and are therefore essential for characterising the typical months.

The months are selected by analyzing the cumulative distribution function (CDF) of the chosen parameters. Five months which are closest to the long term average are selected. These candidate months are checked for persistence of meteorological conditions. The number of consecutive warm days, consecutive cool days and consecutive low radiation days is computed and the months with highest values of the numbers are discarded. The residual months are ranked according to their CDF and the one closest to the mean is selected. After concatenation the time series are smoothed at the month interfaces to get continuous transitions.

7.9 Estimated Electricity Generation

In view of understanding the impact on the estimation of the amount of electricity generated at site using measured data and the corresponding SLOEMI based TMY data at the location, a simulation analysis has been carried out using RETSCREEN software *(www.retscreen.net)*. This analysis takes into account the measured data for the months of March to September 2013 and the corresponding TMY data envisaging a standard 1MWp polycrystalline solar photovoltaic installation with best practiced technical specifications with reference to related energy generation equipment with standard installation procedures (Table 12).

Table 12 - Comparison of Simulated Monthly Electricity Generation (MWh) Using Measured and TMY Data for Killinochchi for the Months of March to September 2013

Month	March	April	May	June	July	August	Sept	Total
Based on measured data	171.0	147.8	148.4	142.2	140.6	151.3	144.0	1045.3
Based on TMY data	188.5	167.5	164.5	157.0	163.0	179.7	151.8	1172.6

Above analysis shows that TMY data has over-estimated the electricity generation by 12% as compared to estimates derived from ground-based measured data

7.10 Conclusion

Using the results of the present study it is possible to characterize the solar climate in Sri Lanka with a high precision and on the current state of technology. For regions where a TMY was calculated a representative seasonal pattern considering the (uneven) cloud distribution over Sri Lanka gives a basis for development of solar energy. Using time series of SOLEMI data it was possible to check the validity of ground based measurements for sun shine duration data. Since two independent approaches were used, it could be shown that both approaches reach comparable results that could be used for development of long term correlations of solar radiation.

The SOLEMI data show that the average annual GHI of 2146 kWh/m^2 recorded for the location of the measurement station at Kilinochchi is comparable with other high-potential regions such as Batticaloa (2226 kWh/m^2) and Hambantota (2239 kWh/m^2) The inter-annual variability of annual insolation sums is quite low. The highest deviation of a single year from the twelve-year average is 3.3 percent.

The Cumulative Frequency Distribution Curves (CFDC), show a non-negligible difference between the curves using the measured data and those using the corresponding TMY data. It is customary to employ CFD curves in comparing locations with similar weather, in particular, with reference to CFD curves of locations with the same clearness indices. This, in principle, provides opportunities to exchange solar radiation and systems design related information, radiation correlations, etc that have been already developed for various locations around the world. Thus, more accurate CFD curves established for the location using measured data makes the above said tasks to be carried out with greater

accuracy than with the currently available TMY data. However, the true potential of this aspect could only be achieved with the CFD curves established with measured data over several years

In the current local context with the government's policy to endeavour reaching 20% of the electricity mix by non conventional renewable energy systems by the year 2020, it is observed that the platform laid down by the government to accommodate net-metered and grid connected electricity generation has encouraged the solar based electricity system developers. In this scenario, it is extremely important to have information and data to enable the most accurate and realistic financial analysis in decision making for project implementation. The preliminary estimations carried out in this project on the amount of electricity generation employing best practiced technologies using ground level measured data shows that the said estimations are 12.1% lower than those predicted by employing SOLEMI based TMY data for this location for the period of March to September 2013. This highlights an important preliminary conclusion indicating that the electricity generation estimated employing measured ground level data would lead to more meaningful, accurate and informed decisions in view of solar based projects. Furthermore, it can also be concluded that the above percentage difference of 12 % would also be further enhanced if the period is extended to a 12 month duration when the complete set of measured data for a single year is available. However, for significantly accurate decision making one should employ ground level measured data at the location over several years to incorporate the long-term radiation characteristics into estimations.

Therefore, current data sources as SOLEMI and ground based measurement stations show deviations, which limit the precision of energy yield calculations. Therefore Satellite derived data cannot replace high quality in-situ measurements like the station installed in Kilinochchi during the present project. Ground based solar resource measurement stations serve as basis for solar resource assessments and will improve precision of long-term and short term predictions. It is therefore highly recommended to operate the station and also to continue local observations of sunshine duration. If the station stays in operation until a solar project is realized at the site Kilinochchi, the measurements can be employed for performance analyses.

On a general note, it would be prudent to expect a non significant deviation on the electricity generation estimations using ground level measurements and using satellite based TMY data at other locations of Sri Lanka. This could be initially verified with ground level data measured at Hambantota but using instruments of first class accuracy (i.e. below the accuracy levels of secondary standard instruments employed at Killinochchi) that is currently available. Based on the results of the said verification, it could be decided to extend the ground level measurements to represent a location in the eastern zone where the currently available solar radiation maps indicate relatively higher solar energy availability from the Sri Lankan perspective. Based on those results, it could be envisaged to investigate the potential to have a gradual transition from satellite based data to ground level data encompassing locations of high solar radiation availability representing the whole country in a meaningful manner.

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Annex 1 - Outline Terms of Reference for the Consultant

1. The project preparatory technical assistance (PPTA) will require 8 person-months of consulting services (3 international and 5 national) for wind and solar resource assessment at the proposed locations for wind and solar parks. An international consulting firm or consortium of firms specialized in conducting actual wind and solar measurements, data gathering, measurement and satellite data modeling to properly assess wind and solar resource, and technical analysis will be recruited from September 2011 to September 2012 to ensure that necessary data and analysis are available to attract interest of private investors for the wind and solar power generation. The consultants' outline terms of reference will include, but not necessarily be limited to, the following tasks.

1 Wind Resource Assessment Specialist /Team Leader

2. An international wind resource assessment specialist, as a team leader, will be responsible for the overall quality and implementation of the TA assignment, providing the required support for the executing agency/implementing agency (the EA/IA) and reporting to ADB's project officer. With input from a national wind resource assessment specialist and other team members, the international wind resource assessment specialist and team leader will prepare overall wind and solar resource assessment at the proposed wind and solar park locations in consultation with EA/IA staff. In particular, the tasks of the renewable energy specialist and team leader will include, but not be limited, to the following:

I. As team leader, coordinate development of a detailed work plan and implementation schedule, work with the EA/IA to oversee the consulting team, and compile, edit, and ensure the quality of reports to be issued under the TA;
II. Estimate Green House Gas Reduction for the proposed wind and solar plants at the project locations in line with best international practice and ADB endorsed methodology;
III. Undertake research and analysis of existing historical wind data available from meteorological stations close to the proposed wind park location, satellite databases, other initial information/studies/surveys available with the IA;
IV. Conduct preliminary evaluation of the potential wind resource based on the existing available information and well-proven simulation techniques together with location and terrain data from the sites;
V. In case some preliminary measurements were conducted by the IA at identified locations, verify reliability of the acquired data, whether it was gathered following international standards and with properly calibrated equipment;
VI. Conduct preliminary wind resource modeling at the proposed sites to provide a basis for the deployment of wind monitoring towers, field supervision of wind monitoring station/equipment installation;

VII. Identify and propose required wind measurement equipment in line with the relevant international standards;

VIII. With support of a national wind resource assessment specialist coordinate/arrange procurement of an appropriate wind measurement equipment using provisional funds available under the PPTA for these purposes in coordination with the EA/IA;

IX. Coordinate/arrange measurement-related survey works including installation and commissioning of measurement equipment at wind measurement locations with support of the national wind resource assessment specialist and the EA/IA using provisional sums available under the PPTA for this purpose;

X. Provide training to staff of the IA on use and maintenance of measurement equipment and undertake periodic maintenance checks with support of the national consultant and staff of the EA/IA;

XI. Conduct actual wind measurements at the proposed wind park locations and arrange relevant data gathering;

XII. Provide monthly interim reports include the following: (a) Summary data sheet showing monthly trends graph to date, wind speed frequency distribution, turbulence intensity, wind rose, diurnal variation in wind speed, diurnal variation in wind shear, time series charts of wind speed and direction; (b) Monthly trends data sheet; (c) Report screen log; and (d) Maintenance issues log;

XIII. Compile screen and balance data and create polished data sets;

XIV. Correlate polished data set with reference data;

XV. Produce long term wind climate at meteorological mast(s);

XVI. Conduct wind flow modeling using measurement data, reference data from local meteorological stations and other available data to properly assess wind resource, and undertake relevant technical analysis; and

XVII. Produce wind regime and resource report.

2. Wind Resource Assessment Specialist (National)

3. The national wind resource assessment specialist will support and assist the international wind resource assessment specialist and team leader with the tasks described in para. 2 above.

3. Solar Resource Assessment Specialist

4. An international solar resource assessment specialist, with input of a national solar resource assessment specialist, will prepare solar resource assessment at the proposed solar park and solar rooftop locations with support and in consultation with EA/IA staff. In particular, the tasks of the international solar resource assessment specialist will include, but not be limited, to the following:

I. Review and analyze solar resource maps, satellite databases and data available in the public domain as well as initial information/studies available with the IA;
II. Procure, as necessary, 10-year historical satellite solar irradiance data (hourly direct normal irradiance [DNI], global horizontal irradiance [GHI], diffuse horizontal irradiance [DIFF]; 3 km resolution) and other meteorological data (hourly wind speed [at 10m], temperature [at 2m] and relative humidity), and review validity of existing solar resource map (budget for purchase will be set aside in the consulting services contract as provisional sums);
III. In case some preliminary measurements were conducted by the IA at identified locations, check reliability of the acquired data, whether it was gathered using international standards and with properly calibrated equipment;
IV. Identify and propose required on-site solar radiation measurement equipment in line with the relevant international standards;
V. With support of a national solar resource assessment specialist assist the team leader in coordinating/arranging procurement of an appropriate solar radiation measurement equipment using provisional sums allocated under the PPTA for this purpose in coordination with the EA/IA;
VI. Install, calibrate and commission the on-site solar measurement equipment at solar measurement locations with support of the national solar resource assessment specialist and the EA/IA;

VII. Provide training to staff of the IA on use and maintenance of measurement equipment and undertake periodic maintenance checks with support of the national consultant and the EA/IA;
VIII. Conduct actual solar measurements at the proposed solar park location and arrange relevant data gathering; establish a data acquisition system to acquire, check and filter the observed data every day (data from the instruments shall be observed and recorded for one year);

IX. Inspect and calibrate the instruments of the ground measurement stations at least once during the one year measurement period to control the functionality of the sensors and properly calibrate the equipment;
X. Correct historical satellite solar irradiance data with observed data from the onsite measurement;
XI. Through statistical corrections and uncertainty analysis, calculate solar resource for a Typical Model Year (TMY) with probability of exceedance of 50%, 75%, 90% and 99% (P50, P75, P90, P99, respectively), or in accordance to best practices, for the proposed site(s); and
XII. Produce solar resource report.

4. Solar Resource Assessment Specialist

5. The national solar resource assessment specialist will support and assist the international solar resource assessment specialist with the tasks described in para. 4 above.

Annex 2 - Division of Responsibilities between RMA and SLSEA

Task	**Responsibility**	
	RMA	**SEA**
Project Planning		
Prepare draft work plan	X	
Kick-off meeting with SLSEA-M/P&E, discuss plan / responsibilities	X	
Revise as necessary and send plan to GEO-NET	X	
GEO-NET to add activities after equipment installation	X	
Issue letter of Authorisation / Introduction to Consultant		X
Site Visits		
Obtain written permission to visit Mannar meteo station	X	
Visit to Mannar	X	X
Visit Hambantota solar energy park, met station, agro-met stations	X	X
Prepare visit reports	X	
Send visit report to SLSEA and GEO-NET	X	
Data Collection		
Wind data from SLSEA stations and former CEB station, past reports		X
Wind data of Mannar meteo station from Met Dept	X	
Solar data from Hambantota solar energy park		X
Solar data from meteo & agro-meteo stations	X	
Prepare station report for each measurement station	X	
Submit data and station reports to GEO-NET	X	
Submit station reports to SLSEA	X	
Data Analysis		
Analysis of data from on-going / former wind masts	X	
Analysis of solar data	X	
Preliminary modelling of wind and solar climate	X	
Selection of Measurement Sites		
Wind specialist from GEO-NET makes field visits	X	
GEO-NET recommends 2 optional sites for wind mast	X	

Procurement		
Draft "call for quotations"	X	
GEO-NET-review document-refine technical specifications	X	
GEO-NET to name three good suppliers to RMA	X	
Invite offers by email	X	
Receipt of offers	X	
Evaluation of offers by RMA and GEO-NET	X	
Approval from ADB for the selected offer	X	
Order equipment	X	
Pay duty, taxes etc.		X
Arrange clearing / transport of equipment to Mannar	X	
Obtain permission for GPRS facility from SLT		X
Obtain approval from Civil Aviation Authority for wind mast		X
Arrange mobile telephone connection for wind mast	X	
Installation of Wind / Solar Measuring Systems		
Obtain quotes from 3 local contractors for wind mast installation	X	
Study offers, select a contractor in consultation with eq. supplier	X	
Obtain quotes from 3 local contractors for foundation work	X	
Study offers, select a contractor in consultation with eq. supplier	X	
Conduct soil study at the proposed wind mast location	X	
Send soil report to wind mast supplier	X	
Design of the wind mast foundations	X	
Sign necessary agreements with civil / installation contractors	X	
Site clearing, levelling, excavation, etc.	X	
Arrange facilities for installation of solar measuring system	X	
Arrival of supplier’s supervisory staff for installation	X	
Installation of wind mast	X	
Commissioning of wind mast / solar measuring equipment	X	
Fencing of the wind mast site	X	
Provide security arrangements		X
Monitoring of Data Collection		
Monthly visits to wind mast / solar energy park	X	
Prepare and submit visit reports to GEO-NET and SLSEA	X	

Annex 3 - Information on the Met Station in Mannar Island

Date of visit to station	O9 December 2011
Location, coordinates	Mannar Island, wind mast coordinates - N 08° 59.242’ E 79° 54.484’
Date of commissioning	05 June 2007 – see notes below
Wind mast type	Pole with a ladder
Mast material	Wooden
Surface treatment	Painted
Height of measurement	6m
Anemometer type, make	Mechanical cup counter, Casella
Wind direction sensor	Mechanical vane pivoted on an axle, data is descriptive
Wind data type	Wind run in km
Data availability	From 05 Jun 2007 to date
Data collection frequency	0530, 0830, 1130, 1430, 1730, 2030
Data storage	Data is recorded in the “Routine Observation Book” – ROB
Data transmission to Head Office	Three-hourly data by telephone. ROB monthly sheet is sent by post
Maintenance	Done by a person coming from the Head Office. There is no evidence of anemometer calibration

Notes:

Mannar meteorological station was shifted from its original location: N 08° 58.717’ and E79° 54.814’ to the present site due to increased sheltering of the former site caused by gradual urbanisation of the surrounding area. In its present location, the station records wind run, wind direction, air temperature, atmospheric pressure and rainfall using standard instruments.

A new automatic recording system has been installed under Japanese aid. This is a fully automatic system that is equipped with an ultrasonic anemometer, sunshine hour recorder, barometer, thermometer, rain gauge (tipping bucket instrument), and hygrometer. Logged data is retrieved by Head Office through satellite communication system.

Anemometer is somewhat sheltered in the SW direction by the two-storied buildings of the met station and National Youth Services Council.

Figure 1 - Location of Present and Former Sites of the Met Station in Mannar Island

Figure 2 - Layout of the Present Met Station in Mannar Island. Approximate Boundary of the Station is shown by Dark Lines

Figure 3 - General View of the Met Station

Figure 4 - Automatic Weather Station (AWS)