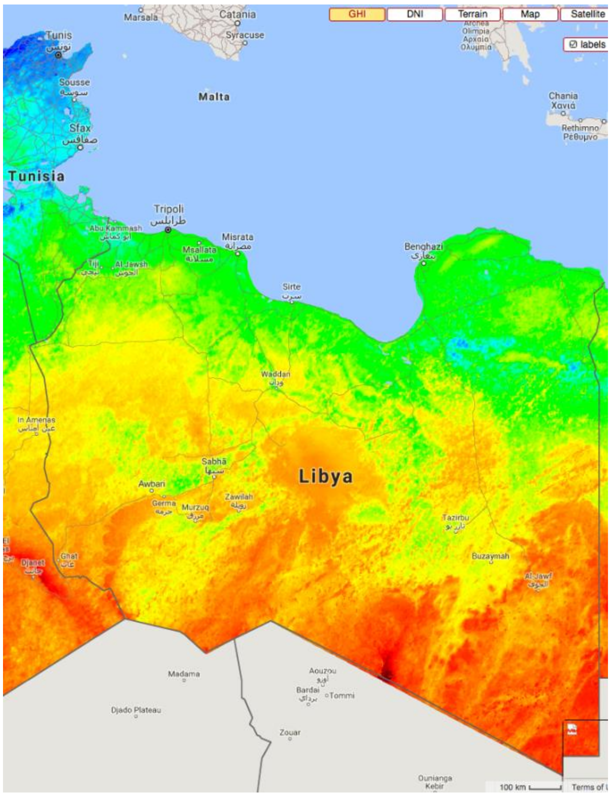
Libya - Supporting Electricity Sector Reform (P154606)



Contract No. 7181909 - Task D:
Strategic Plan for Renewable Energy Development

Feasibility Study for a PV Plant at Jadu Site
18th December 2017

Client:

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Abbreviations Used

AC	Alternating Current
CAPEX	Capital Expenditures
CMFAS	Satellite Application Facility on Climate Monitoring
CSP	Concentrating Solar Power
DC	Direct Current
DNI	Direct Normal Irradiation
DSCR	Debt Service Coverage Ratio
EBITDA	Earnings before Interest, Taxes, Depreciation and Amortization
EHS	Environmental, Health and Safety
ESIA	Environmental and Social Impact Assessment
ESS	Energy Storage System
FLH	Full Load Hours
GCR	Ground Coverage Ratio
GECOL	General Electric Company of Libya
GHI	Global Horizontal Irradiation
GIIP	Good International Industry Practice
GWA	General Water Authority
IFC	International Finance Corporation
IRR	Internal Rate of Return
kV	Kilo Volt
LCEP	Least Cost Expansion Plan
LCoE	Levelized Cost of Electricity
LDS	Long-Duration Energy Storage
MW	Mega Watt
MY	Meteorological Year
OPEX	Operational Expenditures
PCR	Physical Cultural Resources
PPA	Power Purchase Agreement
PSP	Private Sector Participation
PV	Photovoltaics
REAOL	Renewable Energy Authority of Libya
ROE	Return on Equity
RSI	Shadowband Irradiometer
SLD	Single Line Diagram
TMY	Typical Meteorological Year
WACC	Weighted Average Capital Cost
WB	World Bank
WTG	Wind Turbine Generator

1. Executive Summary

The feasibility study in hand is part of a larger set of tasks to analyse the Libyan market for the implementation of utility scale renewable energy producers into the national grid system. Under this general task of analysing the current status of the system and the developments needed to allow for private sector participation, the study in hand shall develop one concrete opportunity to install an RE plant to deliver electrical energy into the national grid.

Generally, the sense of the feasibility analysis is to identify one concrete location and one concrete technology to install there.

An extensive analysis of possible sites has been performed and finally a site was defined, located close to the city of Jadu, some 140 kilometre south-west of the centre of Tripoli. This site showed excellent conditions due to its location in the vicinity of Tripoli (as a big consumer), due to its availability and due to the fact that meteorological resource analyses have been performed close to the site. Also, a connection to the national grid is available and GECOL recommended this site as well.

In other parts of this assignment (preparation of a Least Cost Expansion Plan) a rough estimation for timeline for the installation of the technologies under review (wind, PV and CSP) has been performed. The main outcome was that PV will be the "quickest" technology. This (and the excellent resource data) was the main reason to focus on PV technologies to be implemented.

Based on these basic facts a site visit was performed and was verifying the suitability of the site.

A set of different PV technologies was analysed and compared, differing in:

- Module technology ranging from mono-crystalline over poly-crystalline to thin film technology
- Inverter technology (string inverter concept and central inverter concept), and in
- Mounting system technology, considering fixed mounted and single axis tracked systems.

Comparison was based on LCoE calculations and it turned out that lowest costs were reached by single axis tracked systems. Anyhow, differences in cost were small and due to the fact that a tracked PV system needs moving parts (with the additional risk of failing) the decision was felt to follow up with fixed mounted systems. Here, a 100 MW_{ac} with multi-crystalline modules and central inverter technology was identified for the recommended case.

An additional outcome of the mentioned site visit was a screening of the site with focus on ESIA needs. The site did not show any major hurdles with regard to expected environmental and/ or social impact. It was recommended to run a detailed ESIA analyses for the site.

For this set of information, an economic and financial analysis was performed and finally a recommendation for a tariff to by the produced energy was set. For the financial analysis a number of financial parameters were set, reflecting the currently challenging the situation in Libya and leading to an estimated tariff of 9.31 USD cent/kWh.

A sensitivity analysis showed that only by reducing the ROE expectations of the investors from 15% to 10% causes a tariff reduction by more than 10%. Reduced ROE expectations can only be gained by creating a save, reliable and well-regulated business environment.

Concluding the study, following results are shown:

- A number of sites are ready and suitable to be developed.
- Following the site visit results, the chosen site gives proper conditions
- PV technology is favourable to apply on the short term
- Prices for different PV technologies does not differ to much
- ESIA analysis shall be conducted, but it is not expected to have a negative result
- Even under PSP conditions, reasonable costs for selling the produces energy is shown
- With better conditions in the country expected to be met in the future, costs will go down additionally

2. Introduction

The feasibility study in hand is part of a larger set of tasks to analyse the Libyan market for the implementation of utility scale renewable energy producers into the national grid system. Under this general task of analysing the current status of the system and the developments needed to allow for private sector participation, the study in hand shall develop one concrete opportunity to install an RE plant to deliver electrical energy into the national grid.

The feasibility study describes this approach. In the course of this analysis, a number of extensive documents have been prepared and are partly forming the basis of single steps for the feasibility analyses. Further on, additional detailed documents have been prepared to either develop or justify the work. As the study itself shall be very clear and easy to read, such documents have been attached as annexes and the result / output has been taken into the core document.

Generally, the sense of the feasibility analysis is to identify one concrete location and one concrete technology to install there.

Following section 3 will review the nominated site and name the conditions around. The analysis is based on an extensive review of a number of sites. The results of this extensive review are shown in Annex 1.

Section 4 will reflect a detailed analysis if the resource data on site. This is based on on-site measurements taken in the closer vicinity. An extensive report on the resource evaluation will pick up the details. This is attached in Annex 3.

To describe the technology options section 5 picks up different set-ups for the general layout of the plant on the selected site. Here, the Consultant describes different products which might be installed and explains his path through these opportunities. Following this, the configuration of options form plant concepts is defined, leading to a number of possible layouts. Calculating an LCOE for these configuration leads to a table with plant concepts. A ranking of these concepts, based on LCOE and further facts for the technologies, allows to define a recommended case.

This recommended case is presented in section 6. It forms the basis for the further review and calculation. All technical conditions for this recommended case are mentioned here, allowing for understanding the set-up of the recommended case.

An environmental screening has been performed and the results are shown in section 7. In the document the main outcome for the specific site is displayed. Boundary conditions are displayed in Annex 6.

Wrapping up all information collected and calculated up to here allows for an economic and financial analysis. Section 8 summarizes the financing conditions and shows the results.

Finally. section 9 summarizes the conclusions and underlines the main findings.

3. Site Selection for Feasibility Study

The objective of this activity is to inspect the project region and its environment, assess particularly the local conditions in order to confirm the site for the installation of the technology option and verify already available information from previous analyses. The quality of the collected data will be critical for the future concept design of the technology option.

This section introduces the site which was selected to host the PV plant for the Feasibility Study.

A detailed overview over the sites generally being considered and being analysed in given in Annex 1 of this report.

3.1 Selection of Site for the Feasibility Study

Following the analyses displayed in Annex 1 of this report only the most promising sites have been considered for the final decision on the location for the PV plant.

After discussions with GECOL and REAOL on the most suitable site to perform the feasibility study out of the preselected ones there was consensus that the sites at Jadu, Edri and Zliten display better advantages and have already been considered by the stakeholder for PV development. Based on this fact the Consultant undertook site visits on the three sites accompanied by delegates of REAOL and GECOL.

Although the sites are suitable for PV development the site at Jadu has nearby ground solar measurements and an area already allocated by the Government of Libya for such development. The site visit at Jadu confirmed that the site (see next section) is suitable for PV development and thus it is the site selected for the feasibility study.

3.2 Jadu Site visit

The proposed site of the PV power plant is close to the city of Jadu. Jadu is a mountainous city in western part of Libya, in Nafusa Mountain. The Project site, with coordinates 32°05'55.27N, 12°04'47.14"E is located approximately 11 km east of the town of Shakshuk, approximately 15 km south of Jadu. The PV plant shall be connected to the grid close to Shakshuk with an existing A220 kV substation.

Figure 3-1 shows the proposed site with the existing 220 kV overhead transmission line route, while Figure 3-2 shows a schematic plan for the proposed site, approved from the projects department at Jadu Municipality.

Figure 3-1: Proposed site and substation close to Jadu (32° 5'55.27"N, 12° 4'47.14"E)

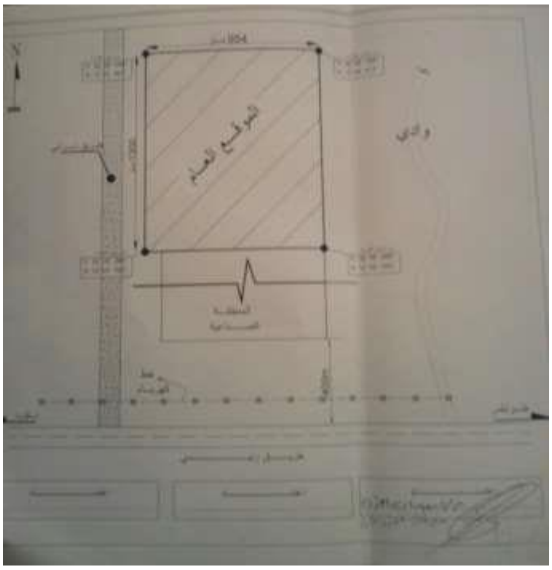


Figure 3-2: Schematic plan for the proposed site

The total area approved by the Municipality of Jadu for the PV plant installation is approximately 125 hectares with availability of additional area of nearly 75 hectares. The terrain is not complex and the area is mainly flat, arid, non-arable, highly exposed to the sun with no plant coverage and clear of natural obstacles such as high mountains or buildings that may influence the power system (see Figure 3-3).

Site soil conditions are regarded as suitable as it comprises of normal soil. The site is easily accessible, located right next to a paved road (Figure 3-4). A220 kV substation is situated less than 9 km away from the site (Figure 3-5). Grid connection to the substation should be possible (Figure 3-6).

Figure 3-3: Landscape at Jadu site

Figure 3-4: Project site located close to the main paved road

Figure 3-5: 220 kV Shakshuk substation

Figure 3-6: Grid connection to the substation

A checklist of the site visit to Jadu can be found as part of Annex 2.

A checklist with the environmental considerations taken into account can be found in Annex 7. The checklist comprises the possible environmental and social impacts, as well as the baseline environmental assessment.

4. Verification of RE Resources

Within the framework of the Strategic Plan for Renewable Energy Development for Libya a site in Libya for the construction of a PV power plant is evaluated. The site with site code LYJAD is located around 20km North-East from Jadu in Libya. The geographical coordinates of the power plant LYJAD, for which this assessment is conducted, are:

Table 4-1: Geographical coordinates of the location

latitude:	32,0986	N
longitude:	12,0797	E
elevation:	141	m a.s.l.

Most important to reach good estimates on electricity yields of a PV power plant is the knowledge on Global Horizontal Irradiance (GHI) conditions.

For evaluating the long-term average of GHI at LYJAD, the site selected for this study, several different solar resource data sets have been analysed: long-term satellite-derived data, such as site-specific satellite data obtained from CMSAF-SARAH (CMSAF) and on-site measurements taken at a location 60km away from the project site for 12 months. In 2010, a meteorological measurement station has been set up at a location (LYJA2) 60km away from the project site. Main instrument is a Rotating Shadowband Irradiometer (RSI), which measures GHI and Diffuse Horizontal Irradiance (DHI) and from which Direct Normal Irradiance (DNI) is calculated. The station also measures air temperature, humidity, pressure, wind speed and direction and precipitation. All data streams are logged in 1-minute time resolution. This station was running properly and the data obtained is without gaps or errors. Measurements are of similar intensity compared to other measurements in the region. Maxima of GHI in each measured month proofed to be realistic.

Long-term site-specific satellite-derived GHI data from CMSAF (11 years) are compared to and adapted to overlapping on-site measurements. Since the location of the on-site measurement station is 60km away from the project site, the correction function for adapting the satellite data is determined by comparison with additional satellite data from CMSAF (11 years) of the location of the on-site measurement station. Then, the correction function is applied to the satellite data (also from CMSAF, 11 years) from the project site LYJAD. In the region of the project site the geographical characteristics are quite homogenous and thus nearly don't change with distance. Therefore, the additional uncertainty due to the relatively high distance of the measurement station from the project site is evaluated to be low since the geographical characteristics of both locations are very similar.

The long-term best estimate for GHI at this site amounts to 228 W/m^2, which is equivalent to **1995 kWh/m^2** per year or 5.5 kWh/m^2 per day. The inter-annual variability is analysed on the basis of the CMSAF data set. A year-to-year volatility of 0.9 % is calculated for GHI, which is very low compared to many other regions worldwide. The assessment of uncertainties takes into account the length of record of various data sets, uncertainty of the measurements at the site LYJAD and the methodological uncertainty of the adaption process. Accordingly, the above given long-term average for GHI is assumed to have an uncertainty of 3.2 % associated with the inter-annual variability related to multiple years and 3.3 % related to a single year. The monthly averages for measured ground data, satellite data and adapted satellite data is provided in Figure 4-1.

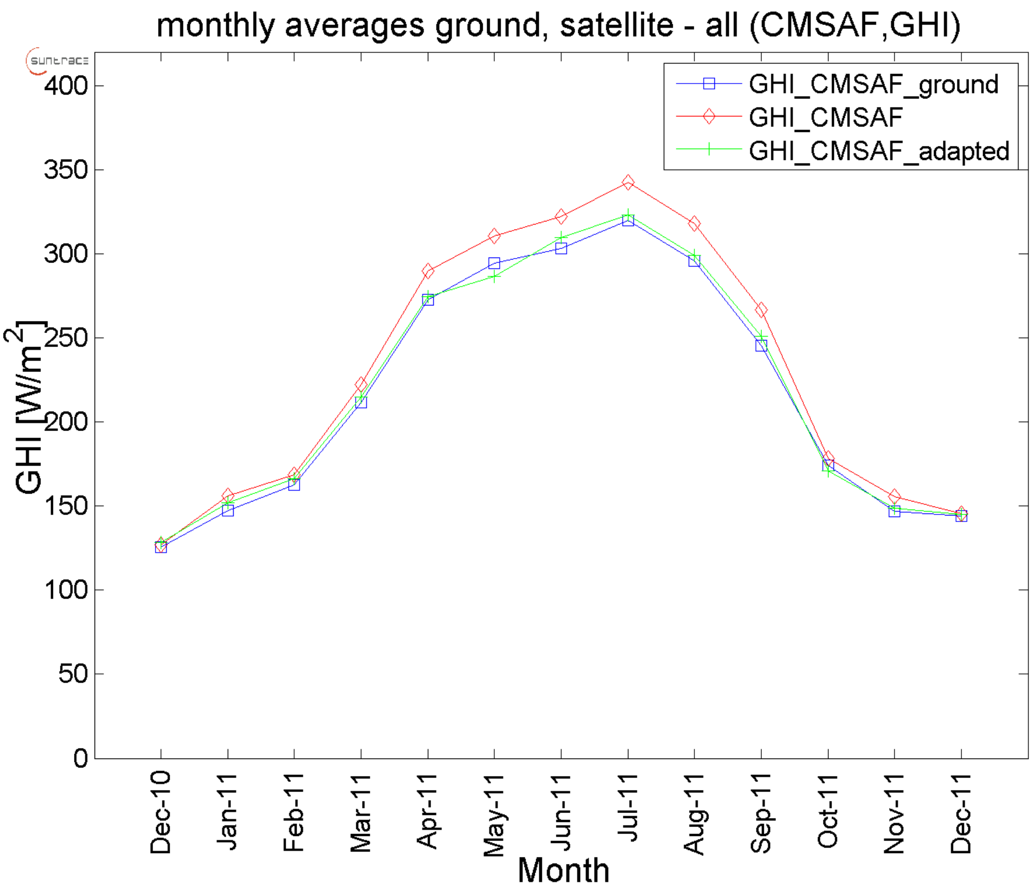


Figure 4-1: GHI monthly averages during the full overlapping period for all values(CMSAF).

For the long-term average (P50), a characteristic meteorological year in hourly time resolution is provided. Besides GHI, this data set also provides Diffuse Horizontal Irradiance (DHI) and auxiliary meteorological parameters, such as air temperature, wind speed and wind direction derived from the on-site measurements, where auxiliary parameters support site-specific plant layout and performance calculations.

For risk assessment of the solar power project, P75 and P90 Meteorological Years are created based on the P50 value. The multiple years P75 value of GHI at this site is estimated to be 2.2 % below the long-term best estimate (P50). This leads to a long-term average P75 value for GHI of 223 W/m^2 or 1952 kWh/m^2 per year or 5.3 kWh/m^2 per day. The single year P75 value of GHI at this site is estimated to be 2.3 % below the long-term best estimate (P50). This leads to a long-term average P75 value for GHI, based on a single year uncertainty of 222 W/m^2 or 1950 kWh/m^2 per year or 5.3 kWh/m^2 per day. An overview of the PXY values in comparison to the best estimate (P50) for each month is provided inTable 4-2.

Table 4-2: Overview of PXY values in comparison to best estimate (P50) for each month and the whole year with respect to multiple year and single year uncertainty.

		P50 [W/m²]	multiple year PXY values [W/m²]		single year PXY values [W/m²]	
			P75	P90	P75	P90
Jan		140	137	134	137	134
Feb		176	172	168	172	168
Mar		222	217	213	217	213
Apr		275	269	263	269	263
May		295	289	283	288	282
Jun		311	305	299	304	298
Jul		323	316	310	316	309
Aug		291	285	279	285	279
Sep		236	231	227	231	226
Oct		189	185	181	185	181
Nov		147	144	141	144	141
Dec		123	121	118	120	118
year	**avg.** [W/m²]	228	223	218	222	218
	sum [kWh/m²]	**1995**	**1952**	**1913**	**1950**	**1910**
avg. day sum [kWh/m²]		**5.46**	**5.34**	**5.24**	**5.34**	**5.23**
deviation from P50 (PXY-P50)/P50		-	-2.17%	-4.11%	-2.26%	-4.29%

Conclusion

The quality of obtained satellite-derived data is found to be good. The on-site measurements are taken with good instrumentation in form of a Rotating Shadowband Irradiometer (RSI). No documentation of the sensors and the meteorological measurement stations is available, thus it is not known if the radiation instruments had been regularly recalibrated and cleaned. However, in comparison to a thermopile pyranometer equipped with a glass a glass dome, the RSI is quite insensitive against soiling. The length of the measurement period is in total 12 months which is long enough to achieve reasonable results taken into account all seasons during adaption of the satellite data.

The long-term best estimate for GHI at this site amounts to 1995 kWh/m2 per year with an uncertainty for the long-term average for GHI related to multiple years of 3.3 %. This leads to a multiple years long-term average P75 value for GHI of 1952 kWh/m2 and 1913 kWh/m2 at P90 probability level.

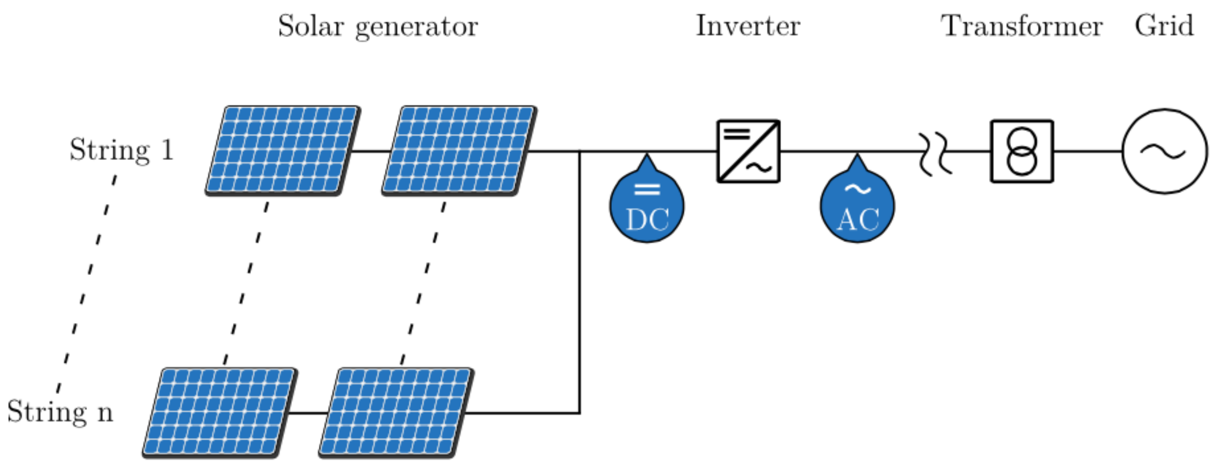
The complete Solar Resource Assessment report is attached as Annex 3 to this report.

5. Definition of Feasible Options for Analyses

5.1 Selection of Technology Options

In general, solar photovoltaic plants use Global Irradiation (GI), which is converted into electric energy in a solar generator. The solar generator consists of PV modules connected in series to form strings, which are connected in parallel and deliver DC power to the inverters. The inverter converts the DC power to AC power before transforming to the required voltage level allowing evacuation of power to the grid, as illustrated in the figure below.

Figure 5-1: General principle of a solar PV power system



Source: *Suntrace GmbH*

The components and layout of such plant are typically based on a 1000-volt system. This includes all components such as modules, cabling, combiner boxes, inverters, switchgears, etc. In general, there is a tendency in the solar market towards 1500-Volt systems offering higher flexibility in terms of module interconnection, less cable losses, more simple installation and potentially lower specific equipment cost. However, for this project, a 1000-volt system will be considered as the number of potential suppliers and experience with 1500-volt systems is still limited at the time of this study.

The project specific boundary conditions have been assessed for the conceptual engineering and technology selection. The technology has been analysed in terms of availability, inter-operability, reliability, scalability and maintenance aspects, suitability for the site, command and control systems, load consumption, system architecture, system output and performance. The main technologies selected for the feasibility study analysis are based on the high-level technology assessment described in Annex 4 and summarised hereafter:

- **PV modules:** multi/mono-crystalline and thin film module technology
- **Mounting system:** fixed-tilt system vs. single axis tracking
- **Inverter concept:** central vs. string inverter concept

5.1.1 Solar PV Module

The main PV module technologies available in the market at commercial level were compared from a techno-economic point of view in order to find the technology that best fit the local ambient conditions found on the site. Three main technologies were evaluated:

- Multicrystalline modules (multi-Si)
- Monocrystalline modules (mono-Si)
- Thin film: CdTe, modules (TF)

In the following table, the different main PV module technologies are compared.

Table 5-1: Comparison of different technologies

Module Technology	Advantage	Disadvantage
Multicrystalline	• Mature and commercially proven technology • Long lifetime of panels • Low degradation of about 0.5% per year • Low installation costs • Low production costs compared to monocrystalline modules • Crystalline cells are not harmful to the environment. • Established global competitions and high number of tier 1 companies	• Lower efficiency in comparison to monocrystalline technology, due to lower purity of the cell material: 14-18%. • Because of the lower efficiency, a larger surface is required to reach the same capacity. • Higher risk of cracks during transport or mounting in comparison to thin film technology.
Monocrystalline	• Mature and commercially proven technology • Long lifetime of panels • Low degradation of about 0.5% per year • High efficiencies typically within 15-20%.	• The initial investment costs are higher compared to multicrystalline modules. • Higher risk of cracks during transport or mounting in comparison to thin film technology.
Thin film	• Easier to manufacture and lower production cost compared to crystalline modules. • Homogenous appearance. • Flexible, hence for use at different applications and surfaces. • Less affected by high temperatures and shadowing.	• **Very few market players,** with only First Solar having a significant market share (CdTe modules). • Faster degradation compared to crystalline modules. • Higher cost for mounting, installation, cabling compared to crystalline modules. • CdTe modules use cadmium telluride as semiconductor layer. Under extreme conditions, e.g. high temperatures, it might happen that CdTe breaks into Cd and Te. As Cadmium is a toxic metal, the recycling of the modules by the manufacturer has to be secured to avoid emissions to the environment at the end of the lifecycle. • Thin Film technologies have faced technical problems with degradation in the last decade. A special accuracy is needed in the selection of the product.

The CIGS based thin film technology has been excluded from this analysis since it is still not considered as major technology with sufficient suppliers allowing competitive bidding.
Different module technologies have been compared in terms of energy production and LCoE.

5.1.2 Mounting Structure

Besides the project specific boundary conditions, the electricity production, required land usage, EPC costs, O&M costs and material liability must be analysed during the selection of the optimal mounting structure for utility scale solar PV plants. The market situation in Libya and the availability of skilled labour force in the region of the site during construction and operation of the plant has to be taken into account.

The Consultant has analysed the following mounting structures:
- Fixed-tilt system
- Single axis tracked system

Fixed structures in the northern hemisphere are tilted towards the south with an inclination between 10° and 25° for the latitude of the project site. The fixed position of the modules leads to a generation curve with a peak at midday on cloudless days.

For tracker solutions, the aim is to follow the sun and maintain the panels perpendicular to the axis of incidence of the sun. Thus a greater share of solar energy can be converted into electricity. A single axis tracked system typically tracks the sun’s position from East to West while being mounted along a North to South axis.

Advantages of tracking systems:
In general, the tracking systems can harness more energy, making them an attractive alternative in areas of high solar irradiation. Tracking systems are able to keep shading to a minimum but typically they require more space for the same power output (number of modules) as compared to a fixed-tilt system. One of the most important aspects of tracking systems is the increased energy yield during the morning and evening hours, which helps to deliver a more constant electricity supply.

Disadvantages of tracking systems:
One of the big advantages of PV power production is that no "moving" or "rotating" parts are needed for or within the power plants. If tracking systems are applied, this advantage will be reduced. Tracking systems are more susceptible to failure, due to the number of moving parts and therefore, they also require more maintenance and maintenance costs can be around 15% higher. Trackers are more susceptible to high wind loads and in areas of high wind speeds the limited warranty for tracker systems may be reduced.

Both, the fixed-tilt system and single axis tracked system has been optimised as described in chapter 5.2 and compared in terms of energy production and LCOE.

5.1.3 Inverter Technology

The selection of inverter technology is crucial for the plant conceptual layout and equipment requirements such as string combiner boxes, DC and AC cabling, distribution transformers, and others. Typically, a central inverter concept is applied for large-scale PV plants having several MW of capacity, while the string inverter concept offers more flexibility often required for smaller installations.

String inverter concept
The individual PV modules are connected in series to form strings. When using string inverters, the DC power from few strings runs directly into a string inverter where it is converted to AC power. The string inverter is a small unit and it can eventually be mounted underneath the PV mounting system. This concept offers higher modularity and flexibility of the system configuration compared to the central inverter concept and is typically applied for small PV plants and systems with different array angles and/or orientations. The nominal DC capacity of string inverters is typically below 100kW.

Central inverter concept
When using central inverters, the strings are connected in parallel through combiner boxes and they are then connected to the central inverter, which summarize typically between 500 kW to 2.5 MW of DC PV power. In utility scale PV plants, the PV field is generally divided into subfields, each of them served by an inverter of its own. This configuration is optimal for large systems where production is consistent across arrays. Moreover, the central inverter concept offers lower capacity specific costs and fewer component connections compared to the string inverter concept.

The use of large turnkey central inverter station is proposed for the project based on the following considerations:

- Maximize the performance and reduce investment cost. The average price per watt peak of a central inverter is about 8% lower compare to a string inverter.
- The central inverter concept requires less equipment and BOS activities compared to a string inverter concept. Turnkey systems available on the market also offer plug and play solutions combining, for example, inverters, MV transformers and switchgear in a single inverter station, which further minimises the BOS requirements.

5.2 Conceptual Design Optimization

The Consultant has optimised the conceptual plant design for the fixed-tilt system and single axis tracked system respectively. This analysis is based on multicrystalline modules and a plant capacity of 100 MW_{AC}. The tilt angle and a suitable pitch (distance between rows) has been assessed as well as the optimal ration between the total installed module capacity (DC capacity) and the total installed inverter capacity (AC capacity) in terms of an optimal LCOE.

5.2.1 Assessment of Tilt Angle and Pitch

The module tilt angle determines the angle of incidence of solar radiation on the PV module to utilize maximum solar energy for generation of maximum possible energy. A PV module would produce more power with lower reflection and incident angle losses when the solar radiation is normal to its surface as compared to solar radiation incident at any other angle. The most optimum angle of tilt of PV modules at any given location depends on the latitude and the variation of solar irradiation over the year. Since each site has its own characteristics, it is necessary to determine the most optimum tilt for the site.

By increasing the tilt angle and keeping the pitch (distance between two consecutive rows of PV modules) constant, the shadow created by one row of PV modules on the next row of PV modules increases. This decreases the annual energy output of the PV power plant. Hence, the optimal tilt angle varies with the applied pitch.

For the fixed-tilt system, the Consultant has considered a table width of 6m and a minimum space between PV tables of 2.5m to ensure sufficient space for maintenance work while enable optimal land utilisation. The tilt angle has been optimised in terms of highest specific energy yield under these assumptions as shown in Figure 5-2. The specific energy yield of the fixed-tilt system for a tilt angle varying from 10° to 30° is calculated. The figure shows, that the highest specific yield is obtained by applying a tilt angle of 17°, which has been considered for further investigations.

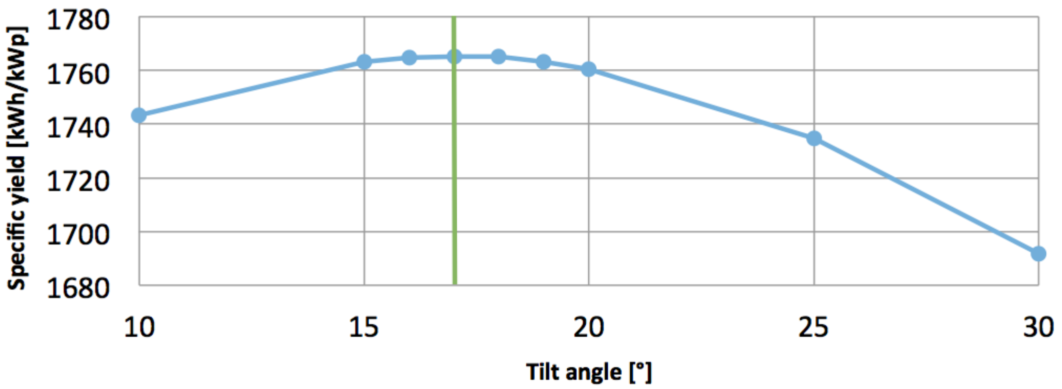


Figure 5-2: Tilt angle variation for fixed-tilt system at Jadu site

For the single axis tracked system a moderate ground coverage ratio (GCR) of 50% is most suitable to allow implementation of a 100 MW_{AC} PV plant with DC/AC ratios of up to 1.4.within the available area of 200 ha at the project site. A GCR of 50% for the tracked PV installation has been considered for further investigations.

Summary

- For the fixed-tilt system, a tilt angle of 17° is applied considering 6m table width and 2.5m distance between PV tables, leading to a pitch of 8.24m.
- For the single axis tracked system, a GCR of 50% stands out as the preferred option to allow implementation of a 100 MW_{AC} PV plant with DC/AC ratios of up to 1.4 leading to a pitch of 8m for the 4m table width of the applied tracker system.

5.2.2 DC/AC ratio for Optimal Plant Configuration

The next step is to determine the DC/AC ratio for the optimal plant configuration. The DC/AC ratio is the ratio between the installed module capacity and the installed inverter capacity.

A change in the DC/AC ratio means, not only a change in CAPEX, but also OPEX. Hence, the LCOE is applied to determine the most optimum DC/AC ratio for the proposed solar PV power plant. The LCOE considers the complete cash flow including CAPEX, OPEX and also the financing conditions, and hence it is an ideal metrics to be considered. The bais for the LCOE calculation is described in chapter 5.4.3. The CAPEX, OPEX and the annual energy produced are the main inputs; those are estimated for different DC/AC ratios of both, the fixed-tilt system and single axis tracked system, to calculate respective LCOEs. The plant configuration with the lowest value of LCOE is considered to be the most optimum. In the Figure 5-3 the DC/AC ratio variation is shown for the fixed-tilt system, while Figure 5-4 shows the DC/AC ratio variation for the single axis tracked system.

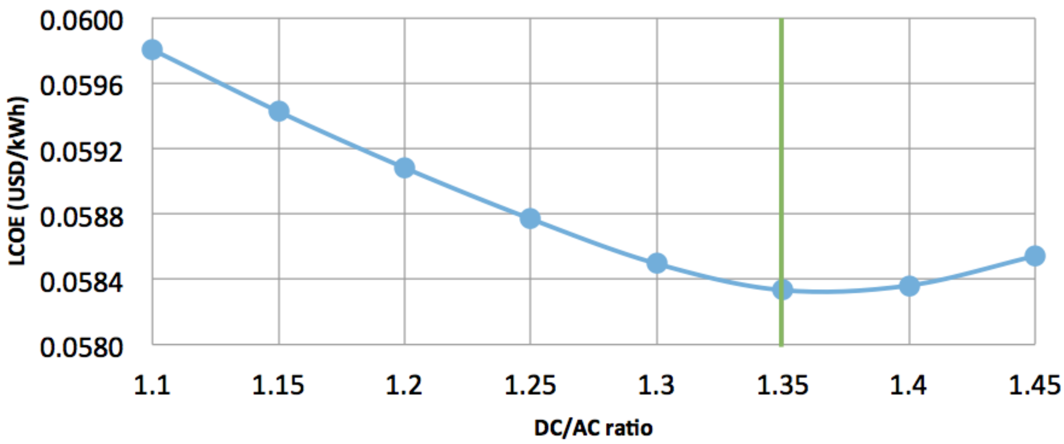


Figure 5-3: DC/AC ratio variation of fixed tilt system

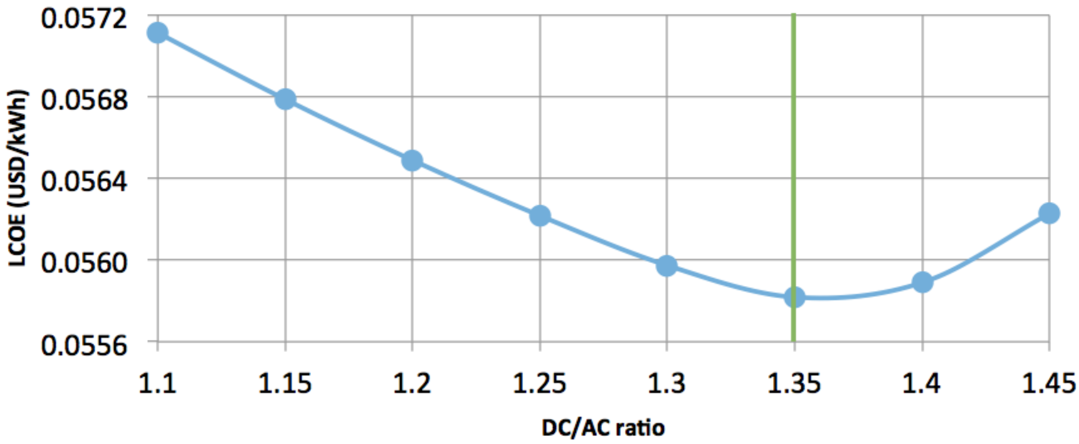


Figure 5-4: DC/AC ratio variation for single axis track system

The electricity production of the power plant has been calculated by varying the DC/AC ratio from 1.1 to 1.45 with an ascending interval of 0.5 for both, the fixed-tilt system and single axis tracked system. For each case the respective LCOE has been calculated and the results are shown in the Figures above. It should be noted that the energy yield calculation for the DC/AC optimisation is based on a plant capacity of 100 MW_{AC} considering multicrystalline module technology.

From this analysis it can be seen that by increasing the DC/AC ratio, the energy produced by the solar PV power plant increases as more number of modules are installed for the same AC capacity of the inverters (with consideration of inverter losses). It can be seen that lowest LCOEs can be reached for DC/AC ratios of 1.35 for both systems, while LCOEs rises again for higher ratios as the increase in energy production fail to compensate for the increased CAPEX and OPEX.

Summary

- The optimal DC/AC ratio considering the applied technical and financial assumptions is 1.35, which has been applied for the base case scenarios.
- It should be noted that during tendering stage, bidders should usually assess the optimal DC/AC ratio for the presented technical concept in compliance with the minimum requirements.

5.3 Base Case Scenarios

Based on the selected technologies and optimised conceptual plant layout as described in Chapter 5.1 and 5.2, the following technology options have been assessed and compared in order to identify the most suitable plant configuration.

- **Plant capacity**: 50 MW_{AC} and 100 MW_{AC}
- **Mounting system**: fixed-tilt system (fix) and single axis tracked system (1-axis)
- **Module technology**: multicrystalline (multi-Si), monocrystalline (mono-Si), and CdTe thin film (TF)

These options are referred to as **base case scenarios** in the following sections.

The applied technologies and conceptual system configurations are further described in subsequent chapters. A summary of the base case scenarios is shown in the Table below.

Table 5-2: Overview of Base Case Scenarios

Case N°	Installed Capacity	DC Capacity	Module Techn.	System type	Area PV installation
-	MWAC	MWDC	-	-	ha
1	50	68	multi-Si	Fix	64
2	100	135	multi-Si	Fix	127
3	50	67	mono-Si	Fix	61
4	100	135	mono-Si	Fix	121
5	50	67	TF	Fix	62
6	100	135	TF	Fix	125
7	50	68	multi-Si	1-Axis	95
8	100	135	multi-Si	1-Axis	190
9	50	67	mono-Si	1-Axis	90
10	100	135	mono-Si	1-Axis	181
11	50	67	TF	1-Axis	93
12	100	135	TF	1-Axis	185

5.3.1 Technical Data Module Technology

Different general module technologies have been analysed to identify the most suitable option for this project. This analysis has been conducted for both, the fixed-tilt system and single axis tracked system. The following module technologies have been assessed:

- Multicrystalline module technology: Triana Solar TSM-320PD14 320Wp
- High efficiency thin film modules: First Solar (CdTe) FS-4117A-2 118Wp
- Monocrystalline module technology: Triana Solar TSM-335DD14A(II) 335Wp

For the feasibility study, state of the art modules from reputable manufacturers, mentioned in the table above, are selected. The technical characteristics of the chosen modules are given in the table below.

Table 5-3: Characteristics of PV modules

Description	Value	Value	Value
Technology	**Multicrystalline**	**Monocrystalline**	**Thin film (CdTe)**
Manufacturer	Trina Solar	Trina Solar	First Solar
Model	TSM-320PD14	TSM-335DD14A(II)	FS-4117A-2
Power output	320 W	335 W	117.5 W
Optimum operating voltage (@ STC conditions)	37.1 V	37.6 V	71.2 V
Current at Pmax (@STC conditions)	8.63 A	8.91 A	1.65 A
Open-Circuit Voltage	45.8 V	46.3 V	88.2 V
Short-Circuit Current	9.10 A	9.39 A	1.79 A
Temperature coefficient of Pmax	-0.41%/°C	-0.41%/°C	-0.34%/°C
Temperature coefficient of Voc	-0.32%/°C	-0.32%/°C	-0.29%/°C
Temperature coefficient of Isc	-0.05%/°C	-0.05%/°C	-0.04%/°C
Maximum System Voltage (DC)	1000 V (IEC) or 1000 V (UL)	1000 V (IEC) or 1000 V (UL)	1000 V (IEC) or 1000 V (UL)
Module efficiency; no. of cells	16.50%; 72	17.30%; 72	16.3%
Power Tolerance	0 ~ + 5 W	0 ~ + 5 W	0 ~ + 5 W
Length	1956 mm	1956 mm	1200 mm
Width	992 mm	992 mm	600 mm
High	40 mm	40 mm	6.8 mm
Weight	22.5 kg	22.5 kg	12 kg

5.3.2 Technical Data Mounting Structure

With respect to the specific geometrical assumptions of PV tables and plant configurations, the following has been considered.

Table 5-4: Geometrical layout of mounting systems crystalline modules

Parameter	Unit	Fix (multi /mono-Si)	Fix (TF)	1-Axis (multi /mono-Si)	1-Axis (TF)
Table width	m	6	6	4	3.6
Table length	m	30	30	30	30
Modules per table width	-	3	5	2	3
Modules per table length	-	30	50	30	50

Module orientation	-	Horizontal	Horizontal	Horizontal	Horizontal
Minimum distance between PV tables	m	2.5	2.5	2.5	2.5
Distance between PV tables	m	2.5	2.5	4	3.6
Pitch	m	8.24	8.24	8	7.2
Length of one tracker	m	-	-	150	150
Tilt angle	°	10	10	0	0
Min / max rotation angle	°	-	-	±45	±45

For the fixed-tilt system, the following schematic Figure shows the tilt angle (β), the distance between PV tables or inter-row distance (b) and the pitch or distance between rows (d).

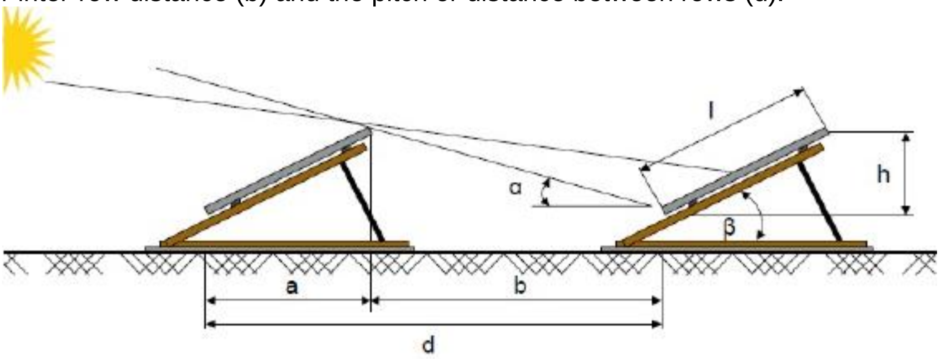


Figure 5-5 Illustration of tilt angle (beta), the pitch (d) and distance between PV tables (b)

The single-axis tracker system safeTrack Horizon from Ideematec has been selected for the project's conceptual design. The selected tracker offers a flexible design and does not use a linked row system, which increases accessibility for maintenance work. The tracker system is shown in the following Figures.

Figure 5-6: Single axis tracker frontal view (Source: system supplier)

Figure 5-7: Single axis tracker rear view (Source: system supplier)

5.3.3 Technical Data Inverter Station

The SMA central inverter station MVPS 2000SC has been selected for the PV plant design. The station comprises of two (2) SMA Sunny Central 1000CP XT outdoor inverters, a medium voltage transformer and medium voltage switchgear. The technical specifications for the inverter station are shown in the below table.

Table 5-5: Technical Specification of the inverter station

TECHNICAL DATA	MV Power Station 20005C
Input (DC)	
Max. DC power (at cos ϕ = 1)	2,244 kW
Max. input voltage	1,000 V
MPP voltage range (at 25°C / at 50°C)[1, 2]	688 V to 850 V / 596 V to 850 V
Rated input voltage	688 V
Max. input current	2 x 1,635 A
Number of independent MPP inputs	2
Output (AC) on the Medium-Voltage Side	
AC power (at 25°C / at 40°C / at 50°C)[3]	2,200 kVA / 2,000 kVA / 1,800 kVA
AC nominal voltages	11 kV
AC power frequency	50 Hz / 60 Hz
Transformer vector group Dy11y11 / YNd11d11	● /○
Max. output current at 20 kV	64 A
Max. total harmonic distortion	<3%
Power factor at rated power / displacement power factor adjustable[3]	1 / 0.9 overexcited to 0.9 underexcited
Feed-in phases / connection phases	3 / 3
Overall Effciency[4]	
Max. efficiency	97.7%
European weighted efficiency	97.4%
General Data	
Dimensions (W / H / D)[8]	6.058 m / 2.591 m / 2.438 m
Weight	< 14 t
TECHNICAL DATA	**SC 1000CP XT inverter (2 x)**

Nominal AC output power	1000 kW
Max. AC output power (@25 °C)	1100 kVA
Max. DC voltage	1000 V
MPP DC voltage range (@40 °C)	625 to 850 V
Max. DC current	1,635 A
Max. DC input power (@ cos ϕ=1)	1,122 kW
AC output voltage	405V
AC grid frequency	50 Hz./60 Hz.
Protection rating	IP54
Ambient temperature range	-25 to +62 °C
Efficiency (CEC)	98.5%

1) At 1.05 $V_{AC, nom}$ and cos φ = 1
2) Further DC voltages upon request
3) Information based on inverter
4) Efficiency measured without internal power supply

Figure 5-8: SMA MV Power Station 2000SC (Source: System supplier)

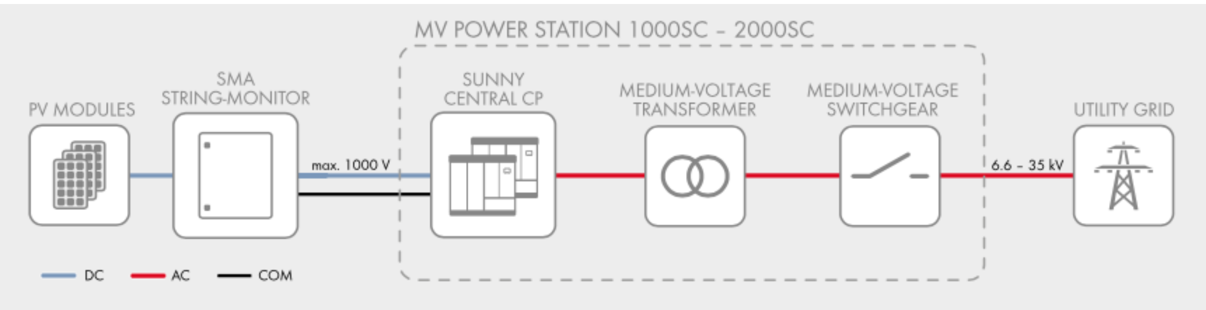


Figure 5-9: Schematic plant diagram (Source: System supplier)

5.4 Estimation of Key Performance Indicators, CAPEX, OPEX and LCoE

5.4.1 CAPEX Cost Assumptions

The CAPEX comprise all costs for the installation of the plant, including civil structures and interconnection to the closest substation. For solar PV installations, the major driving factor of capital expenditures is the cost of solar PV panels. In the past years, solar panel prices have represented approximately 40% to 50% of total solar PV system installed, price depending on the market and application type.
The following three key components of the CAPEX shall be explained in more detail:

- EPC cost
- Owner's cost
- Financing cost

EPC cost
For a non-recourse project-financing scheme, a so-called EPC contract is mostly mandatory to integrate the construction risk and allocate it to a party that can manage it. As such, in case of an EPC turnkey project, an experienced EPC contractor will carry out the engineering for the project, procure all the equipment and materials necessary and construct the plant, thus, providing the owner a facility that is "ready to use". The EPC contractor has to execute and deliver the project within an agreed time and budget, commonly known as a fixed-price, Date Certain Turn Key contract, providing the owner (or the Special Purpose Company) the respective guarantees.
EPC costs consist of the costs of plant equipment, on-site facilities and all infrastructure supporting the plant installation (e.g. workshops, office and roads) as well as costs for the direct and indirect labour required for the construction of the plant. These costs are often summarized as "bare erected costs". Further, there is the cost of services provided by the EPC contractor, including the basic and detail engineering, contractor permitting, project and construction management, site related studies, commissioning and start-up services or other indirect costs. Last, the EPC costs include the profit margin of the contractor and his contingencies.

Owner's cost
The owner's cost includes all further expenses for the owner, which are not included in the EPC turnkey package and which are not related to the financing of the project. The owner's cost can be grouped into the following:

- Project development (incl. preparatory studies and surveys, permits and licensing, taxes, development fees, etc.)
- Land cost (purchase or land lease during construction)
- Additional owner's cost (owner's management, owner's engineering, advisory services, lender's technical, legal and insurance advisors, insurances, O&M mobilization, pre-operating costs and contingencies…etc.)

The following table shows the CAPEX assumptions for the solar PV base case estimates:

Table 5-6: CAPEX cost assumptions

Description	100 MW_{AC} (135 MW_{DC})		50 MW_{AC} (67.5 MW_{DC})	
	Value	Unit	Value	Unit
EPC cost				
Multicrystalline modules (multi-Si)	342,000 $	USD/MWp	350,000 $	USD/MWp
Monocrystalline modules (mono-Si)	375,000 $	USD/MWp	383,772 $	USD/MWp
Thin film modules CdTe (TF)	360,000 $	USD/MWp	368,421 $	USD/MWp
Fix-tilt mounting systems	77,850 $	USD/MWp	80,000 $	USD/MWp
Single axis tracking system	147,350 $	USD/MWp	149,500 $	USD/MWp
Inverter stations, combiner boxes, cabling etc.	95,533 $	USD/MWac	96,222 $	USD/MWac
Electrical, mechanical, civil works	185,200 $	USD/MWp	192,200 $	USD/MWp
Emerging market factor (add. cost)	25	%	25	%
Grid connection	5,400,000 $	USD	5,400,000 $	USD
Owner's cost				
Development cost (including fees)	3,750,000 $	USD	3,000,000 $	USD
Land acquisition	1,700,000 $	USD	1,000,000 $	USD

The cost assumptions considered by the Consultant reflect international prices for utility scale PV projects. Taking into account that PV technology based utility scale projects are new to the Libyan market with limited experienced local market players available, the Consultant has considered an emerging market factor based on his experience from other emerging markets to be considered on top of international EPC cost.

5.4.2 OPEX Cost Assumptions

The OPEX are the fixed and variable O&M costs, which include the following:

- Monitoring (reporting, failure management)
- Corrective maintenance
- Preventive maintenance
- Special inspections all 4 years
- O&M staff
- PV module cleaning
- Site maintenance / vegetation management
- Commercial plant management
- Security
- Insurance (Equipment & third party liability)
- Accruals

The day-to-day operation and maintenance of a solar PV plant is conducted by an experienced O&M contractor, which guarantees his services at a fixed price. The assumed O&M insurance does not consider business interruption.

Table 5-7: OPEX cost assumptions

Description	Value	Unit
Fixed-tilt system	15.36	USD/kW_{dc}
Single axis tracked system	17.47	USD/kW_{dc}

5.4.3 LCOE Calculation

The technical solution is evaluated by calculating the LCOE (levelized costs of energy):

Table 5-8: Calculation of LCOE

$LCOE = \frac{PresentValue_{Costs}}{PresentValue_{Energy}}$	
$LCOE = \frac{\sum_{n=1}^{n} \frac{I_n + O\&M_n}{(1+i)^n}}{\sum_{n=1}^{n} \frac{E_n}{(1+i)^n}}$	I Investment costs (CAPEX) O&M Operating and maintenance costs (OPEX) E Energy generation at feed-in point (P50)

The LCOE calculations are done in constant prices. The division of the present value of costs by the present value of electricity production results in the levelized costs (LCOE). This value shows the expected unit costs of electricity produced by the PV plant at the feed-in point. It facilitates the cost comparison of the electricity produced by the new project compared to other forms of electricity generation (e.g. thermal power plants, diesel generators) or imports.

The development and construction period is assumed to be 6 months. 20 years of operation have been considered and discounting of future values is done with a discount rate of 8%. The input data are summarized in Table 5-9:

Table 5-9: General Input Data of the Economic Analysis

Discount rate	8 %
Construction Period	0.5 years
Repartition of investment costs	100% in 2018
Assessment period	20 years
Lifetime of equipment	20 years (no salvage value)

5.4.4 Comparison of Base Case Scenarios

The LCOE has been estimated for each of the base case scenarios taking into account the respective energy yield as well as CAPEX and OPEX cost assumptions (without financing costs). The results are summarised in the Table below:

Table 5-10: Comparison of base case scenarios

N°	Installed Capacity	Module Techn.	System type	DC Capacity	CAPEX	OPEX	Energy Yield	LCOE
-	MWAC	-	-	MWDC	MUSD	TUSD/year	MWh	USD/kWh

1	50.00	multi-Si	Fix	67.5	70.0	1,037	118,889	0.071
2	100.00	multi-Si	Fix	135	129.1	2,075	237,718	0.066
3	50.00	mono-Si	Fix	67.5	72.2	1,034	119,347	0.073
4	100.00	mono-Si	Fix	135	133.2	2,069	238,459	0.068
5	50.00	TF	Fix	67.5	71.1	1,033	120,878	0.071
6	100.00	TF	Fix	135	131.1	2,067	241,702	0.066
7	50.00	multi-Si	1-Axis	67.5	75.9	1,180	137,143	0.067
8	100.00	multi-Si	1-Axis	135	140.8	2,360	272,760	0.063
9	50.00	mono-Si	1-Axis	67.5	78.0	1,177	137,061	0.069
10	100.00	mono-Si	1-Axis	135	144.9	2,353	273,005	0.065
11	50.00	TF	1-Axis	67.5	76.9	1,175	138,900	0.067
12	100.00	TF	1-Axis	135	142.8	2,351	278,082	0.063

Comparing these base cases on the bases of the calculated LCOE. one can understand that cases with least costs for energy are more often in the second part of Table 5-10. This second part starting with No 7 reflects scenarios being based on single axis tracked systems.

Mounting System

In general, the single axis tracked system (case 7-12) is more attractive in terms of LCOE compared to the fixed-tilt system (case 1-6). The Consultant, however, recommends the fixed-tilt systems for the following reasons:

- From the Consultant's experience, it is recommended to apply fixed-tilt systems for a few early implementations of PV technology in emerging markets without a variety of experienced market players.
- PV technology in general generates electrical energy without rotating parts. This is an advantage with regard to long-term reliability. Tracked systems carry an additional operation risk.
- A single axis tracked system is more complex compared to fixed-tilt systems due to moving parts and higher maintenance requirements.

From this point of view, the recommended case will be part of the first part number 1 to 6.

Plant Capacity

The plant configuration with a capacity of 100 MW_{AC} is more attractive in terms of LCOE compared to a 50 MW_{AC} for all technology configurations since specific CAPEX are less for 100 MW_{AC} due to economy of scale effects and cost such as project development cost and grid connection cost do not decrease linear with the installed capacity.

This analysis limits the selection to number 2, number 4 or number 6.

Module Technology

In general, the average prices per watt peak of the modules vary among the different technologies with multi-Si modules being slightly cheaper than TF and mono-Si modules as shown in chapter 5.4.1. The resulting LCOEs indicate that the higher efficiency of mono-Si modules cannot compensate the additional cost compared to the multi-Si module technology while the difference between TF and multi-Si module technology is marginally and both options appear equally attractive in terms of LCOE.

However, with respect to the very limited number of system suppliers for the TF technology and experience available in the PV market, the multi-Si technology stands out as the preferred option. The multi-Si technology is a proven technology offering a wide range of system suppliers with a strong price competition in the market, which in turn enables a competitive bidding process.

Based on these arguments, the **recommended case is selected to be number 2**!

Conclusion

Based on the applied technical and financial assumptions as well as the project specific boundary conditions, a fixed-tilt system with multicrystalline module technology, central inverter system, 100 MW_{AC} capacity and 135 MW_{DC} peak capacity stands out as the preferred option for the Project site. During tendering stage however, the selection of the module technology, inverter concept and optimisation of the plant conceptual layout should be left open to bidders.

6. Recommended Case

From the previously conducted analysis of different base case scenarios, the Consultant has identified the recommended case as described in chapter 5.4.4 comprising of a fixed-tilt system with polycrystalline module technology and central inverter concept. The applied equipment and system configuration for the recommended case is summarised in the Table below.

Table 6-1: Summary of indicative technical specifications for recommended case

Parameter	Value
AC capacity	100 MWac
DC capacity	135 MWdc
Modules	Polycrystalline modules; Trina Solar TSM-320PD14; 320 Wp; 422000 modules; 20 modules in series/string; 21100 strings in parallel, 422 strings per inverter station
Combiner boxes (DC)	String combiner boxes; SMA DC-CMB-U-DEN1629-V15 (24 DC inputs) 18 combiner boxes per inverter station (8 x with 24 DC inputs and 10 x with 23 DC inputs per inverter station), 900 DC combiner boxes in total
Inverters	Central Inverter stations; SMA MVPS 2000SC with 2 x SC 1000CP XT outdoor inverters, MV transformer and switchgear; 50 inverter stations.
Mounting type	Fixed-tilt system; tilt angle 17°, pitch 8.24m, table width 6m 3 modules in portrait orientation per table width
Area required	approx. 127.5 ha

In subsequent chapters 6.1 to 6.3, the technical assumptions and simulation results of the energy yield estimation with PVsyst and respective uncertainties based on P75 and P90 confidence level are provided.

6.1 Applied Software and Technical Assumptions

This chapter describes the software used for simulating the performance of PV power plant. The main metric considered for performance simulation of PV plants is the annual energy produced. The specifications of the recommended case are used for the energy yield assessment.

PVSyst Software

The simulation of the various technical concepts was realized using the software PVSYST version 6.43. The applied software is a state of the art tool that considers all relevant loss effects of a PV plant and is a widely accepted tool for the analysis of electricity yields of large-scale solar parks.

Definition of losses

Once the basic system components and the layout are defined, the next step is to define various losses that occur in the system. The following assumptions (Table 6-2) are used during the energy yield modelling process:

Table 6-2: Technical assumptions for energy losses within PVsyst

Energy loss	Value
Constant Temperature loss factor (Uc)	29 W/m^2K
DC losses (at STC)	1.5 %
Light Induced degradation	1 %
Module mismatch losses (at MPP)	0.4 %
Incident effect, ASHRAE parameterisation (IAM = 1 – bo (1/cos I – 1)	0.05 (bo)
AC losses (at STC)	1.1 %
Soling losses	2 %
Auxiliary consumption (fans etc.)	190 kW
Unavailability of the system (time fraction)	1 %
Annual degradation	0.5 %

6.2 Energy Yield Assessment

The PVsyst software calculates the energy produced for 8760 hours of the year by taking into consideration various losses mentioned above. A Sankey diagram summarising the major energy losses that take place in the PV power plant is shown in Figure 6-1below. It should be noted, that direct shading (near shading) losses are calculated for each calculation step based on a 3D model of the PV plant built in PVsyst scene view.

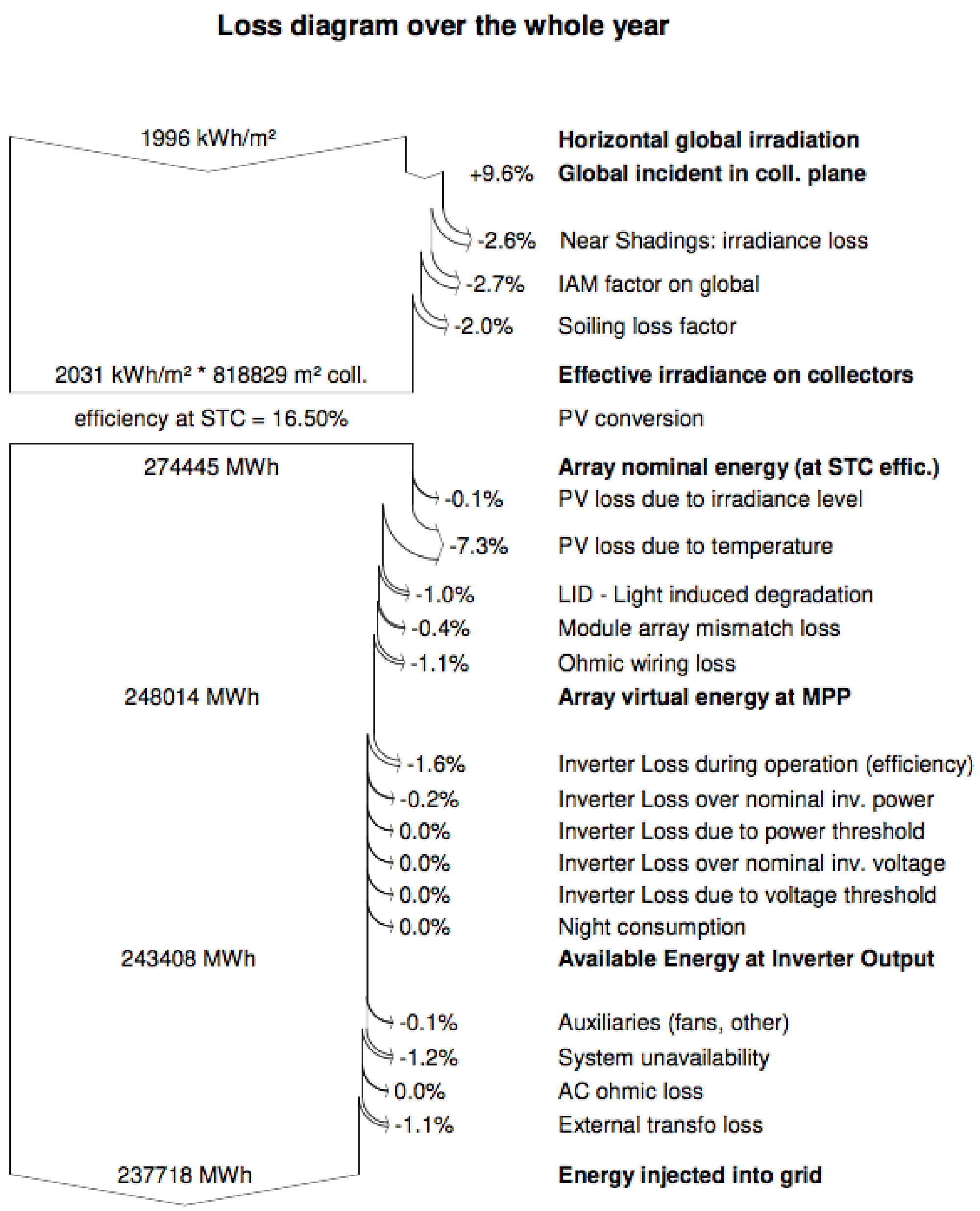


Figure 6-1: Sankey diagram obtained from PVSyst software representing the energy gain/loss at various stages of the simulation of the annual energy produced from the PV power plant.

The monthly electricity generation shows a peak generation from April to August with a maximum variation between months in the range of 79%. The monthly generation profile is shown in the Figure hereafter. The total net electricity production based on TMY input data amounts to **237.718 GWh/a.** The complete PVsyst report for the recommended case is attached as Annex 5 to this report.

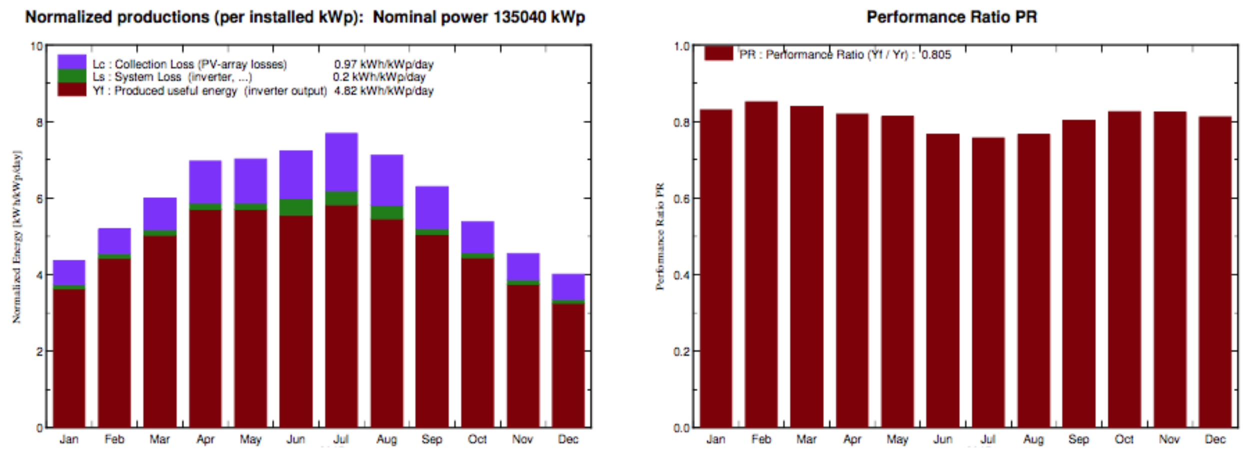


Figure 6-2: Monthly generation profile

Table 6-3: Monthly generation profile

Month	Electricity Production [MWh]
January	15179
February	16725
March	21054
April	23141
May	23906
June	22471
July	24385
August	22877
September	20509
October	18618
November	15214
December	13639
ANNUAL (P50)	**237718**

6.3 Uncertainty Analysis

The solar resource uncertainty has been assessed in detail during the solar resource assessment as described in chapter 4 from which the meteorological year (MY) on P75 and P90 confidence level is calculated based on multiyear uncertainties. The MY75 and MY90 input files with hourly time resolution (similar to the TMY) are than applied to calculate the respective energy yield and LCOEs on P75 and P90 confidence level as shown in Table 6-4hereafter.

Table 6-4: Summary of energy yield modelling uncertainties

Parameter	Unit	P50	P75	P90
Solar Resource (GHI)	kWh/m^2	1996	1963	1924
Energy Yield	GWh/a	237.72	234.01	229.62

LCOE	USD/kWh	0.066	0.067	0.069

6.4 Investment Cost Breakdown

The cost breakdown for the initial investment related to the recommended case is provided in Table 6-5.

Table 6-5: Investment cost breakdown for the recommended case

EPC cost	Cost
	USD
Polycrystalline modules (p-Si)	46,183,680 $
Mounting systems (fixed-tilt)	10,512,864 $
Cabling (DC/AC)	4,591,360 $
Inverter, MV transformer	8,307,000 $
Electrical, mechanical, civil works	25,009,408 $
Grid connection	5,400,000 $
Emerging market factor (25%)	23,651,693 $
Development cost (including fees)	3,750,000 $
Land acquisition	1,700,000 $
Total Investment Cost (TIC)	129,106,005 $

6.5 Grid Connection

The Shakshuk substation is located about 9 km away from the site. It is a 220/66/11 kV substation and allows for connection to the 220 kV overhead line. It is recommended that the plant connects with the substation at 11 kV via OHL. Figure 3-1 shows the location of the substation in relation to the site.

6.6 Single Line Diagram

To demonstrate the general concept being the basis for further calculation, an SLD is shown in Figure 6-3. The SLD mirrors the set-up up to the 11 kV bus bar. As discussed in section 6.5 from here the system can be connected to the Shakshuk substation. If the voltage level shall be changed, another transformer station needs to be add.

The SLD show the set-up starting for the number of modules per string over combiner boxes up to inverters. Always two inverters are installed in one inverter station. In total, 50 inverter stations with similar layout are calculated to be installed on site.

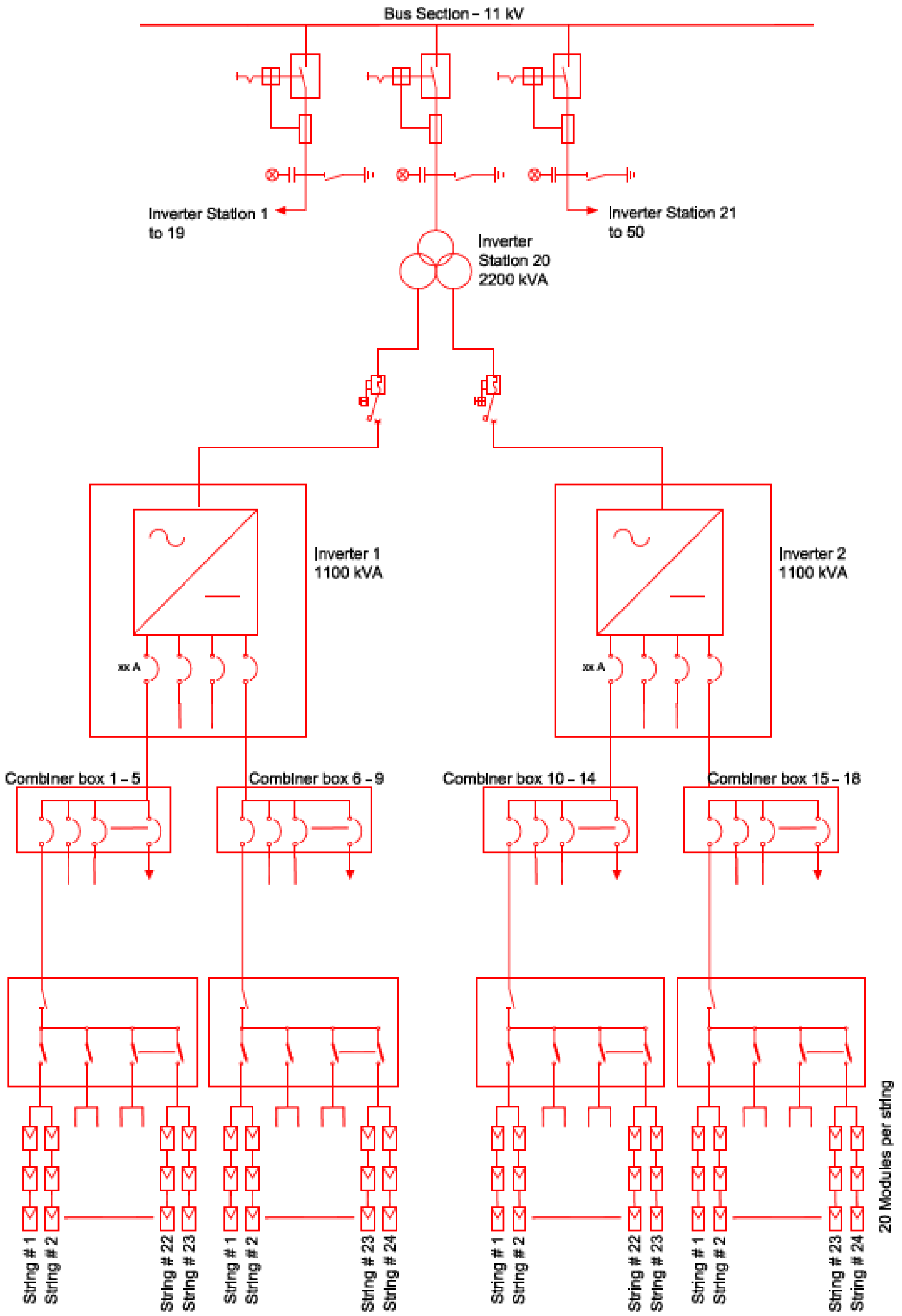


Figure 6-3: SLD reflecting the calculated plant set-up up to 11 kV bus bar

7. Environmental Screening

An intensive part of Consultant's task is the analysis of the environmental impact of renewable energy systems to be implemented in Libya.

Here, in this report, the focus shall be led omto the impact to be expected onto the selected site. An extensive review of the national conditions is displayed in Annex 6 of the study in hand.

Libya is located in the North Africa region between longitude 9°-25° east and latitude 18°-33° 18 north. The Libyan territory spreads from the Mediterranean coast in the north to the Sahara with a total surface area of approximately 1.750 million km^2. Libya has borders on the east with Egypt, on the west with Tunisia and Algeria and on the south with Chad, Niger and Sudan[1].

7.1 Environmental Screening of PV Technology

PV technology has reached several year ago a mature status, passed grid parity in almost all countries and became one of the highly competitive technologies for power generation. Prices of main components have dropped dramatically during the last years. The global PV industry has already passed a strong learning curve with plenty of innovations and efficiency increase.

The main component in solar PV power plants is the PV module. A module consists of several cells that have the capacity to convert the solar radiation into electrical energy. The most dominant cell technologies are made of crystalline silicon and thin films. Each module, independent of the technology, has to be certified with clearly defined and guaranteed performances over a period of 5-20 years. PV modules are mounted on fixed structures or on tracking systems that follow the sun. The tracking systems require a higher investment and result in increased O&M cost, but they offer an energy yield gain of up to 35%.

Energy produced from PV technology cannot be stored at economic price levels today because batteries are too expensive, thus the produced energy has to be fed into the grid at the time of generation.

Another key component in a solar PV power plant is the inverter that changes the electric current from DC to AC. Large-scale power plants can utilize both small and large inverters. The largest inverters have power outputs of more than a megawatt and they often represent the cheapest solution. However, the large-scale inverters are also very heavy; their implementation, therefore, relies on special equipment for heavy transportation and lifting. In addition, any maintenance on these inverters has to be performed by people certified by the supplier. On the other hand, by using smaller inverters of approximately 20-60 kW each (string inverter concept) would reduce the risk of long downtime during malfunctions. Downtime of one single inverter would only affect a small part of the plant; in addition, the inverter can be exchanged by a trained electrician.

7.2 Expected Project Activities

The main project activities that are needed to implement a solar project could be divided in:

[1] https://sustainabledevelopment.un.org/content/documents/2136Country_intervention_on_drought_Libya.pdf

1. Design and mobilization phase

Once all permits and development processes are completed, the project implementation starts. The following key activities form the essential milestones of the mobilization and design phase:

- Preparation of a temporary campsite;
- Establishing fences around the project site;
- Transportation of materials, equipment and machinery to project site;
- Storing materials;
- Mobilization and hiring workers and employees;
- Preparation of site construction materials; and,
- Setting security and safety rules, procedures and deploying staff.

2. Construction Phase

Generally, a solar PV project construction phase consists of the following key activities:

- Construction of an adequate access infrastructures to the site;
- Site clearance, including earth movements, clearing works, excavations and stockpiling of excavated materials;
- Transportation of construction materials from extraction areas, commerce and storage areas to the project site;
- Transportation of equipment, machineries and workforce to the project site;
- Civil work;
- Mechanical and electrical work;
- Installing the mounting structures;
- Mounting solar panels, collectors, etc.;
- Installing pipes, cables, recievers, etc.;
- Erection and installation of inverters, transformers, power plants central units, etc.; and,
- Connecting the solar power plants to the power transmission / evacuation lines.

3. Operation Phase

Generally, the operation phase consists of the following:

- Operating, cleaning and maintaining the solar panels;
- Operating the automated machines in the power plant;
- Periodic examination and maintenances of the solar panels and related equipment in the power plant; and,
- Monitoring and repairing the transmission/distribution lines.

To build the project, there would need for construction materials, construction water and for drinking water and sanitary water. This process should respect environment. The selection of the site from where to source construction materials such as stones, gravels, etc. should respect environmental conditions and Libyan regulations as well as international best practices.

The construction and operation phases will need qualified and unqualified workforce. Operation phase will create fewer, but skillful, jobs compared to construction. This labor shall be sourced locally in order to generate positive impacts on local employment, however, realistic and tangible measures should be created in order to train on jobs and hire locally.

Waste generation is expected during construction phase and will consist of construction wastes and domestic wastes. At the same time, solid wastes will be generated by workers in forms of food packaging, cans, bottles, etc. Waste management should be handled carefully as the local ecosystems are so fragile and would be very sensitive receptors.

Liquid wastes will be also generated by workers. Septic tanks should be installed on sites to collect this waste and they should be emptied in regular basis and transferred to an authorized liquid waste treatment station.

7.3 Anticipation of Impacts

The initial environmental screening has identified the following environmental impacts at Jadu site.

Table 7-1: Identification of possible impacts at Jadu site

Impacts	
Land use	Although the land is not arable and there is almost no vegetal cover, the installation of a PV power plant in this site might affect flora mostly inhabited by small reptiles, insects, etc. However, the effect of this impact will be limited. On the other hand, it is recommended that the detailed ESIA considers assessing the use of this site for pastoralism.
Landscape and visual impacts	The nearest town is 11 km from this site and it is anticipated that the project will have very limited visual impact during construction and operation. Meanwhile, only during construction the presence of construction machineries and quite large number of vehicles might give negative visual impacts.
Hydrology	For this initial screening, the site is considered to have ground water at a depth of 100 m; therefore, it is recommended to check in details the use of ground water by the adjacent communities during ESIA, and that during construction and operation, proper measures are adopted in order to avoid any contamination.
Biodiversity	There are no protected areas adjacent to the site. Furthermore, the site soil is sporadically covered by vegetation. It is anticipated that most sensitive receptors would be small reptiles. Project construction activities could destroy habitats and their flora and fauna. However, the ESIA shall consider assessing the use of site by birds or existence of any endemic Saharan vegetal species.
Archeology	The initial screening demonstrated that there is no evidence on the existence of an archeology site, which might be impacted by the construction of the solar project.
Air quality	The nearest town is 11 Km from this site and it is anticipated that the project will have

	very limited impacts on the adjacent communities with regards to air quality; however, workers shall wear the adequate personnel protective equipment during construction. It is anticipated that during construction activities, particles will be emitted as consequence of combustion exhaust gases from generators, machineries and vehicles; dust from soil during land clearance and movement of vehicles and machineries.
Noise	The nearest town is 11 Km from this site and it is anticipated that the project will have very limited impacts on the adjacent communities with regards to noise; however, workers who will operate machineries generating noises, shall wear the adequate personnel protective equipment during construction such as ear muffins. In case, materials transportations to the site will pass closed to villages, machineries and vehicles shall observe safety measures and limited speed in order to avoid any potential damage on residents.
Traffic and Transportation of materials	In case, materials transportations to the site will pass closed to villages, machineries and vehicles shall observe safety measures and limited speed in order to avoid any potential damage. From this initial screening, it could be stated that there is already a paved road that could be used for accessing the site; so, there would be no need to build an access road and assess potential impacts.
Soil and Land degradation	The construction of a solar project will need the clearance of soil vegetation; however, given that the vegetal cover is very limited; Land degradation will be very limited. On the other hand, specific measures shall be taken in order to maintain soil. It is also anticipated potential soil contamination from accidental spillage.
Wastes	During construction and operation, solid and liquid wastes will be generated by workers engaged. Liquid waste will be in form of grey and black water. Solid wastes will be in form of canes, cartons, food packages, etc. During construction, construction wastes such as rocks, stones and other materials will be generated in addition to woods, pellets and cartons from components packaging.
Community safety, security and health	The nearest town is 11 Km from this site and it is anticipated that the project will have very limited impacts on community safety, security and health.
Occupational health, security and safety	Workers will need to observe safety and security measures, and wear the proper personnel protective equipment.
Water	For this initial screening, the site is considered to have ground water; therefore, it is recommended to check in details the use of ground water by the adjacent communi-

	ties during ESIA, and that during construction and operation, proper measures are adopted in order to avoid any contaminations through accidental spillages. During construction, there will be need for construction water, sanitary water and drinking water.
Vibration	During construction, workers will have to observe the safety and security measures and wear the proper personnel protective equipment in order to avoid any incidents. Meanwhile, the use of machineries, which generate vibration, shall follow the guidelines and norms to avoid any incident.
Jobs and business opportunities for local population and firms	The construction, operation and maintenance of solar project will create job and business opportunities for local people. However, there would be need to assess local skills offer and projects needs and work in cooperation with local authorities and population representatives to avoid any unrealistic expectation with regards to project positive impacts on local population.

7.4 Recommendations

Based on this initial screening, it is concluded that the Jadu site is adequate for solar PV installations. However, it is recommended to conduct an ESIA for the site. The ESIA shall mainly respond to the national requirements, the World Bank Environmental Safeguard Policies, IFC Environmental, Health and Safety (EHS) General Guidelines, as well as other international best practices such as Equatorial Principles.

The ESIA shall establish baseline environmental and social information at a level of detail necessary to conduct the analysis and assessment of potential impacts, and anticipate an assessment of solar module glint on the basis of technical design that would be initially set.

In the ESIA, a special focus shall be given to waste disposal and waste management, which shall comply with local standards. Developer(s) shall present a waste management plan, where hazardous and toxic wastes such as paints, adhesives and resins or lubricants shall be managed and disposed in full respect of the local regulations.

Developer shall also set an EHS where general frame of guidelines for health and safety standards for solar projects, as well as for the associated infrastructure and activities outside the site. ESH shall cover safety rules on site and during transportation to the site, emergency plans, access to site, setting HSE management program; provision of sanitary services and welfare amenities on site; identify critical health and safety relevant activities; access only to qualified personnel undertaking activities relevant to their duties and provision of suitable personal protection equipment.

ESIA shall propose mitigation measures for impacts that are considered significant. Furthermore, ESIA shall develop a comprehensive Environmental and Social Management Plan, which will describe and prioritize the actions needed to implement mitigation measures, corrective actions and monitoring measures necessary to manage the identified impacts. ESIA shall also include environmental monitoring plan with allocation of duties and timeframes in order to implement the mitigation measures. Environmental and monitoring plan will also include reporting requirements and schedules for periodic reports on the implementation of the environmental and social management plan.

It is strongly advised that the developer(s) consider(s) and implement(s) an adequate stakeholder's engagement. The stakeholders' engagement shall include: a comprehensive description of the project, its components, its potential impacts and the standards that govern its development and implementation; engagement planning activities to be carried out. These activities will define the objectives, the modes of engagement of the stakeholders in the activities, the appropriate methods of communication (adapted to the cultural characteristics and the corresponding language(s) and in prior consultation with the participants), the support to be used, timing and engagement activities of stakeholders.

Stakeholder consultation to support the ESIA process specifically aims to achieve the following objectives:

- To provide information about the project and its potential impacts to those interested in or affected by the project, and gather their views in this regard;
- To provide opportunities to stakeholders to discuss their expectations and concerns;
- To manage expectations and concerns regarding the project;
- To discuss significance of anticipated environmental and social impacts;
- To discuss the process of developing appropriate mitigation measures;
- To build a continuous communication with stakeholders;
- To adequately integrated the views and concerns of stakeholders with regard to the proposed project;
- To discuss the environmental and social management plan.

8. Financial Analysis and Financing Strategy

The objective of the financial analysis is to assess the financial feasibility of the project from the perspective of an IPP investor. The calculations are done with market prices and taxes as they represent relevant costs for the investor(s).

A minimum feed-in price was calculated for the project at which the IPP can sell electricity to the grid in order to achieve a minimum Return on Equity (RoE). The calculation of this tariff includes all costs that have to be incurred by the investor compared to the calculated annual electricity production.

The input data of the financial analysis are as follows:

Table 8-1: Input Data of the Financial Analysis

Item	Value
Construction Period	0.5 years (starting 1st July 2018)
Assessment period	20 years
CAPEX	130.0 Mio USD (incl. financing costs during construction)
OPEX	2.1 Mio USD (annual price increase:3%)
Financing - Debt	70 % debt financing 20 years loan tenor 5 % interest rate
Financing – Equity	30 % equity financing 15% required return on equity
Accounting equipment depreciation	5 % annually
Working capital	45 days of accounts receivables (operating revenue) – 30 days of accounts payables (operating expenditures)
Taxes	30 % corporate tax

The technical data in terms of annual generation and degradation are the same as in the economic analysis. The cost estimate is higher in the financial analysis as financing costs (interest during construction) is included. The input data mentioned above are partially based on assumptions (e.g. loan tenor, tax rate, equipment depreciation).

8.1 Results of the Financial Analysis

The result of the financial analysis reflects the minimum costs for the off-taker required to satisfy the IPP and guaranteeing the availability of funds for debt service and ensuring financial solvency of the project. In order to assess the project's ability to service the loan, the debt service coverage ratio was determined by dividing the free cash flow for debt service by the annual debt service. The free cash flow for debt service is calculated by adding back the interest and depreciation outflows on the profit after taxes determined in the profit & loss statement or by subtracting the corporate & education tax from the earnings before interest, taxes, depreciation and amortization (EBITDA).

The debt service coverage ratio is an important instrument to evaluate the sustainability of a project from financier's point of view. A DSCR below 1.0 would indicate that there is not enough cash to cover the loan. If the debt service coverage ratio is over 1.0, this still does not mean necessarily that the bank will lend at this rate. The ratio should ideally be above 1.2.

Table 8-2 shows the required tariff to ensure a 15 % return on equity given the costs to be recovered in Table 8-1. Two tariffs are shown:

1) Tariff based on cash flow resulting from the income statement (profit after taxes)
2) Tariff based on cash flow resulting from the cash flow statement

The tariff is lower in the second case as the cash flow statement considers the annual credit repayments (principal + interest) without considering depreciation of equipment. This does not represent a cash outflow within the cash flow statement, but represents an accounting item in the income statement. Therefore, deductions in the income statement are higher than in the cash flow statement as depreciation + interest payments are higher than just principal + interest repayments. This is particularly valid in the present annuity based loan calculation where principal repayments are comparatively low in the first years and increasing from one year to the next whereas interest payments are decreasing to keep constant annuities. Furthermore, depreciation period and principal repayment period are assumed to be the same here. The resulting tariffs are shown in Table 8-2.

Table 8-2: Results of the Financial Analysis

Cash flow basis	Required tariff	Minimum DSCR
Income statement	9.31 USD cents/kWh	1.8
Cash flow statement	7.61 USD cents/kWh	1.5

Both results show a proper range of DSCR, but due to the discussion in the paragraph above the more realistic case is the Income statement case leading to a required tariff of 9.31 USD cents/ kWh.

In the following sensitivity tests, the tariff based on income statement will be considered (equity investment compared to dividend payment). This is defined as the base case of the analysis.

8.2 Sensitivity Analysis

The solar PV plant has been analysed based on different input data and assumptions. A sensitivity analysis was performed on key parameters to test the result of a change in the variables on the financial performance of the project.

Table 8-3: Sensitivity Tests

Sensitivity Test	Required Tariff
P75 electricity generation scenario	9.46 USD cents/kWh
P90 electricity generation scenario	9.64 USD cents/kWh
20 % increased investment costs	10.96 USD cents/kWh
20 % increased O&M costs	9.53 USD cents/kWh

The effects of more positive input factors, which would have the potential to bring down the required tariff are shown below. It should be stated that these values could only be reached under conditions that are not known by the Consultant today.

Possible carbon credits from the Clean Development Mechanism (CDM) are not taken into account in the base case. Therefore, the Consultant introduces into his sensitivity tests a consideration of possible CDM benefits and costs. For the calculation of the benefits, the current CER (certified emission reduction under the CDM) Futures price is taken into account. This price is currently very low at 0.21 USD/t CO_2. Another scenario considers the spot price of EU allowances (EUA), reflecting the value of carbon credits traded in the EU Emission Trading System (ETS), which is currently at 8.47 USD/t CO_2. Companies in the EU Emission Trading Scheme are allowed to offset a small proportion of their emissions using CERs. Therefore, negotiation between CDM projects and European industry might lead to higher prices of the CERs. However, if the spot/Futures price remains low at the above-mentioned level, the registration of the project may not be viable as the upfront costs of preparation and registration as well as the annual verification costs calculated over the lifetime of the project are already at least as high as the CER price. According to a recent study, solar projects require high CER prices above 11.7 USD/t CO_2 in order to be viable in terms of carbon credits.2 Consequently, this higher price is also considered within this sensitivity test.

Table 8-4 shows variations of the tariff following "favorable input data":

Table 8-4: Sensitivity Cases – More Favourable Conditions

Sensitivity Test	Required Tariff
Base case	9.31 USD cents/kWh
20 % reduced investment costs	7.68 USD cents/kWh
Consideration of carbon credits (EUA)	8.62 USD cents/kWh
Consideration of carbon credits 11.7 USD/t CO_2	8.34 USD cents/kWh
Improved financing conditions 3 years grace period (no interest during grace p.) 1.5 % interest rate	8.04 USD cents/kWh
Improved financing conditions 10% required return on equity	8.28 USD cents/kWh
Improved financing conditions 3 years grace period (no interest during grace p.) 1.5 % interest rate 10% required return on equity	7.12 USD cents/kWh
Income tax exemption	8.16 USD cents/kWh
Improved financing conditions & income tax exemption	6.27 USD cents/kWh
“Best case” considering all above improvements	4.26 USD cents/kWh

In the "best case" scenario, the required tariff could be as low as 4.26 USD cents per kWh sold. It should be noted that this is not a likely scenario (e.g. best case of carbon credits and reduced investment costs), but it shows a tendency on the level the tariff could ideally reach. The scenario presenting improved financing conditions and income tax exemptions shows the possibilities to reduce costs from the perspective of the Libyan Government as well as the involved financing partners.

2 CER and EUA spot- and futures prices as of www.eex.com, costs of CDM registration and verification as of Ecofys/Climatekos (2013): “CDM Market Support Study”, p. 12 and p. 21ff.

Another very interesting result of the sensitivity analysis is the strong dependency of the needed tariff on the ROE expectations. Reducing this from 15% to 10% will lead to a required tariff of 8.28 USD cent/ kWh. This is a tariff reduction of more than 10%. Such conditions can only be met in case the business environment for the investors is save, reliable and well-regulated.

9. Conclusions

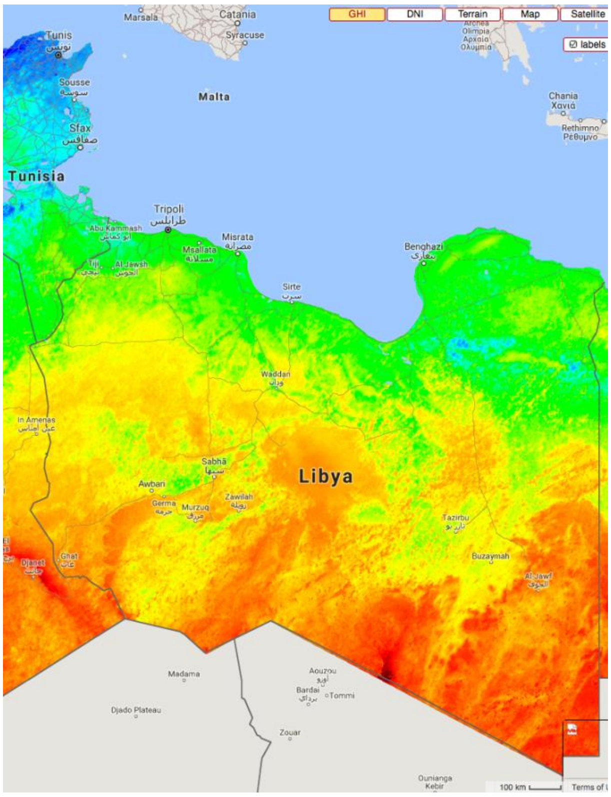
The feasibility study for a first PSP project showed very positive results:

- The number of sites available in Libya is huge.
- The selected site close to Jadu is suitable.
- ESIA screening did not show impacts, which might jeopardise ta project seriously. Nevertheless, a full-scale ESIA has to be performed.
- For the first step, PV technology was selected, mainly due to the chance to implement PV plants on short notice (compared to other RE technology based plants and due to the fact that PV technology in general can be structured based on easy manageable products
- PV technology as such is well matured and not an unknown risk.
- While technology selection, the comparison of different set-up showed that more challenging technologies like one axis tracking do not give a big advantage from a cost perspective.
- Although the analysis in hand defines a set of technologies for the feasibility analysis, this needs not be reflected in an RfP paper. There is the chance to open for further technologies and allow bidders to use "their" solution.
- Financial calculation showed that PV is possible to install considering moderate costs for the energy to be sold from the Utility
- An important driver for the costs is the expectation of a private investor regarding the interest rate for his investment. This rate is strictly depending on his assumption regarding the risk for his investment. By smoothing the political and the legal conditions, more confidence can be stimulated leading to lower expectations.
- Finally, the costs are quite sensitive against these expectation

Wrapping up this information:
There is no hurdle for a development of the Jadu site for a utility scale PV project. Further important and positive conditions can be created by preparing the legal environment for PSP / IPP projects in the country.

Annex 1: Site Selection for Pilot PSP

Libya -
Supporting Electricity
Sector Reform
(P154606)



Contract No. 7181909 - Task D:
Strategic Plan for Renewable Energy Development

Feasibility Study for a PV Plant at Jadu Site
Annex 1 - Site Selection for Pilot PSP
18th December 2017

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1. Introduction

The objective of this activity is to inspect the project region and its environment, assess particularly the local conditions in order to confirm the site for the installation of the technology option and verify already available information from previous analyses. The quality of the so far collected data will be critical for the future concept design of the technology option.

2. Solar Resource

Based on the information made available and the Consultant databases the Consultant reviewed the overall solar and wind resources available in the country and identified the most suitable areas, and when possible sites, of the country for implementation of PV, wind or CSP projects.

Libya has a high potential of solar energy for both, PV-technology and CSP-technology due to the very favourable conditions of global and direct solar radiation for almost the whole country. The annual average of sunshine hours reaches around 3,200 hours.

2.1 Global Horizontal Irradiance (GHI) – PV

The distribution of the long-term annual GHI sums is quite homogeneous in Libya and can reach up to around 2,500 kWh/m^2 for the Tibesti Massif in the South that rises to over 2,200 metres. However, this region is very hard accessible and an almost total empty desert countryside, thus not the first option for solar energy.

In general, almost the whole country reaches long-term annual GHI sums, which are more than suitable for solar energy applications with PV-technology. Higher GHI values occur in the centre, South, Southeast and West (yellow, orange and red colour shades in Solar-Med-Atlas, Figure 2-1). Lower GHI values of around 2,000 kWh/m^2 appear in the North and in Northeast (green colour shades in Solar-Med-Atlas, Figure 2-1). In the coastline, it is partly below, especially in the eastern and southern part of the Gulf of Sirte. Only the Solar-Med-Atlas shows for very small areas long-term annual GHI sums below 1,900 kWh/m^2 indicated by the blue colour shades.

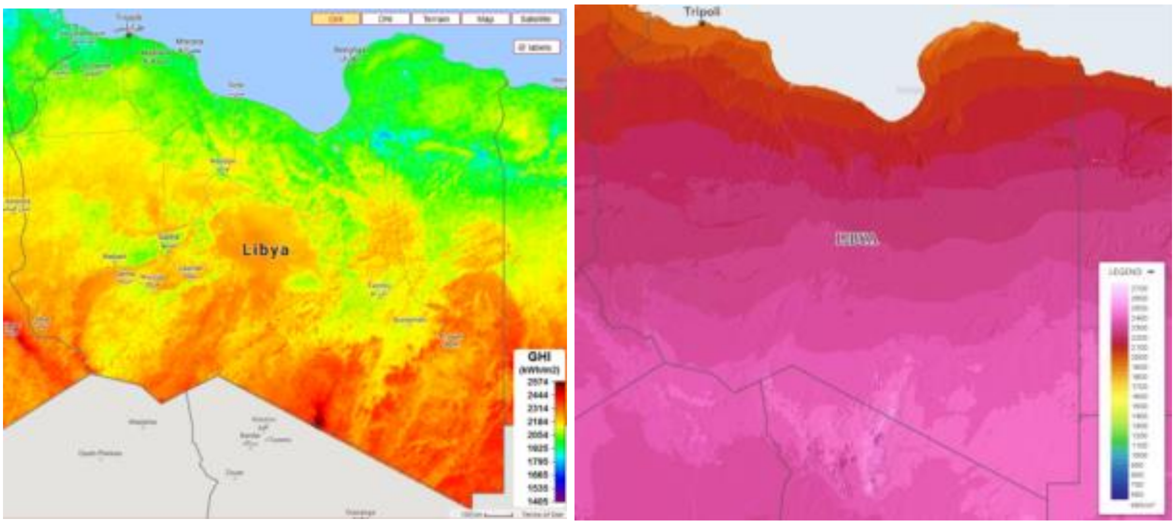


Figure 2-1: GHI map from the Solar-Med-Atlas (left) and World Bank's ESMAP (right)

2.2 Direct Normal Irradiance (DNI) – CSP

In comparison to the GHI distribution the distribution of the long-term annual DNI sums is naturally more heterogeneous in Libya, as can be seen in Figure 2-2. This figure shows the DNI maps from the Solar-Med-Atlas (left) and World Bank's ESMAP Global Solar Atlas (right). The highest values up to around 3,000 kWh/m^2 can also be found for the Tibesti Massif in the South. However, this region is very hard accessible and an almost total empty desert countryside, thus no option for solar energy.

In a big part of the country the long-term annual DNI sums, lying between 2,200 kWh/m^2 and 2,500 kWh/m^2, are suitable for solar energy applications with CSP-technology. Similar to the GHI distribution, higher DNI values occur in the centre, South, Southeast and West (yellow, orange and red colour shades in Solar-Med-Atlas, Figure 2-2). Lower DNI values of around 2,000 kWh/m^2 to 2,200 kWh/m^2 appear in the North, Northeast and Southwest (green colour shades in Solar-Med-Atlas, Figure 2-2). In the coastline it is partly below, especially in the eastern and southern part of the Gulf of Sirte. Only the Solar-Med-Atlas shows for very small areas long-term annual DNI sums below 1,900 kWh/m^2 indicated by the blue colour shades.

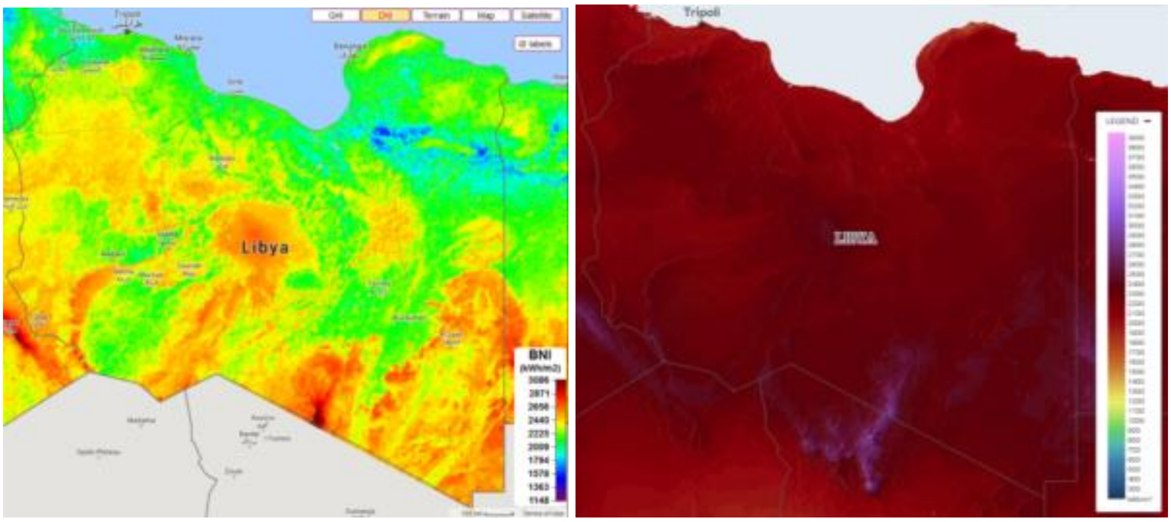


Figure 2-2: DNI map from the Solar-Med-Atlas (left) and World Bank's ESMAP (right)

2.3 Available Ground Solar Measurements in Libya

According to the information made available to the Consultant and direct requests of the stakeholders some locations are pre-selected for studying the solar resource potential available in Libya.

Although several solar resource measurement campaigns were commissioned the bulk of the ground data is missing and cannot be retrieved. The best sets for solar data are at Bir Al-Gahnam, Ghadamis, Edri and Thala, however only Bir Al-Gahnam and Ghadamis include DNI data. Although for some of the remaining sites, there are solar resource assessment reports the ground data is missing and thus only satellite data could be used for the simulations.

Brega, Zliten, Jagboub, Kufra1 and Kufra2 were added to the analyses either by the Consultant or by suggestion of the stakeholders. Data to be used at these sites is also satellite data.

Figure 2-3 shows the locations for solar power plants considered including those with available ground data and those with only satellite based data.

Figure 2-3: Locations selected for solar power plants incl. solar met stations

Table 2-1 presents a summary of the pre-selected sites for verification of the solar resource after performing a review of the solar data provided and, when possible, gives an overview of the long-term estimate of GHI and DNI for the considered locations.

Table 2-1 Summary of pre-selected sites according to solar resources

Area	City/town	Coordinates (Latitude, longitude)	Meteorological station: Name	Coordinates (Latitude, longitude)	Distance (km)	GHI Ground data
Tripoli	Zliten	32°12'37"N; 14°30'1"E	N/A[1]	satellite data	N/A[1]	Satellite
Tripoli	Jadu	32° 5'55"N; 12° 4'47"E	Bir al Gahnam	32° 21' 3.19" N; 12° 39' 21.39" E	60	Data
Bengazhi	Al Tamimi	32°27'2"N; 23° 5'28"E	N/A[1]	satellite data	N/A[1]	Satellite
Bengazhi	Shahat	32°48'37"N; 21°44'16"E	Shahat	32°45'36.00"N; 21°53'24.00"E	15	Report
Sebah	Sebah	26°47'20"N; 14°25'16"E	Sebah	26°47'19.65"N; 14°25'16.22"E	4	Report
Sebah	Edri	27°29'19"N; 13°10'50"E	Argiba	26°34'50.28"N; 13°34'25.56"E	100	Data
Ghadamis	Ghadamis	30° 5'35"N; 9°36'17"E	Ghadamis	30°10'4.80"N; 9°45'21.60"E	17	Data/Report
Hun	Hun	29° 8'34"N; 15°51'34"E	Hun	29° 9'15.69"N; 16° 0'17.60"E	15	Report
Ghat	Thala	25°24'37"N; 10°21'34"E	Ghat	24°57'51.53"N; 10°10'32.72"E	52	Data
Jagboub	Jagboub	29°44'28"N; 24°30'0"E	N/A[1]	satellite data	N/A[1]	Satellite
Jagboub	Kufra1	27°38'53"N; 21°42'47"E	N/A[1]	satellite data	N/A[1]	Satellite
Jagboub	Kufra2	26°56'49"N; 22° 9'3"E	N/A[1]	satellite data	N/A[1]	Satellite

1 Sites considered for PV implementation however no solar measurements have been performed there

3. Grid Connection Alternatives

This assignment focuses on grid connected solar and wind facilities and therefore it is of foremost importance to locate these facilities at suitable distances from potential connection points. Typically suitable connection points are substations on the 66 or 30 kV level and under certain conditions at 220 kV level for the case of Libya. A reasonable proximity to the connection points will not only reduce transmission losses but will also maintain CAPEX at predictable levels as transmission lines are capital intensive and require complex permits and authorization processes.

This assignment, and for extension this section, does not deal with analyses of power networks. Due to its complexity, such analyses if required shall be part of a separate assignment or shall be carried out during the implementation of the project. It is a main assumption that potential connection points/substations shall be analysed in more detail in further steps of implementation where decisions on either expansions or upgrades of these connection points shall be taken.

For the identification of sites the Consultant will focus on existing substations by identifying connection points:

- Either existing or planned, defined in the transmission system network studies;
- Mentioned in existing feasibility studies;
- Close to sites with existing ground measurements (see section 2); and
- Suggested by the stakeholders.

Figure 3-1 depicts a screenshot of the georeferenced Libyan grid as provided by GECOL to the Consultant.

Figure 3-1: Georeferenced Libyan grid as provided by GECOL[1]

The substations identified have been, to the extent possible, georeferenced, characterized and cross-checked with the latest information provided by GECOL and the existing feasibility studies. The areas proposed for the analysis were presented and agreed with the stakeholders with no major objections to use the substations on those areas for further analyses.

With regard to the location of potential RE power plants, GECOL generally stated that such power plants should be installed preferably more in the south of the overall transmission and distribution grid (e.g. in the southern centres of the two main North-south branches of the grid). Since the main conventional power plant fleet is located more in the northern coastal line, GECOL suggestion will help to balance the overall load flow, to avoid negative impact of short circuit issues and overall stabilize with this the system.

3.1 Transmission System Network Studies

In an initial step, the Consultant has screened the existing transmission system network studies for potential substations near the selected sites defined in section 2. Figure 3-2 sets out the location of the identified substations and Table 3-1 summarizes the current status of the following information of each substation:

- Name of substation in English language;
- Voltage level;
- Coordinates;
- Available capacity of connection (MW);
- Existing, under construction or planned; and

[1] Libyan networks georeferenced in GoogleEarth (.kmz file with substations), provided by GECOL, 2017

- Year of installation.

This information allows the Consultant to determine the areas for installation with better resolution, as well as the size of RE facilities and the distance of interconnection.

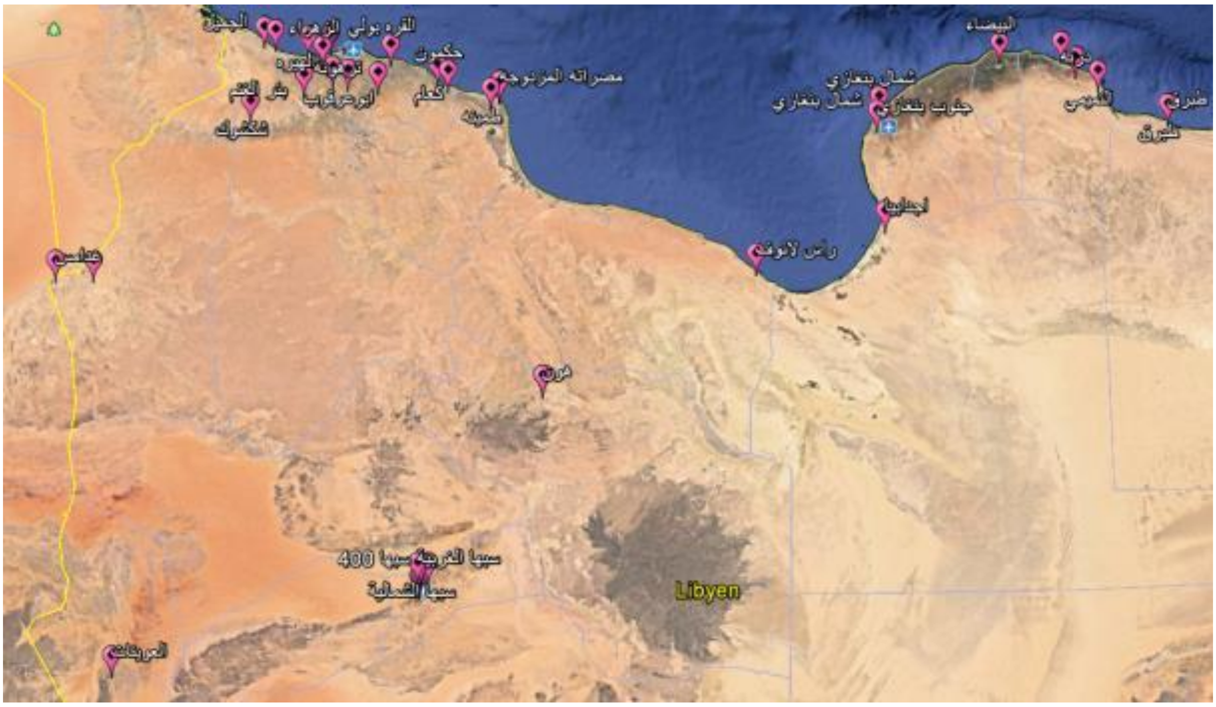


Figure 3-2: Potential connection points for RE facilities in Libya acc. to transmission studies

Table 3-1: Summary of identified connection points – Transmission system network studies

Connection point - Substation													
Name	Coordinates	Check with GECOL geodata			Distance	TFR Rating	Capacity	Year	Voltage	Planned load [MW]			Av.
	(Latitude, longitude)	Name	(Latitude, longitude)	Info	[km]	[MVA]	MW		[kV]	2020	2025	2030	MW
Gyrian	(MISSING)	الهيره	32°27'3.87"N; 13° 2'9.07"E	محطة تحويل 220/66/30/11 ك.ف الهيره			0						0
El Hira	(MISSING)	ابوعرقوب	32°25'15.03"N; 13°14'18.85"E	محطة تحويل 220/30/11 ابوعرقوب			0						0
Alzahara (Azahra)	32°40'45.10"N; 12°52'44.50"E	الزهراء	32°40'46.86"N; 12°52'43.32"E	محطة تحويل 220 ك.ف الزهراء	40	126	101	1974	220/66/30	126	145	165	-64
Bir Huisa	32°31'26.30"N; 12°40'57.70"E	PLANNED?			40	200	160	2015	220/30	26	30	34	126
Bir Alganam	32°21'6.00"N; 32°21'6.00"N	بئر الغنم	32°21'3.19"N; 12°39'21.39"E	محطة تحويل 220/30/11 ك.ف بئر الغنم	36	126	101	1981	220/30	144	165	188	-87
Mislata	32°35'28.68"N; 14° 4'14.93"E	القره بولي	32°42'55.01"N; 13°47'9.22"E	محطة 220/30/11 ك.ف القره بولي	20	200	160	2015	220/30	63	73	83	77
Wadi Rabea (Ramil?)	32°31'51.50"N; 13°56'12.71"E	PLANNED?			11	200	160	2015	220/30	97	112	127	33
Tarhona	32°23'52.90"N; 13°38'17.20"E	ترهونة	32°23'50.61"N; 13°38'15.89"E	محطة تحويل 220/30/11 ك.ف ترهونة	31	63	50	1980	220/30	146	169	192	-142
Zlitan	32°27'13.31"N; 14°34'55.33"E	حكمون	32°26'14.80"N; 14°33'28.29"E	محطة تحويل 220/30/11 ك.ف حكمون زليتن	21	126	101	1980	220/30	107	123	140	-39
Misurata South	32°14'16.97"N; 14°56'43.25"E	طمينه	32°14'59.64"N; 15° 7'27.03"E	محطة تحويل 220/30/11 ك.ف طمينة	25	126	101	1983	220/30	22	25	28	73
Misurata Switching	32° 8'29.91"N; 15° 7'1.00"E	PLANNED?			42	300	240	2015	220/30	116	134	153	87
Misurata Power (Steel 400?)	32°18'16.71"N; 15°11'22.56"	مصراته المزدوجه	32°19'48.09"N; 15°14'37.70"E	محطة 400/220/30 ك.ف مصراته المزدوجة		630	504	1988	220/30	650	650	650	-146
Misurata Power (Steel 400?)	32°18'16.71"N; 15°11'22.56"		32°19'50.65"N; 15°13'54.40"E	محطة تحويل 220 ك.ف الحديد			750	E	400/220				
Tripoli West 220/30	32°49'24.00"N; 12°58'24.00"E	PLANNED?				126	101	1980	220/30	106	123	140	-39
Tripoli West 400/220	32°49'24.00"N; 12°58'24.00"E	غرب طرابلس	32°49'22.81"N; 12°58'28.44"E	محطة تحويل 400/220 ك.ف غرب طرابلس			1400	U	400/220				
Homs Power	32°31'25.73"N; 14°20'47.73"E	كعام	32°29'49.49"N; 14°25'9.10"E	محطة تحويل 220/30/11 ك.ف كعام		126	101	1974	220/30	85	98	112	-11
Homs Power	32°31'25.73"N; 14°20'47.73"E	??					1400	P	400/220				
Zawia Power	32°47'15.20"N; 12°40'30.20"E		32°47'15.18"N; 12°40'27.64"E	محطة تحويل 220/30/11 ك.ف الزاوية		300	240	2006	400/220	55	62	71	169
Zawia Power	32°47'15.20"N; 12°40'30.20"E		32°47'17.27"N; 12°40'16.71"E	محطة تحويل 400/220 ك.ف الزاوية			450	E	400/220				
Milita	32°50'46.90"N; 12°15'16.75"E	[empty lot?]	32°50'51.28"N; 12°13'44.07"E	محطة 220 ك.ف مجمع مليته المقترحة		200	160	2015	220/30	63	73	83	77
Milita	32°50'46.90"N; 12°15'16.75"E	الجميل	32°52'32.48"N; 12° 4'25.03"E	محطة تحويل 220/30/11 ك.ف الجميل			1640	P	400/220				
Abu Kamash	32° 1'34.10"N; 11°47'44.70"E	شكشوك	32° 2'6.12"N; 11°57'52.38"E	محطة تحويل 220/66/11 ك.ف شكشوك		126	101	1980	220/30	39	45	51	50
Abu Kamash	32° 1'34.10"N; 11°47'44.70"E	شكشوك	32° 2'6.12"N; 11°57'52.38"E	محطة تحويل 220/66/11 ك.ف شكشوك			820	P	400/220				
Bengazhi North Old	32°11'13.70"N; 20° 8'59.10"E	شمال بنغازي	32°11'10.45"N; 20° 8'53.15"E	محطة 220/30/11 ك.ف شمال بنغازي القديمة		83	66	1976	220/30	117	135	154	-88
Bengazhi North New+power	32°11'57.37"N; 20° 8'6.24"E	شمال بنغازي	32°12'2.54"N; 20° 8'2.99"E	محطة تحويل 400/220 ك.ف شمال بنغازي		126	101	2005	220/30	115	132	150	-49
Bengazhi North New+power	32°11'57.37"N; 20° 8'6.24"E	شمال بنغازي	32°12'6.14"N; 20° 8'8.47"E	محطة تحويل 220/30/11 ك.ف شمال بنغازي			820	E	400/220				
Bengazhi West	(See Gwarsha old - CLOSE)	جنوب بنغازي	32° 1'50.33"N; 20° 6'52.54"E	محطة تحويل 220/30/11 ك.ف جنوب بنغازي			1400	P	400/220				
Gwarsha old	32° 0'0.80"N; 20° 4'23.10"E	جنوب بنغازي	32° 1'50.33"N; 20° 6'52.54"E	محطة تحويل 220/30/11 ك.ف جنوب بنغازي		315	252	1984	220/66/30	291	295	381	-129
Derna	32°46'23.49"N; 22°34'31.02"E		32°36'17.65"N; 22°46'9.07"E	محطة تحويل /66/11 ك.ف الفتائح		126	101	1976	220/30	97	112	127	-26
Derna Al-Meyna	32°45'32.18"N; 22°39'17.19"E	درنه	32°46'49.81"N; 22°35'12.16"E	محطة تحويل 220/30/11 ك.ف درنة التوليد		300	240	2015	220/30	88	100	114	126
Al Fatiyah	(MISSING)	PLANNED?				200	160	2015	220/30	49	56	64	96
Tamimi	32°20'0.75"N; 23° 3'19.88"E	التميمي	32°26'56.32"N; 23° 3'39.18"E	محطة 220/66/11 ك.ف التميمي	15	126	101	1984	220/66	31	36	41	60
Beada North	32°47'9.02"N; 21°45'4.01"E	البيضاء	32°46'41.08"N; 21°45'35.91"E	محطة 220/30/11 ك.ف البيضاء	13	250	200	2009	220/66	85	98	111	89
Sebha Airport	26°57'47.70"N; 14°26'21.20"E	سبها كم 18	26°53'11.66"N; 14°25'8.97"E	محطة تحويل 220/66/11 ك.ف سبها كم	20	126	101	2015	220/66	24	29	33	68
Sebha North	27° 2'42.60"N; 14°26'31.70"E	سبها 400	27° 2'23.98"N; 14°31'48.57"E	محطة تحويل 400/220/66/11 ك.ف سبها	30	250	200	2010	220/66	158	163	150	50
Sebha North	27° 2'42.60"N; 14°26'31.70"E	سبها الشمالية	27° 2'43.03"N; 14°26'35.38"E	محطة تحويل 220 ك.ف سبها الشمالية									
Sebha North	27° 2'42.60"N; 14°26'31.70"E	سبها الغربية	27° 2'28.88"N; 14°23'51.91"E	محطة تحويل 220 ك.ف سبها الغربية									
Ghadamis	30°10'4.80"N; 9°45'21.60"E	غدامس	30° 8'57.23"N; 9°29'26.49"E	محطة تحويل 400/220 ك.ف غدامس	6		0		440/220/66	21	25	28	-28
Ghadamis	30°10'4.80"N; 9°45'21.60"E		30°10'13.76"N; 10° 0'40.78"E	محطة كهرباء									
Brega	30°26'6.10"N; 19°42'25.30"E	اجدابيا	30°55'24.60"N; 20°11'26.54"E	محطة تحويل 400/220 ك.ف اجدابيا	53	126	101	1984	220/30	93	106	121	-20
Ras Lanof	30°34'26.15"N; 18°25'6.34"E	راس لانوف	30°27'48.85"N; 18°32'46.92"E	محطة 400/220/66 ك.ف راس لانوف	90	126	101	2006	220/66/306	63	73	83	18
Hoon	29° 8'50.18"N; 16° 0'59.66"E	هون	29° 7'2.26"N; 15°53'28.96"E	محطة تحويل 220/66/11 ك.ف هون	1,5	189	151	1983	400/220/66	111	128	146	5
Thala	25°47'16.76"N; 10°33'18.82"E	العوينات	25°47'16.76"N; 10°33'18.82"E	محطة 220/66/11 ك.ف العوينات									

4. Site Restrictions

Having an overview of site restrictions in Libya will enable the Consultant to identify those areas which are restricted to installation of RE generation facilities. Based on the information collected the Consultant focuses on environmental restrictions, exclusion areas for oil and gas exploration / exploitation, restricted accessibility for construction, adverse climatic conditions and security restrictions, as described below.

4.1.1 Environmental Restrictions

National parks and nature reserves can be considered as restricted areas due to environmental and conservation reasons. Table 4-1 lists the national parks and nature reserves in Libya[2]. These areas will be excluded for a selection of potential sites for RE implementation.

Table 4-1: Some of the national parks and nature reserves in Libya

Protected area	Date of creation	Total area (Ha)	Status
El Kouf	1978	100,000	National Park
Alhesha	1984	160,000	Nature reserve
Algharabolli	1992	8,000	National Park
Abughylan	1992	4,000	National Park
Bir Ayad	1992	12,000	Nature reserve
Surman	1992	4,000	National Park
El Naggaza	1993	4,000	National Park
Sabrata	1995	500	National Park
Msalata	1998	1,800	Nature reserve
Nalout	1998	200	Nature reserve
Zulton	1998	1,000	Nature reserve

4.1.2 Adverse Climatic Conditions

Adverse climatic conditions such extreme high temperatures and sand storms will affect negatively the implementation of RE. Although irradiance might be higher in areas with higher temperatures, sometimes it is not worth the trade off as technologies might be affected by high temperatures and dust with the subsequent curtailment of electricity production.

As mentioned in section 2 the highest values of DNI irradiance can be found for the Tibesti Massif in the South. However, this region is very hard accessible and an almost total empty desert countryside, thus no option for solar energy.

The south area, the Sahara desert, is also well known for their adverse climatic conditions and little settlements and grid connection possibilities exist, thus this area will not be the focus for potential implementation of RE.

2 Bouras, Essam M. "National parks and reserves" (PDF). Head, of protected area & biodiversity section,Nature conservation Dept, Environment General Authority, Convention on Biological Diversity. Retrieved 26 March 2013

4.1.3 Accessibility

Areas not accessible for transportation of large equipment will not be considered for further analyses. Although this is more relevant for CSP and WTGs the Consultant will initially exclude those areas for further analyses for all technologies and focus on areas with suitable access.

4.1.4 Allocated Areas for Oil Field Exploitation or Exploration

The Consultant assumes that, at least initially, oil field areas cannot be considered for RE implementation. Further, the Consultant will try to the extent possible to identify the boundaries of those areas as well as other areas allocated for oil and gas exploration.

4.1.5 Security and Integrity of Facilities

Due to the ongoing conflict it is necessary to identify together with other stakeholders the areas and technologies which are preferred for deployment of RE. Amongst others, issues related to safe access to construction sites and sabotage/destruction of electricity generation facilities were discussed with the stakeholders.

5. Identification of Potential Areas and Sites

For the purposes of the feasibility study the Consultant has performed a desktop appraisal of the solar resource and potential connection points as they are the two most important aspects. Further to these aspects, the Consultant has also performed a desktop appraisal of:

- Land required by different technology configurations;
- Environmental restrictions;
- Topography;
- Proximity to consume centres or areas with important demand growth;
- Water availability; and
- Access and transportation infrastructure for especial equipment including roads and railways.

The objective is to screen the country for the most convenient areas for PV implementation.

5.1 Areas of Analysis

Based on the analyses performed in sections 2 and 3 the Consultant has identified main areas for installation of RE facilities as shown in Figure 5-3. This section presents an overview of these areas, as well as other assumptions made in order to evaluate and rank them for this study.

Figure 5-1: Preselected areas

The following assumptions were made by the Consultant in order to define preselected areas:

- Areas considered shall be large enough to reduce issues related to exclusion of areas due to environmental aspects (e.g. natural reserves) or land use (e.g. areas reserved for oil activities);
- Water availability will not be considered a major issue since CSP plants will be equipped with dry

cooling systems;

- GECOL recommendation that RE facilities may be installed preferably more in the south of the overall transmission and distribution grid (e.g. in the southern centres of the two main North-south branches of the grid); and
- A major need of present and future demand is expected close to Tripoli.

The Consultant has selected areas for further analyses and ranking i.e. Tripoli, Bengazhi, Sebah, Ghadamis, Brega, Hun; Thala and Jagboub. An overview of these areas is presented in the sections below.

Figure 5-2 sets out the conventions used throughout this section in order to easily identify objects herein.

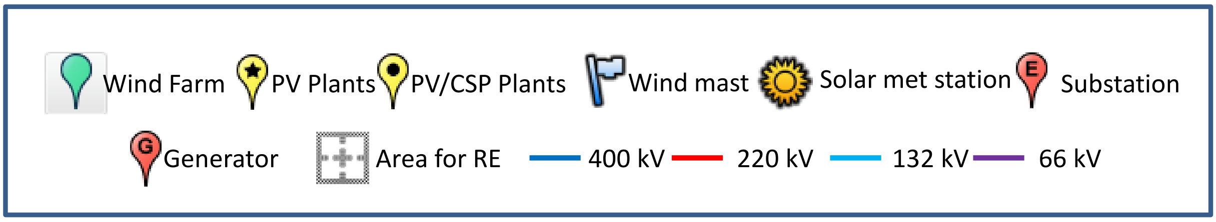


Figure 5-2: Conventions used in the maps

5.1.1 Tripoli Area

Although no feasibility study for RE has been performed within this area, the Tripoli area is the major consumer area in Libya also characterized for a good quantity of potential connection points and good infrastructure for transport due to the proximity to the north coast. In terms of resource the area offers reduced solar irradiation in comparison with other areas in Libya with solar ground measurements of GHI and DNI at Bir Al-Gahnam.

Identified potential sites for PV are: Jadu and Zliten only for PV.

Security is not a high concern in this area according to the Consultant’s information.

A preliminary snap shot of the Tripoli area is shown in Figure 5-3.

Figure 5-3: Tripoli area (Google Earth)

5.1.2 Bengazhi Area

The Bengazhi area is located in the north-west part of the country in the proximities of the city of Bengazhi. Different to the Tripoli area, this area includes sites some hundred kilometres away from Bengazhi, the main consumption center, to the west such as Tamimi, Dernah, Al Maqron and Shahat.

Although solar resource in this area is not the highest in Libya it is still very good resource for both PV and CSP deployments.

Feasibility studies have been performed already in this area for wind, PV and CSP

It is important to clarify the status of interconnection between east and west of Libya since according to information received the transmission line could be disconnected due to serious damages of infrastructure near Bengazhi. This area is also a main consume centre of the country although considerably less demand is expected there in comparison to Tripoli area.

Figure 5-4 shows a snapshot of the Bengazhi area.

Figure 5-4: Bengazhi area (Google Earth)

5.1.3 Sebah Area

The Sebah area is located approximately 650 km south of Tripoli area and encompasses the area nearby Sebah city, capital of the Sebah district. The area offers very good solar resource, alongside with good transport infrastructure and security conditions. Feasibility studies for both a PV and a CSP plants have been already performed in this area. GHI measurements have been taken in this area at Sebah and Argiba, unfortunately the data of the former location are missing.

The site at Edri has been recommended by REAOL and GECOL since the area is available and already secured by the Libyan government for solar power developments. Wanzreck substation has been confirmed by GECOL for connection of solar plants.

Another attractive of this area is the vicinity to an important consumption centre of the country.

Figure 5-5 shows a snapshot of the Sebah area.

Figure 5-5: Sebah area (Google Earth)

5.1.4 Ghadamis, Brega and Hun Areas

Ghadamis. Brega and Hun areas offer good wind and solar resources together with sufficient potential for connecting RE facilities to the Libyan grid. Although not as important as the Tripoli, Bengazhi and Sebha areas the Consultant recommends the implementation of RE in these areas as they will help deploying solar and wind facilities close to remote consume centres. RE projects in these areas will support the stability of the network and reduce transmission losses while benefiting from the infrastructure associated to the nearby settlements.

Figure 5-6, Figure 5-7 and Figure 5-8 show snapshots of the Ghadamis, Brega and Hun areas respectively for reference.

Ghadamis and Hun areas have solar measurement systems for GHI with available data. There is also available DNI data at Ghadamis.

Figure 5-6: Ghadamis area (Google Earth)

Figure 5-7: Brega area (Google Earth)

Figure 5-8: Hun area (Google Earth)

5.1.5 Thala and Jagboub areas

The Thala and Jagboub areas offer good solar resources together with sufficient potential option for connecting RE facilities to the Libyan grid. Different to the other areas these areas have been suggested by GECOL as they are of essential importance for electricity supply as they are in very remote areas. PV plants will be considered in these areas since restrictions in accessibility and harsh climatic conditions will make CSP and wind developments difficult. Such issues are to be addressed via the feasibility study for a concrete development.

For the Jagboub area, three sites have been considered for simulation of the PV plants i.e. Jagboub, Kufra1 and Kufra2. There is not ground data available for the Jagboub area.

The Thala area has GHI ground measurement at Ghat site and a substation for connection of solar power at the Thala substation.

Figure 5-9 and Figure 5-10 show snapshots of the Thala and Jagboub areas for reference.

Figure 5-9: Thala area (Google Earth)

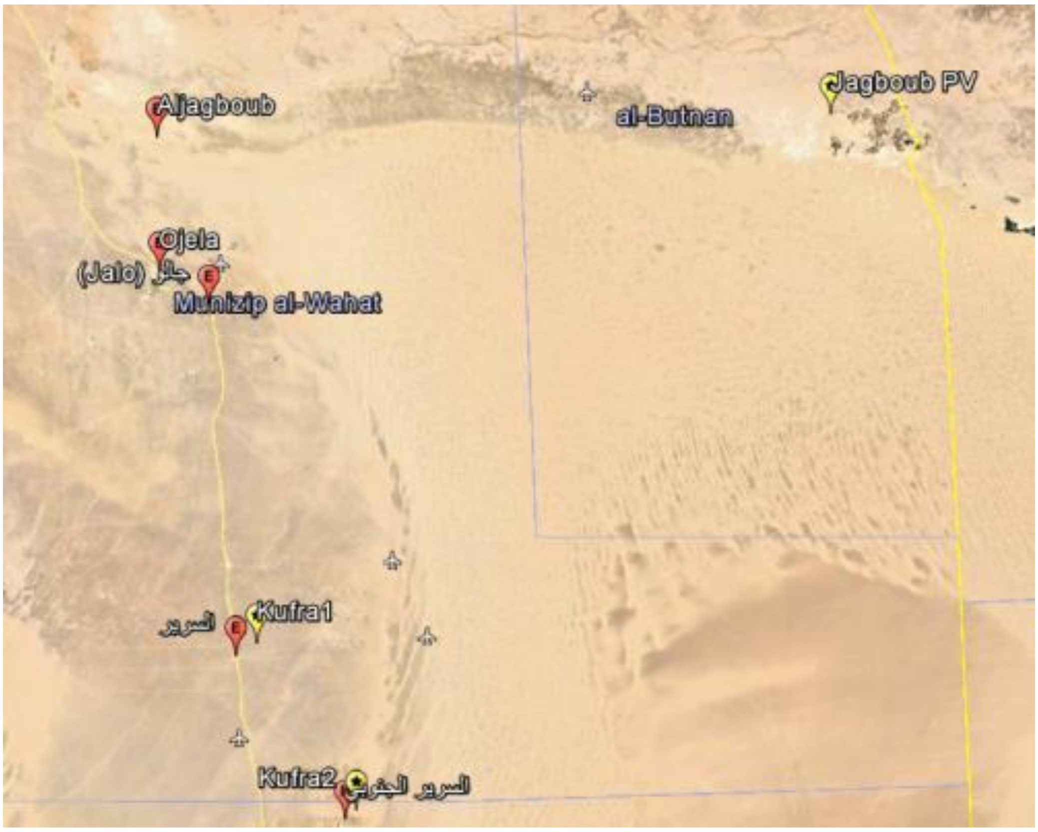


Figure 5-10: Jagboub area (Google Earth)

5.1.6 Final Sites

The process and criteria applied so far allowed the Consultant to identify a set of sites suitable for development of RE and most specific for PV projects.

The set of sites, including substations, met stations and short-term restrictions is shown in Table 5-1. Figure 5-11 shows the final proposed PV sites in Libya.

It is also important to note that distances to substations were roughly estimated in order to add CAPEX for connection.

Figure 5-11: Selected locations for PV installation in Libya

Table 5-1: Final set of sites for PV installations in Libya

		Meteorological station								Substations			
Area	**City/town**	**Name**	**Coordinates (Latitude, longitude)**	**Distance (km)**	**Type**	**GHI[1] kWh/m²/y**	**GHI Ground data**	**DNI[1] kWh/m²/y**	**DNI Ground data**	**SS Name (arabic)**	**SS Name (english)**	**Coordinates (Latitude, longitude)**	**Distance (km)**
Tripoli	Zliten	satellite data			GHI		Satellite			البرج	Zliten SS	32°12'38.00"N; 14°34'51.00"E	5
Tripoli	Jadu	Bir al Gahnam	32° 21' 3.19" N; 12° 39' 21.39" E	60	GHI/DNI	1987	Data	2023	Data	شكشوك	Shakshuk	32° 2'6.12"N; 11°57'52.38"E	13
Bengazhi	Al Tamimi	satellite data			GHI	2004	Satellite	1999		التميمي	Tamimi	32°26'56.32"N; 23° 3'39.18"E	3
Bengazhi	Shahat	Shahat	32°45'36.00"N; 21°53'24.00"E	15	GHI		Report			البيضاء	Beada	32°46'41.08"N; 21°45'35.91"E	4
Sebah	Sebah	Sebah	26°47'19.65"N; 14°25'16.22"E	4	GHI/DNI	2248	Report	2259	Report	سبها كم 18	Sebha	26°53'11.66"N; 14°25'8.97"E	13
Sebah	Edri	Argiba	26°34'50.28"N; 13°34'25.56"E	100	GHI		Data				Wanzreck	27°29'20.60"N; 13°10'47.78"E	0.5
Ghadamis	Ghadamis	Ghadamis	30°10'4.80"N; 9°45'21.60"E	17	GHI/DNI	2127	Data/Report	2162	Data	غدامس	Ghadamis	30° 8'57.23"N; 9°29'26.49"E	13
Hun	Hun	Hun	29° 9'15.69"N; 16° 0'17.60"E	15	GHI	2157	Report	2212		هون	Hoon	29° 7'2.26"N; 15°53'28.96"E	4
Ghat	Thala	Ghat	24°57'51.53"N; 10°10'32.72"E	52	GHI		Data				Thala	25°24'29.22"N; 10°21'25.88"E	0.5
Jagboub	Jagboub	satellite data			GHI		Satellite				Aljagboub	29°44'45.00"N; 21°17'58.00"E	300
Jagboub	Kufra1	satellite data			GHI		Satellite			السرير		27°35'52.58"N; 21°36'48.66"E	7
Jagboub	Kufra2	satellite data			GHI		Satellite			السرير الجنوبي		26°54'33.47"N; 22° 5'53.83"E	10

5.1.7 Selection of Site for the Feasibility Study

After discussions with GECOL and REAOL on the most suitable site to perform the feasibility study out of the preselected ones there was consensus that the sites at Jadu, Edri and Zliten display better advantages and have already been considered by the stakeholder for PV development. Based on this fact the Consultant undertook site visits on the three sites accompanied by delegates of REAOL and GECOL.

Although the sites are suitable for PV development the site at Jadu has nearby ground solar measurements and an area already allocated by the Government of Libya for such development. The site visit at Jadu confirmed that the site (see next section) is suitable for PV development and thus it is the site selected for the feasibility study.

5.1.8 Jadu Site visit

The proposed site of the PV power plant is close to the city of Jadu. Jadu is a mountainous city in western part of Libya, in Nafusa Mountain. The Project site, with coordinates 32°05'55.27N, 12°04'47.14"E is located approximately 11 km east of the town of Shakshuk, approximately 15 km south of Jadu. The PV plant shall be connected to the grid close to Shakshuk with an existing A220 kV substation.

Figure 5-12 shows the proposed site with the existing 220 kV overhead transmission line route, while Figure 5-13 shows a schematic plan for the proposed site, approved from the projects department at Jadu Municipality.

Figure 5-12: Proposed site and substation close to Jadu (32° 5'55.27"N, 12° 4'47.14"E)

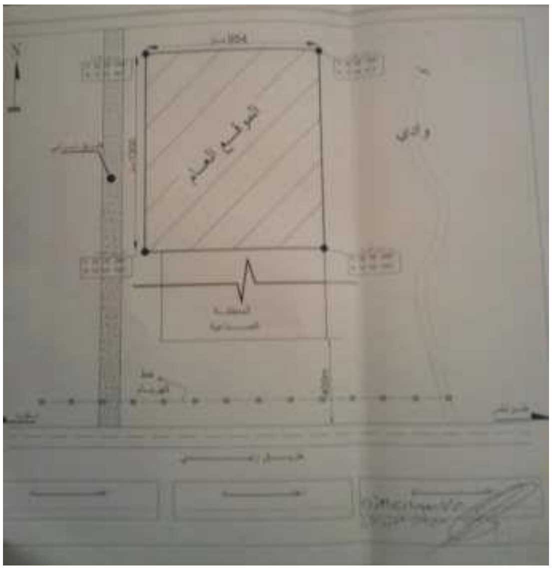


Figure 5-13: Schematic plan for the proposed site

The total area approved by the Municipality of Jadu for the PV plant installation is approximately 125 hectares with availability of additional area of nearly 75 hectares. The terrain is not complex and the area is mainly flat, arid, non-arable, highly exposed to the sun with no plant coverage and clear of natural obstacles such as high mountains or buildings that may influence the power system (see Figure 5-14).

Site soil conditions are regarded as suitable as it comprises of normal soil. The site is easily accessible, located right next to a paved road (Figure 5-15). A220 kV substation is situated less than 9 km away from the site (Figure 5-16). Grid connection to the substation should be possible (Figure 5-17).

Figure 5-14: Landscape at Jadu site

Figure 5-15: Project site located close to the main paved road

Figure 5-16: 220 kV Shakshuk substation

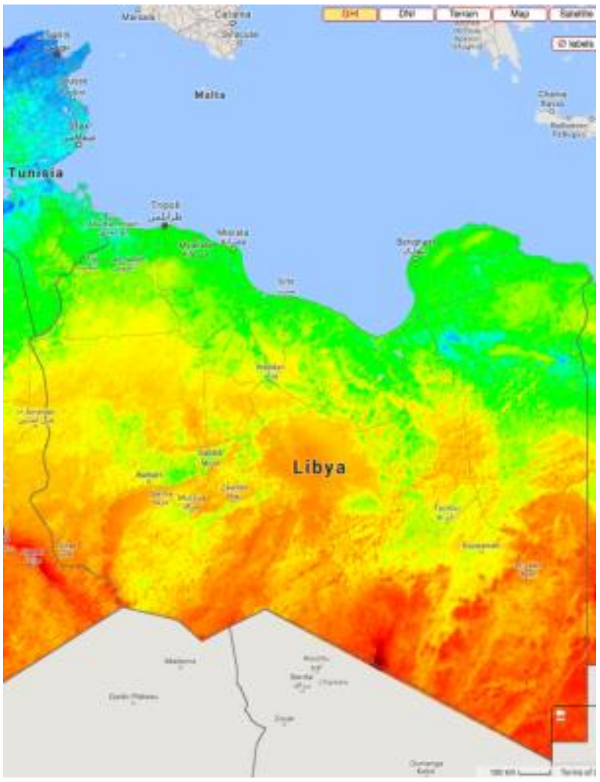
Figure 5-17: Grid connection to the substation

Annex 2: Checklist for site visit at Jadu site

Category	Criteria	Unit	Site
Location	Site Name	N/A	**Jadu**
	Region/Municipality	N/A	**Jabal al Gharbi District**
	Latitude	N D.D	**N32°05'55.27"**
	Longitude	E D.D	**E12°04'47.14"**
	Elevation	Meters	**680**
	Time zone	Hours +/- GMT	**+2**
	Summer time	Hours +/- GMT	**+1**
Land characteristics	Use of Land		**Pastoral**
	Landowner ship		**State owned**
	Landcover (Type of Vegetation)		**No existing vegetation in the area**
	surface profile		**Flat**
	Cost of Land	Currency /m^2	**Free**
	slope		**Horizontal**
	type of near shading obstacles	yes/no	**Free of shading obstacles**
	Distance to these obstacles	Meters	**More than 15 km**
	type of distant shading obstacles		**Towns**
	shading angle		**0°**
	Distance from the Coast	km	**Approx. 100 km**
	Distance from greater water bodies	km	**None**
	Surface soil composition (if available)		**Clay and small stone**
	Ground composition (if available)		**N/A**
	Earthquake frequency and strenght		**None**
	Flooding risk	yes/no	**No floods**
	site protection (environment, military, national park)	yes/no	**none**
	Fire Risk	yes/no	**none**
	armed conflict in region of site		**No**
	Comments to site		**There is a road map for developing this region besides the current project**
	Comments to site		**Other site for industry, recration sports facilities**
Water	distance to surface water intake	km	**from wells, 3 km**
	quality of surface water		**fresh water**
	depth of groundwater	m	**about 100 m**
	drilling cost		**about 5000 Lybian Dinar**
	distance to drinking/treated water	km	**On site available**
Infrastructure	Road available to access the site		**National road next to the site**
	Road/Railway to be constructed	km	**New roads will be constructed**
	Distance from Closest Highway	km	**200**
	Distance from Closest Seaport	km	**Approx. 130**
	Distance from Closest City/Town	km	**Approx. 9**
	Distance from Closest Airport	km	**Approx. 170**
	Distance to MV Grid	yes/no	**100 m**
	voltage level	kV	**220**
	Distance to nearest MV substation	km	**8**
	Substation Voltage level	kV	**220**
	Distance to nearest HV substation	km	**8**
	Substation Voltage level	kV	**220**
	telecom available	yes/no	**Wireless**

* Taken from EMPower toolkit (KfW, UNEP, Global Environmental Facility, Federal Ministry for Economic Cooperation and Development)

Annex 3: Solar Resource Assessment at Jadu



Libya - Supporting Electricity Sector Reform (P154606)

Contract No. 7181909 - Task D: Strategic Plan for Renewable Energy Development

Feasibility Study for a PV Plant at Jadu Site

Annex 3 – Solar Resource Assessment, GHI at Site LYJAD (Jadu) in Libya

26 October 2017

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The study described in this report represents a state of the art Expert Opinion on Solar Resource Assessment, which is prepared by taking into consideration the best available datasets (ground-measured and satellite-derived) at the time of executing this study. Suntrace GmbH has worked in great details, used accurate information and employed proven methodology to provide this report and its associated datasets with least possible uncertainty with the current state of knowledge. Utmost care has been taken to produce this expert opinion, which is suitable for due diligence and financial assessment of solar power plants.

authored		**checked**		**released**	
Date	Name	Date	Name	Date	Name
2017-10-26	MA	2017-10-27	AK	2017-10-27	MA

Executive Summary

Within the framework of the Strategic Plan for Renewable Energy Development for Libya a site in Libya for the construction of a PV power plant is evaluated. The site with site code LYJAD is located around 20km North-East from Jadu in Libya. Most important to reach good estimates on electricity yields of a PV power plant is the knowledge on Global Horizontal Irradiance (GHI) conditions.

For evaluating the long-term average of GHI at LYJAD, the site selected for this study, several different solar resource data sets have been analysed: long-term satellite-derived data, such as site-specific satellite data obtained from CMSAF-SARAH (CMSAF) and on-site measurements taken at a location 60km away from the project site for 12 months. Long-term site-specific satellite-derived GHI data from CMSAF (11 years) are compared to and adapted to overlapping on-site measurements. Since the location of the on-site measurement station is 60km away from the project site, the correction function for adapting the satellite data is determined by comparison with additional satellite data from CMSAF (11 years) of the location of the on-site measurement station. Then, the correction function is applied to the satellite data (also from CMSAF, 11 years) from the project site LYJAD. In the region of the project site the geographical characteristics are quite homogenous and thus nearly don’t change with distance. Therefore, the additional uncertainty due to the relatively high distance of the measurement station from the project site is evaluated to be low since the geographical characteristics of both locations are very similar.

The long-term best estimate for GHI at this site amounts to **228 W/m^2**, which is equivalent to **1995 kWh/m^2** per year or **5.5 kWh/m^2** per day. The inter-annual variability is analysed on the basis of the CMSAF data set. A year-to-year volatility of 0.9 % is calculated for GHI, which is very low compared to many other regions worldwide. The assessment of uncertainties takes into account the length of record of various data sets, uncertainty of the measurements at the site LYJAD and the methodological uncertainty of the adaption process. Accordingly, the above given long-term average for GHI is assumed to have an uncertainty of 3.2 % associated with the inter-annual variability related to multiple years and 3.3 % related to a single year.

For the long-term average (P50), a characteristic meteorological year in hourly time resolution is provided. Besides GHI, this data set also provides Diffuse Horizontal Irradiance (DHI) and auxiliary meteorological parameters, such as air temperature, wind speed and wind direction derived from the on-site measurements, where auxiliary parameters support site-specific plant layout and performance calculations.

For risk assessment of the solar power project, P75 and P90 Meteorological Years are created based on the P50 value. The multiple years P75 value of GHI at this site is estimated to be 2.2 % below the long-term best estimate (P50). This leads to a long-term average P75 value for GHI of 223 W/m^2 or 1952 kWh/m^2 per year or 5.3 kWh/m^2 per day. The single year P75 value of GHI at this site is estimated to be 2.3 % below the long-term best estimate (P50). This leads to a long-term average P75 value for GHI, based on a single year uncertainty of 222 W/m^2 or 1950 kWh/m^2 per year or 5.3 kWh/m^2 per day

Contents

Abbreviations

Name	Description
AOD	Aerosol Optical Depth
DHI	Diffuse Horizontal Irradiance
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
DNI	Direct Normal Irradiance
GHI	Global Horizontal Irradiance
LYJAD	Site code for project site near Jadu, Libya
LYJA2	Site code for location of the on-site measurement station
MFG	Meteosat First Generation
MSG	Meteosat Second Generation
NASA	National Aeronautics and Space Administration, USA
NCAR	U.S. National Center for Atmospheric Research
NOAA	U.S. National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory, USA
PV	Photovoltaic
RSI	Rotating Shadowband Irradiometer
TMY	Typical Meteorological Year
WGS84	World Geodetic System 1984 reference ellipsoid

1 Introduction

Within the framework of the Strategic Plan for Renewable Energy Development for Libya a site in Libya for the construction of a PV power plant is evaluated. Most important to reach good estimates on electricity yields of a PV power plant is the knowledge on Global Horizontal Irradiance (GHI) conditions.

The geographical coordinates of the power plant LYJAD, for which this assessment is conducted, are:

latitude:	32,0986	N
longitude:	12,0797	E
elevation:	141	m a.s.l.

All coordinates are given according to WGS84 geodetic date. In the following, this site is referred to by the assigned site code LYJAD. Currently, the state of knowledge on solar resources is good for the region under consideration. There are various satellite-derived GHI data sets available for this region. Several satellite-derived data are compared to get an overview and find the most suitable data for adaption by on-site measurements. The long-term average of GHI for this site shall be derived from a combination of local measurements with site-specific long-term time series based on satellite data. To derive the long-term average of GHI the long-term time series based on satellite data are adapted to the on-site measurements.

For solar power plant performance simulations a representative annual data set (Typical Meteorological Year-TMY), as well as P75 and P90 Meteorological Years (MYs) in hourly time resolution shall be given. The average of the TMY shall closely meet the long-term average (P50) GHI, whereas the average of the MY75 represents an average of GHI, which will be exceeded in 75 % of all years. This is also applicable for all other MYs, such as MY90. To derive these values, data uncertainties need to be analysed. The accuracy of the underlying data sets, the length of the time series, and the inter-annual variability are taken into account.

The annual hourly data set shall be accompanied by auxiliary meteorological data, which are also required for executing realistic performance calculations of PV plants. Especially the ambient air temperature, wind speed, as well as wind direction are relevant for PV plants and therefore, they are included in the delivered datasets.

This report first assesses the available input data sets. The methodology followed to derive long-term average of GHI and the corresponding uncertainty is explained in brief. The following chapter reports the main results including long-term average of GHI and the analysis of corresponding uncertainties, properties of GHI, and ambient air conditions at the site. Besides main findings, the conclusion chapter gives advice on how to further improve these results.

2 Description of the available input data sets

For the site LYJAD several independent GHI data sets are available. In this study the following data sets are considered: on-site measurements covering a period of 12 months taken from a location 60km away from the project site LYJAD, satellite-derived data from the DLR-ISIS data set of the German Aerospace Center, site-specific satellite-derived solar radiation products from CMSAF-SARAH (CMSAF), data derived from the Meteonorm software issued by the Swiss company Meteotest AG, SolarMed and NASA-SSE data set provided by the US National Air and Space Administration. For the calculation of the long-term best estimate only the satellite-derived data from CMSAF adapted to on-site measurements are used. However, all mentioned data sets are used for inter comparison and plausibility checks. In the following the location of the on-site measurement station is referred to by the assigned site code LYJA2.

2.1 On-site Measurements at LYJA2

In 2010, a meteorological measurement station has been set up at a location (LYJA2) 60km away from the project site. Main instrument is a Rotating Shadowband Irradiometer (RSI), which measures GHI and Diffuse Horizontal Irradiance (DHI) and from which Direct Normal Irradiance (DNI) is calculated. The station also measures air temperature, humidity, pressure, wind speed and direction and precipitation. All data streams are logged in 1-minute time resolution. This station was running properly and the data obtained is without gaps or errors. Measurements are of similar intensity compared to other measurements in the region. Maxima of GHI in each measured month proofed to be realistic.

2.2 DLR-ISIS

For climatological studies and solar energy applications the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt - DLR) developed the worldwide ISIS data set (Lohmann et al. 2006). The DLR-ISIS data set is mainly based on the D1-type cloud data set of the International Cloud Climatology Project (ISCPP). This data set is available over more than 21 years in 3-hourly time-resolution and integrated to approximately 280 km by 280 km wide boxes. Water vapour is accounted for by data in daily resolution from U.S. NOAA's GFS (Global Forecasting System) reanalysis data in 2° by 2° spatial resolution. Input on total column ozone is provided from the Total Ozone Mapping Satellites (TOMS). Tropospheric aerosols are taken from the monthly climatology generated within the Global Aerosol Climatology Project (GACP). In addition, real month stratospheric aerosols are overlaid, which are mainly influenced by highreaching volcanic eruptions. Radiative transfer calculations with the libRadtran 2-stream solver are used to derive GHI according to the procedure described in Lohmann et al. 2006.

2.3 NASA-SSE

The Surface and Solar Energy (SSE) data set of the U.S. National Air and Space Administration (NASA) also provides GHI and GHI data (Stackhouse et al. 2002). Similar to DLR-ISIS it builds on ISCCP cloud data products, but processes it to an equally spaced latitude longitude grid with 1° resolution in both directions. Thus, the spatial resolution is increased. In this study, SSE release 6.1 is used, which uses enhanced aerosol data for the recent years derived from the Moderate Resolution Spectroradiometer (MODIS) flown aboard the U.S. NASA's Terra and Aqua platforms as part of the Earth Observing System. Before MODIS started operating in 2001, aerosol data simulated by NCAR's MATCH-model are used.

The spatial resolution of NASA-SSE is 100 x 100 km^2 while that of DLR-ISIS is 280 x 280 km^2. Generally, solar radiation varies significantly from one site to another and even more with additional differences in the topography. The values of solar radiation derived from DLR-ISIS and NASA-SSE are hence representative of such large areas. As a result, the GHI values from these two datasets are not as representative as CMSAF values for the site due to the coarse spatial resolution.

2.4 CMSAF

For evaluation of the long-term average of GHI at the LYJAD site, site-specific satellite data obtained from CMSAF-SARAH (CMSAF) are evaluated. CMSAF is the EUMETSAT Network of Satellite Application Facility (Müller et al. 2015), (Huld, Müller, and Gambardella 2012). The CMSAF solar surface irradiance is part of a suite of products derived within the Satellite Application Facility on Climate Monitoring. It contributes to the operational long term monitoring of the climate system by providing Essential Climate Variables related to the energy and water cycle of the atmosphere (e.g. surface and top of the atmosphere (TOA) radiation budget components) (Woick, H., et al. 2002).

The CMSAF solar radiation database consists of solar irradiance data derived from Meteosat Second Generation (MSG) and from Meteosat First Generation (MFG) satellites. The algorithms applied to retrieve the solar surface irradiance differ between MSG and MFG. For MSG the retrieval is based on the method of (Pinker, R., Laszlo, I. 1992). The method originally relates the top of atmosphere albedo to the surface irradiance for clear sky and cloudy cases. In the CMSAF method this is only done for cloudy skies. For clear sky situation a clear sky model described in (Mueller, R. et al. 2009) is used, without explicit need of satellite data as input. The respective clear sky model is gnuMAGIC. The cloudy sky part of the operational CMSAF hybrideigenvector LUT algorithm is not applicable to MFG. Instead, the well established Heliosat method (Cano et al. 1986) is used to consider the effect of clouds on the solar irradiance for the MFG satellites. A modified version of Heliosat discussed in (Posselt, R. et al. 2011) is used to retrieve the effective cloud albedo (CAL, also called cloud index) from the observed reflections in the visible broadband channel. The water vapour information results from the analysis of the global Numerical Weather Prediction model (NWP) of the European Center for Medium Weather Forecast (ECMWF). For the aerosol information reanalysis data from the project “Monitoring Atmospheric Composition and Climate” (MACC) have been used to calculate long-term monthly means of aerosol optical depth.

In addition to the solar surface irradiance (global irradiance), CMSAF provides also direct irradiance for MSG and MFG. An adaptation of the approach of (Skartveit, Olseth, and Tuft 1998) is used, which relates the clear sky index to the direct irradiance, see (Mueller, R. et al. 2009) for further details.

The current available data covers 11 full years from January 2005 to December 2015 in hourly time resolution. The spatial resolution of the visible channel of MFG in the analysed region is approximately 3 km to 4 km. MSG reaches down to around 1 km resolution.

2.5 Meteonorm

The METEONORM software issued by the Swiss company Meteotest AG allows the derivation of key meteorological parameters mainly for solar energy applications at any point on Earth. The latest version (Meteonorm 7) is used for this study (Meteotest 2012). Its input data are mainly based on more than 8055 weather stations, of which 1422 record GHI. Many of these GHI measurements cover the 20-year period from 1986 to 2005. Data for any location can be derived by the built-in geostatistical kriging procedure. DHI is then calculated from GHI values. Due to the limited availability of nearby GHI-measurement stations in Libya, the quality of this data set is expected to be moderate.

2.6 SolarMed

The SolarMed dataset is part of the online portal ‘Solar Med Atlas’. It is sited in the project ‘Solar Atlas for the Southern and Eastern Mediterranean’. The database consists of high-resolution satellite derived solar radiation data for GHI and DNI. The gridded data has a resolution of 1 km and covers the countries Syria, Jordan, Israel, Lebanon, Egypt, Libya, Tunisia, Algeria, Morocco, Palestine National Authority, Mauretania and Turkey for the years from 1991 – 2010. Within the project data from the SOLEMI archive of DLR was used for the period from 1991 – 2005 and the Helioclim archive of Mines ParisTech for the years 2006 – 2010. The data was validated with existing ground measurement stations in the southern and eastern Mediterranean region (Hoyer-Klick et al. 2011).

3 Methodology

In the following it is briefly described how the site-specific satellite data from CMSAF are adapted to the on-site measured data from LYJA2 and how the long-term average is calculated in this assessment. Further, it is explained how the site-specific TMY is created based on the available data.

3.1 QC of on-site measurement data

The data from the meteorological measurement station at LYJA2 is available from 13.12.2010. For this assessment the data up to 13.12.2011, which is 12 months, was used. The measured data are available in 1-minute time resolution for the entire period of measurements. To check the quality of data, various quality control tests are applied to the on-site measurement data. These tests check the plausibility of the data following best practices like those recommended by BSRN (Long and Dutton, 2002 and Long and Shi, 2008) and NREL-SERI QC (NREL 1993). For this study only data that have passed the QC test are used. In addition, the quality-controlled data have been visually checked. Monthly summary reports including monthly QC statistics were generated.

3.2 Analysis of satellite-derived data

Long-term satellite-derived time series obtained from CMSAF from January 2005 up to December 2015 in hourly time resolution are used for this study for the site LYJAD. In addition, this data is inter-compared with satellite-derived data from DLR-ISIS and NASA-SSE, as well as data derived from the Meteonorm software and the SolarMed database. These additional data sets are not used for the calculation of the long-term best estimate.

These datasets have been checked for completeness, accuracy and plausibility. Various statistical characteristics of the data are analysed, such as long-term annual average, yearly averages, inter-annual variability, monthly averages over every single year, long-term monthly averages and the frequency distribution. This analysis is done to better understand the characteristics and occurrence of solar radiation at the particular site under consideration.

3.3 Comparison of satellite-derived data with on-site measurement data

As explained in chapter 2.1, a GHI data set consisting of on-site measurements at the station in LYJA2 from the various irradiation instruments is compared with satellite-derived GHI data obtained from CMSAF for the overlapping time period. In the following, only data pairs are inter-compared when both, measured and satellite data, are available and have passed QC.

3.4 Site-specific adaption of satellite-derived GHI data

Following the approach of Mieslinger et al. (2014), the satellite-derived GHI values of CMSAF at the site LYJAD are adapted to the more accurate measured values at LYJA2. The GHI values measured by on-site solar radiation measurement station 60km from LYJAD are taken as the reference in this procedure. The main aim of the Mieslinger-method is to reduce the mean bias of satellite data with respect to that of measured data and to improve the frequency distribution of satellite data. The frequency distribution of measured data is taken as reference, with respect to which the frequency distribution of satellite data is characterized and adapted. In this manner the satellite data is adapted in terms of the frequency distribution and its annual mean to on-site measurement data.

Mieslinger et al. (2014) method makes use of regression analysis and a regression model is fitted to the time-series of ground-measured and satellite-derived datasets. A 3rd degree polynomial fit is used in the regression model.

$$y(x) = p_1 x^3 + p_2 x^2 + p_3 x + p_4$$

Two conditions are used in this regression model: a) the intercept (p_4) should be zero because negative values do not exist in a physical sense and b) the modified time series shall be free of bias or at least be within the average level of uncertainty of the measurements. Hence, the degrees of freedom of this function are reduced to two and a cost function is applied optimising the values of the other two coefficients (p_2 and p_3).

The Mieslinger-method includes extra conditions for reducing the large difference at high irradiance values and reducing RMSD between ground-measured and original CMSAF values. These conditions are such that after adaption of satellite-derived values the average GHI for the overlapping period should be equal to the average ground-measured GHI during the overlapping period.

This method is applied separately for four different seasons (1st: December, January, February, 2nd: March, April, May, 3rd: June, July, August, 4th: September, November, December) to the data for this site LYJAD for an overlapping period between measured solar radiation and CMSAF data from 13.12.2010 to 13.12.2011.

The inter-comparison and adaption is done with respect to various parameters like average, minimum, maximum, standard deviation, frequency distribution, monthly averages and values under different solar radiation conditions like clear-sky and cloudy-sky situations, different seasons of the year etc.

Since the location of the on-site measurement station (LYJA2) is 60km away from the project site, the correction function for adapting the satellite data is determined by comparison with additional satellite data of the location of the on-site measurement station. Then, the correction function is applied to the satellite data from the project site LYJAD.

After applying this method to the satellite data, the statistical characteristics such as mean, minima, maxima, standard deviation etc. of adapted CMSAF datasets is checked and compared with that of on-site measurement data at the solar radiation station at LYJA2. It is found that applying the correction changes the characteristics of CMSAF towards more realistic results compared to the original. The mean of the adapted satellite-derived datasets closely matches with that of the on-site measurement data during the overlapping time period. Frequency distribution of adapted-satellite derived datasets is also better approaching the characteristics of the on-site measurement data compared to the original satellite data. The results are very promising and comply with the aim of transferring the characteristic of on-site measurement data to the satellite-derived data for the overlapping period.

3.5 Determination of long term best estimate of GHI

To determine the long-term best estimate of Global Horizontal Irradiance (GHI) the recommendations from the International Electrotechnical Commission (IEC) documented in (IEC TC117 2016, 62862-1-2): '*Solar thermal electric plants - Part 1-2: Creation of annual solar radiation data set for solar thermal electric plant simulation'* are followed. Relevant for the current assessment at site LYJAD are recommendations given in chapter 5.2.1 in (IEC TC117 2016, 62862-1-2) for determining the long term best estimate based on a single solar radiation data source for an overall period of ten or more years.

The representative long-term best estimate of GHI for each month is calculated by the sum of the daily values of the adapted satellite data for the specific month of all available years. Following the Sandia National Laboratories Method [4], a weighted mean (WM) is evaluated using the Finkelstein-Schafer statistic (FS) for each month available in the data source. This statistic considers the distance between the distribution functions (CDF or cumulative density function) of the daily data for GHI in a specific month and the CDF for daily data in that month in all the years available.

$$FS_{jk} = \sum_{r=1}^{n_r} \left| FDA_j(r) - FDA_{jk}(r) \right|$$

where:

r:	values of each of the ranges (abscissas) the daily values are distributed in, where the distribution function is evaluated
nr:	number of ranges (abscissas) in the distribution functions
$FDA_{jk}(r)$:	value of the distribution function of the daily data evaluated in range ***r***, in the daily data sample in month ***j*** and year ***k***
$FDA_{j}(r)$:	value of the distribution function of the daily data evaluated in range ***r***, in the daily data sample in month ***j*** of all the years

The specific month for determining the representative long-term best estimate is selected according to the following procedure. First, the 5 months with lower FS statistic value are chosen. Second, from these 5 months, the one with the most similar monthly mean value compared to the whole data set monthly mean for the specific month (e.g. January) is chosen.

3.6 Analysis of the long-term best estimate of GHI

As discussed in chapter 3.5, the long-term best estimate of GHI from CMSAF are determined from their long-term time-series covering about 11 years, which are adapted to the on-site measurements. The long-term best estimate of GHI determined by adapted CMSAF data is 5.8 % lower in comparison to the original CMSAF data set at this site. Frequency distribution of GHI is also a factor that indirectly determines the long-term best estimate of GHI.

3.7 Analysis of the uncertainty of long-term best estimate GHI

The goal of the uncertainty analysis is to determine the uncertainty of the long-term average of GHI, which is in most cases the dominating source of uncertainty for calculating potential yields. This overall uncertainty of the long-term average depends on the one side on methodological shortcomings like uncertainty of measurements, satellite data and on adaption methodology. On the other side - independent from the technical source of errors - is the uncertainty caused by inter-annual variability and the limited number of years taken to derive the long-term average.

The uncertainty of the measured data depends on

a) the uncertainty of the instrument measuring GHI,

b) the uncertainty related to the calibration and maintenance of instrument measuring GHI, and

c) the uncertainty due to temporal coverage taking into account the inter-annual variability and the limited number of years for calculating the long-term average.

These three uncertainties together give the total measurement uncertainty.

The adaption methodology of Mieslinger et al. (2014) eliminates the bias of satellite-derived irradiance data against measured values during the overlap period. As it can be assumed that the systematic deviations of the satellite data are similar during earlier or later times, applying this method to long-term satellite-derived data strongly reduces the systematic error of the satellite-derived data. However, some additional errors are caused by changes in the quality of the satellite data when extrapolating the adaption to times before measurements had been available or to later times. A reason for not using the complete period of available measurements for the adaption can be low data quality. Thus, although during the overlap the bias can be zeroed out, the method leaves a methodological uncertainty, which is estimated based on the results of Mieslinger et al. (2014). The uncertainty due to the variability of the solar resource and the limited length of the observation period is calculated from the standard deviation of the yearly averages over the period, for which the measurement adapted satellite-derived data are available.

3.8 Generation of Typical Meteorological Year (P50) Data Set

Energy performance calculations to predict potential energy production of a solar power plant commonly use a Typical Meteorological Year (TMY) data set as input. TMYs need to cover a full year and shall provide the most relevant meteorological parameters for the technology to be evaluated. For PV plants this is GHI, DHI, ambient air temperature, wind speed and wind direction among other auxiliary meteorological parameters, which help to simulate energy losses more realistically and which may influence design parameters of the plant. A TMY shall well represent the characteristic meteorological conditions of average years at a site. The annual average GHI in a TMY shall represent the average or P50 case of the long-term best estimate GHI within a certain tolerance. At the P50 level of exceedance, the probability that the actual long-term average is exceeded is equal to the probability that it will be lower to this P50, in relation to uncertainty effects.

Concerning inter-annual variability, the P50 also expresses the value, which is exceeded in 50% of all years (hence 50% of all years show lower irradiance) assuming the long-term average value was correctly determined and neither over- or underestimated. Extreme weather events, which are not typical for a site, are filtered out for the TMY. Hence, a TMY is not suitable as the only base for system or component design with respect to the robustness to resist extreme weather events such as very high wind speeds, precipitations, high/low temperatures, hazards, etc.

The typical meteorological year (TMY) for performance simulation of PV power plants generally includes GHI and DHI values of solar radiation and also other meteorological parameters like ambient temperature, wind speed and wind direction. Preferably, a TMY should be created from a multi-year data set of ground-based meteorological measurement data, with sufficient quality.

The annual GHI cycle is also important for yield prediction of PV plants. Thus, the values of the TMY should well represent the annual GHI cycle. The TMY shall also have a frequency distribution, which matches the one from the site measurements. Therefore, a TMY is built in such a way that it represents the long-term average value of GHI, but including the characteristic fluctuations throughout the year.

Typical meteorological years can be created by several procedures. In the context of the present work an improved concatenating method as described by Hoyer-Klick et al. (2009) is used to create the TMY under consideration to fulfil the criteria given by the International Electrotechnical Commission in (IEC TC117 2016, 62862-1-2).

These criteria are:

- The difference between monthly irradiance of the TMY (for each month) and the corresponding representative long-term best estimate for each month must not be higher than the 2% of the twelfth part of the annual representative long-term best estimate: $TMY_{month} – P50_{month} < 0.02 \times P50_{year}/12$.
- Substitution of days with other day of the same month must be done within a range of ±5 days
- In a generated dataset, the same day (from the original dataset) must not appear more than 4 times.
- A generated dataset must not contain more than a 50 % substituted dates per month.
- The result has to be an annual dataset found by concatenation of 365 days of complete valid days, which includes all the simultaneous variables

As mentioned above, here an improved concatenating method as described by Hoyer-Klick et al. (2009) is used to create the TMY. The original method uses only one complete year of ground-based measurements, because often not more than one year of measurements are available at a site. The monthly averages of each month in this case are adapted by replacing sunny days with cloudy days and vice-versa as required, until the monthly average of GHI matches with the long-term monthly average of GHI. One drawback of using only one year of data is that the frequency distribution can be changed because of the frequent synthesizing of days. By copying many days with similar irradiance conditions as sometimes needed when the single measured year in a month has larger deviations the natural variability is flattened out.

Using a longer measured data set improves these shortcomings substantially. Therefore, a slight modification is applied here: In this improved methodology, when available, the use of more than one year of ground-based measurements (or modelled data set if no on-site measurements are available) is allowed. Individual months from different years are selected which are closest to the long-term monthly averages of GHI. If the difference in the monthly average of GHI of the month selected as compared to the long-term monthly average of GHI is more than the allowed tolerance, only then the monthly averages are adapted by replacing sunny days with cloudy days or vice-versa. This method leads to more realistic TMYs as the number of shifting days is reduced.

After adapting the data of the individual months to represent the long-term monthly averages, individual months of the year are selected and concatenated to create a representative year. In case it is not possible to reach the allowed difference between the monthly GHI average and the long-term monthly GHI average by concatenating of complete days, a constant factor is applied to some selected days. These selected days are all the days of the month excluding the four days with the two highest and the two lowest daily averages in the month and excluding the days of the month which were replaced before.

In the case of the site LYJAD the values of GHI, DHI as well as the auxiliary meteorological data like ambient air temperature, wind speed and wind direction in 1-minute time resolution are obtained from the on-site measurements at LYJA2 and used for the TMY creation. The auxiliary meteorological parameters used in the TMY are coherent with GHI values selected for the TMY. Thus, a complete TMY is created in 60-minute time resolution by averaging, which does not only match the best estimate of GHI within the acceptable tolerance, but also represents the annual GHI cycle.

3.9 Determination of data sets for risk assessments (P75 and P90)

P75 value of GHI means that this GHI value would be exceeded in 75 % of the cases. These values are necessary for risk assessment of solar power plants during due diligence. Assuming normal probability distribution and taking into consideration P50 value and associated uncertainty, the P75 GHI value is derived.

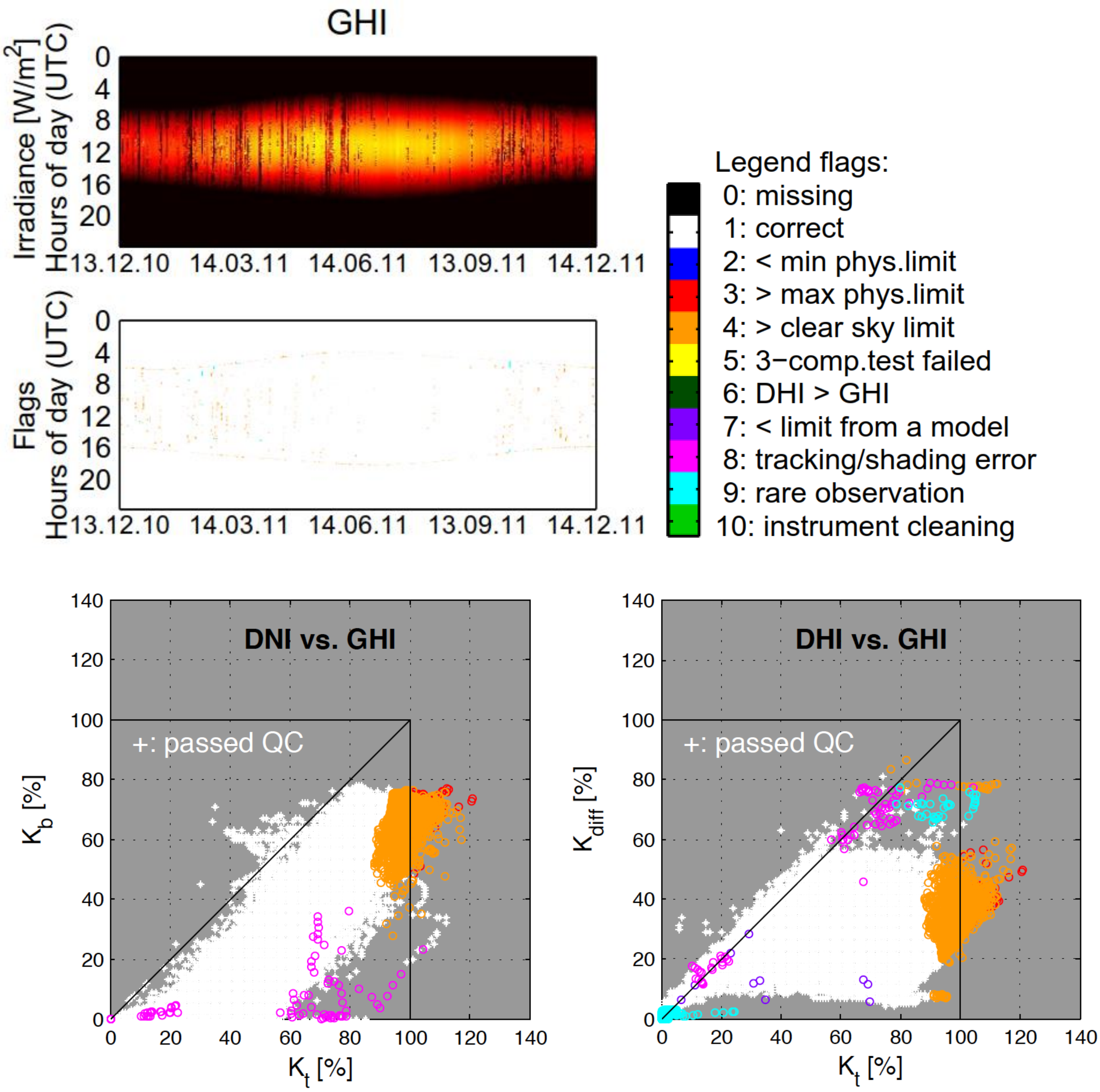
There is a difference between a Meteorological Year (MY) considering single year inter-annual variability and a Meteorological Year (MY) considering multiple year inter-annual variability. The distinction consists in the underlying overall uncertainty of the P50 value, which is used to calculate the P75 value. If the 75 % probability of exceedance is requested for each single year, single year uncertainty is applied, which takes the continuation of inter-annual variation into account. When the overall uncertainty considers single year inter-annual variability, this uncertainty is applied for the predicted annual power production of only one single year. When the overall uncertainty of the predicted power production is applied for the whole planed production time of the power plant this uncertainty considers multiple year inter-annual variability. Hence, the multiple year uncertainty is lower than the single year uncertainty and thus, the P75 values considering multiple year uncertainty are higher than the P75 values considering single year uncertainty. As a result, one P75 value of GHI can be derived from the uncertainty considering inter-annual variability of GHI related to multiple years and the other P75 value of GHI can be derived from the uncertainty considering inter-annual variability of GHI related to single year.

For risk assessment of the solar power project, in this case, Meteorological Years data sets representing multiple year P75 and P90 values of GHI are derived based on the P50 value and the associated uncertainties using a procedure similar for creating a TMY as mentioned in chapter 3.8.

4 Results

4.1 Analysis of GHI measurements

For the site-specific adaption of the satellite-derived GHI data the measurements from the RSI are used. As mentioned in Chapter 3.1, only quality-controlled data has been used within the analysis. In addition, a visual check of the valid quality-controlled data is done. The results of the QC data of the period 13.12.2010 to 13.12.2011 can be seen in Figure 1. The QC of data revealed that 0.0 % of GHI data was found to be potentially erroneous or discarded due to sensor cleaning events and 0.0 % is missing. 0.5 % of the GHI values exceed the clear sky limit. However, after careful observation of the data, these values are considered to be correct. Under special cloud constellations the global horizontal irradiance may even exceed the extraterrestrial irradiance due to cloud enhancement effects. Exceedance of extraterrestrial values in such cases is not a sign of error, but in fact may be real irradiance conditions. Therefore, in total 100 % of the values can be considered as correct.



K_t=GHI/($I_0 \cdot \varepsilon \cdot \cos\Theta_Z$): clear sky index global irr.
K_b=DNI/($I_0 \cdot \varepsilon$): clear sky index direct irr.
K_{diff}=DHI/($I_0 \cdot \varepsilon \cdot \cos\Theta_Z$): clear sky index diffuse irr.

I_0: solar constant (1367 W/m^2)

ε: eccentricity correction
Θ_Z: solar zenith angle

Figure 1: QC output for GHI for the site LYJA2 with GHI (top) and flags (middle) for each minute of the day throughout the complete time period. Bottom: clear sky index of direct (left) / diffuse (right) on ordinate against clear sky index of global irradiance (abscissas).

4.2 Long-term average of GHI

4.2.1 Adaption of satellite-derived GHI values to on-site measurement data from CMSAF

Figure 2 shows the scatter plot of GHI values in hourly time resolution obtained from the measurements and satellite for the overlapping period from 13.12.2010 up to 13.12.2011. The adaption is applied separately for four different seasons (1st: December, January, February, 2nd: March, April, May, 3rd: June, July, August, 4th: September, November, December) to the data at this site for an overlapping period between measured solar radiation station and the satellite derived radiation data. The inter-comparison and adaption is done with respect to various parameters like average, minimum, maximum, standard deviation, frequency distribution, monthly averages and values under different solar radiation conditions like clear-sky and cloudy-sky situations, different seasons of the year etc. After applying this method to GHI satellite data, the statistical characteristics such as mean, minima, maxima, standard deviation etc. of adapted satellite datasets are checked and compared to on-site measurement data at the solar radiation station at LYJA2. It is found that applying the correction changes the characteristics of CMSAF towards more realistic results than the original.

For the overlapping period the on-site measurement data had an average of 226 W/m^2, while satellite-derived CMSAF data had an average of 239 W/m^2. The method of (Mieslinger et al. 2014) is applied for the overlapping time period to adapt the satellite-derived CMSAF values. After applying this method, the average of adapted CMSAF GHI values is found to be 228 W/m^2. It is seen that the frequency distribution of satellite-derived GHI match better to ground-measured GHI as can be seen in Figure 3 and Figure 4.

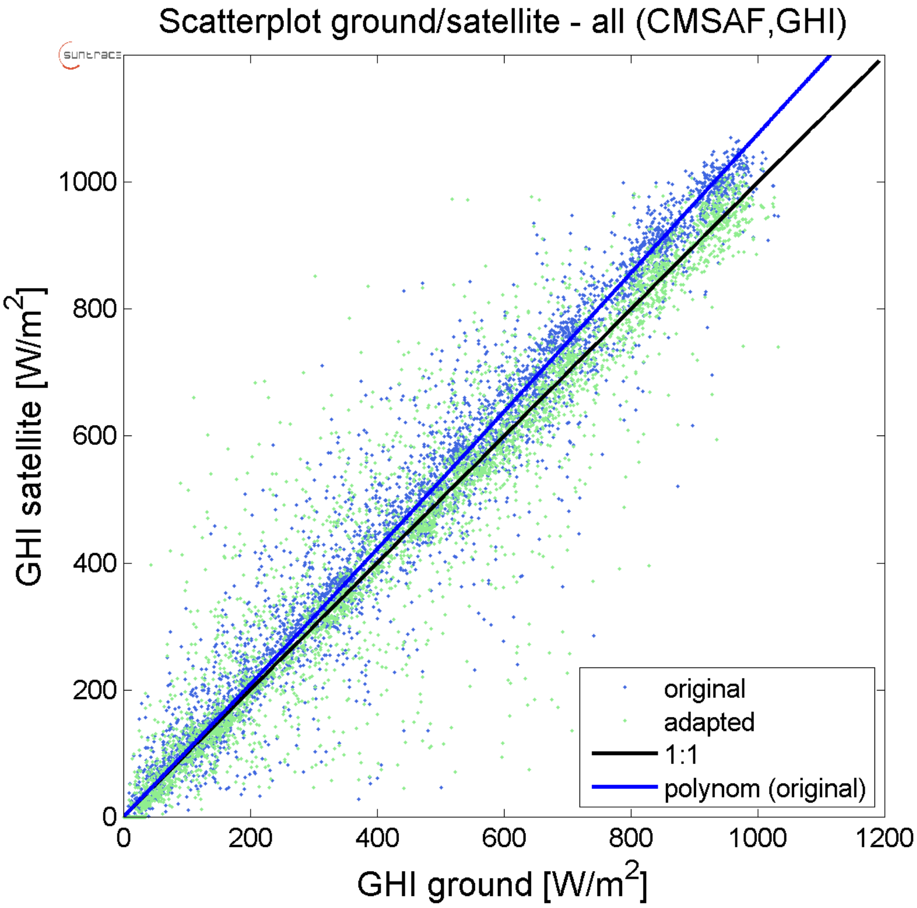


Figure 2: Scatter plot of GHI: ground-measured against adapted (green) and original (blue) GHI from CMSAF in hourly time resolution. The black line represents the 1:1 relationship and the blue line the polynom.

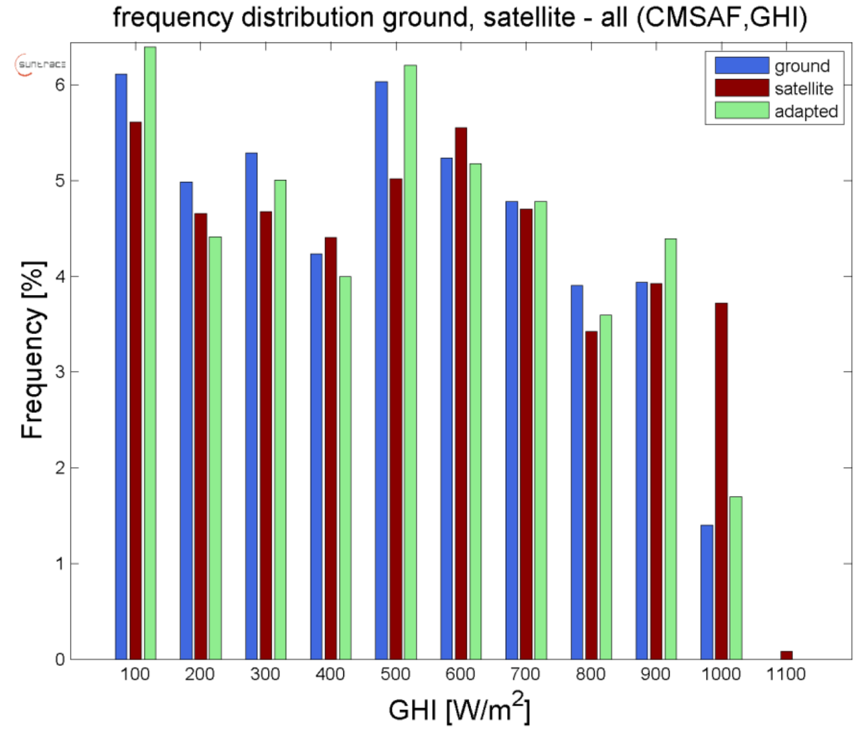


Figure 3: Frequency distribution of GHI: ground-measured values.

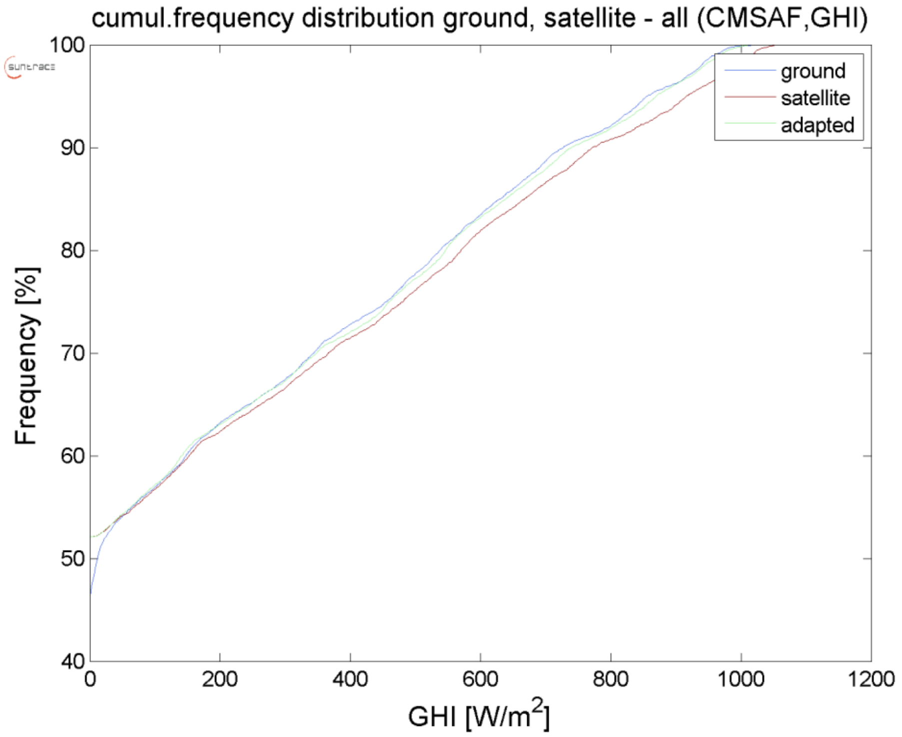


Figure 4: Cumulative frequency distribution of GHI: ground-measured values, not adapted GHI from CMSAF, and adapted GHI from CMSAF for the overlapping.

Based on the results of adaption of satellite-derived data for the overlapping period, the site-specific long-term solar radiation time series from CMSAF covering ca. 11 years at LYJAD is adapted to on-site measurements from LYJA2.

In this case, the adaption results in a noticeable modification of the annual average of CMSAF data set. Moreover, the adaption of CMSAF data results in improved frequency distribution as can be seen in Figure 4. According to Figure 5, the monthly GHI average values of adapted CMSAF dataset matches well with that of on-site measurements.

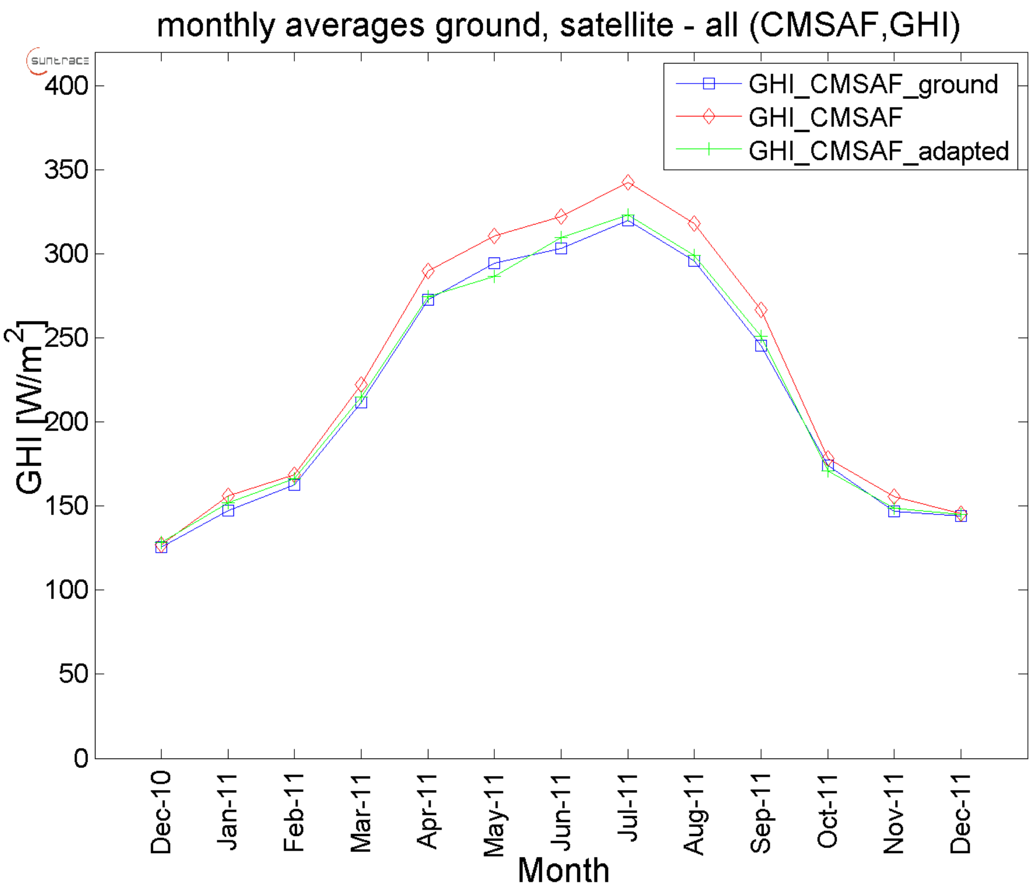


Figure 5: GHI monthly averages during the full overlapping period for all values(CMSAF).

The long-term average for GHI at LYJAD from site-specific CMSAF data (not adapted) amounts to 241 W/m^2. The long-term irradiation average for GHI at LYJAD from site-specific CMSAF data adapted to on-site measurements amounts to 227 W/m^2, which represents a decrease of 5.8 % over the original dataset.

4.2.2 Determination of long-term average of GHI

As discussed in chapter 3.5, the best estimate for the long-tem annual GHI expected at LYJAD is derived from the adapted long-term CMSAF data set following the recommended procedure from the International Electrotechnical Commission (IEC) documented in (IEC TC117 2016, 62862-1-2).

The long-term best estimate for GHI at this site amounts to **228 W/m²**, which is equivalent to **1995 kWh/m²** per year or **5.5 kWh/m²** per day.

For the site LYJAD six different input data sets have been assessed, from which finally the one from CMSAF were taken into account for determining the long-term annual best estimate of GHI. The main results can be found in Table 1 and Figure 6, which visualises the GHI long-term averages for these six data sets together with the best estimate (green line).

From comparing the currently available 6 GHI data sets it is decided to take only the more site-specific adapted data from CMSAF into account to calculate the long-term average.

data sets	no. of years	overall uncertainty				long-term yearly GHI	
		multiple year		single year		average in W/m²	sum in kWh/m²
		in W/m²	in %	in W/m²	in %		
$CMSAF_{original}$	11	7.3	3.2	7.6	3.4	241	2112
$CMSAF_{adapted}$*	11	7.3	3.2	7.6	3.4	227	1993
SolarMed	24	11.3	5.0	11.5	5.1	225	1974
DLR-ISIS	21	48.1	20.0	48.2	20.1	240	2106
NASA-SSE	22	22.2	10.0	22.3	10.0	222	1943
MN7	20	14.5	6.0	14.6	6.1	241	2111
best estimate		**7.3**	**3.2**	**7.6**	**3.3**	**228**	**1995**

* used for calculation of best estimate

Table 1: Overview of long-term averages from various GHI data sets.

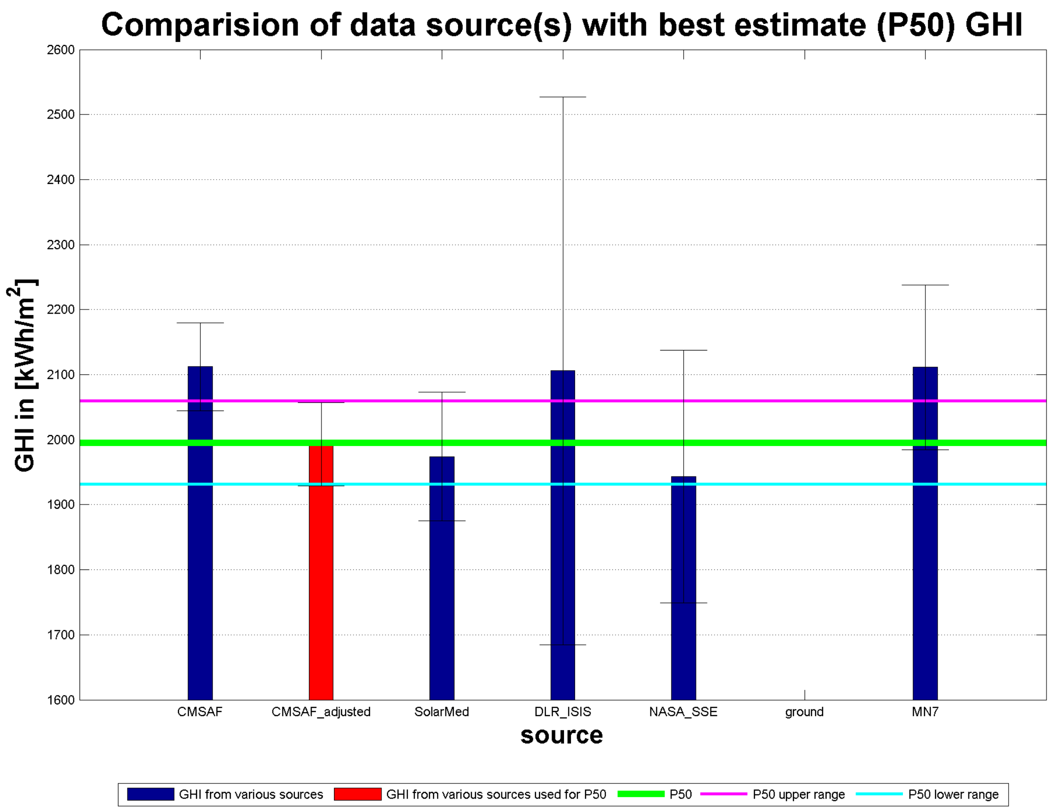


Figure 6: Overview of the long-term GHI values from different data sets (red: used / blue: not used for determination of best estimate) and the best estimate (green line). The lower (cyan) and upper (magenta) lines illustrate the ranges of the best estimate, which are based on the estimated uncertainty of the best estimate.

4.3 Inter-annual variability of GHI

Since CMSAF use daily turbidity input for calculating GHI - which is one of the most important factors affecting GHI - and the temporal coverage of CMSAF is with more than 11 years comfortable and represents well the changes of various atmospheric constituents, adapted CMSAF data are taken to calculate the volatility of GHI from year to year. Based on the adapted CMSAF data set, the inter-annual variability of GHI at LYJAD is 2 W/m^2 approximately equivalent to ± 0.9 %. Compared to other regions in the world this is a very low volatility for GHI, which is favourable for financing solar energy projects.

Following Meyer et al. (2009) the uncertainty due to considering only a few years reduces with the number of years. In this analysis the main base for fixing the long-term value is the ca. 11 years data set of adapted CMSAF. Thus, the contribution to uncertainty due to inter-annual variations is 0.3 %. This is taken as an input in chapter 4.4 to derive the overall uncertainty.

4.4 Analysis of uncertainty of GHI

As explained in 3.7 the total long-term uncertainty of long-term best estimate of GHI depends on the uncertainty of measurements, uncertainty of long-term data and the inter-annual variability of GHI. From the available GHI measurements 100% are flagged as correct. As a result, the long-term instrument uncertainty of GHI measured by the Rotating Shadowband Irradiometer (RSI) is assumed to be 2.5 %. No documentation of the sensors and the meteorological measurement stations is available, thus it is not known if the radiation instruments had been regularly recalibrated and cleaned. However, in comparison to thermopile pyranometers equipped with a glass dome, the RSI is quite insensitive against soiling since its sensing element is a photo diode covered by a plastic diffuser disk. Thus, the uncertainty of GHI measured due to calibration and maintenance issues is assumed to be 0.5 %. The total uncertainty of GHI data measured by RSI is obtained by considering these two factors according to Gaussian error law of propagation and found to be about 2.5 %. Further details can be found in Table 2.

As explained in chapter 3.7, the uncertainty of satellite data is reduced by using the adaption methodology to the data. According to Mieslinger et al. (2014), the uncertainty of the adaption methodology is approximately 3 % on average, which varies depending on the site, the data source, and the duration of the overlapping period with on-site measurements. The overlapping period with on-site measurements is 12 months. Although the location of the measurement station is around 60km away from the project site, and thus the correction functions of the satellite data are determined by a different satellite data set (corresponding to the location of the measurement station), the additional uncertainty due to the relatively high distance of the measurement station from the project site is evaluated to be low. Reason is that in the region of the project site the geographical characteristics are quite homogenous and nearly don’t change with distance, and thus the geographical characteristics of both locations are very similar. As a result, for this study an uncertainty of 2.0 % is assumed for the adaption methodology for CMSAF. Based on the above-mentioned values, the total uncertainty of the long-term best estimates of GHI (P50) is found to be 3.2 % for multiple years and 3.3 % for a single year.

Calculation of long-term uncertainty of long-term average of GHIfor multiple year and single year							
overall uncertainty				adjustment uncertainty	uncertainty on-site meas.	uncertainty due to temporal coverage	
						multiple year	single year
multiple year $U_{my}=\sqrt{(A^2+B^2+C_{my}^2)}$		single year $U_{sy}=\sqrt{(U_{my}^2+C_{sy}^2)}$		A	B	$C_{my}=C_{sy}/\sqrt{n}$	C_{sy}
abs. [W/m^2]	rel.[%]	abs. [W/m^2]	rel.[%]	[%]	[%]	[%]	[%]
7	**3.2**	8	**3.3**	2.0	2.5	0.3	0.9

Table 2: Explanation of derivation of the total long-term uncertainty of GHI following Meyer et al. (2008).

4.5 P75 and P90 value of GHI at LYJAD

As mentioned in Chapter 3.9, for risk assessment of the solar power project, Meteorological Years representing P75 and P90 values of GHI are derived based on the P50 value and the associated uncertainty (multiple year and single year uncertainty). Table 3 gives an overview of the different PXY values in comparison to best estimate (P50) for each month and the whole year with respect to multiple year and single year uncertainty.

		P50 [W/m²]	multiple year PXY values [W/m²]		single year PXY values [W/m²]	
			P75	P90	P75	P90
Jan		140	137	134	137	134
Feb		176	172	168	172	168
Mar		222	217	213	217	213
Apr		275	269	263	269	263
May		295	289	283	288	282
Jun		311	305	299	304	298
Jul		323	316	310	316	309
Aug		291	285	279	285	279
Sep		236	231	227	231	226
Oct		189	185	181	185	181
Nov		147	144	141	144	141
Dec		123	121	118	120	118
year	**avg.** [W/m²]	228	223	218	222	218
	sum [kWh/m²]	**1995**	**1952**	**1913**	**1950**	**1910**
avg. day sum [kWh/m²]		**5.46**	**5.34**	**5.24**	**5.34**	**5.23**
deviation from P50 (PXY-P50)/P50		-	-2.17%	-4.11%	-2.26%	-4.29%

Table 3: Overview of PXY values in comparison to best estimate (P50) for each month and the whole year with respect to multiple year and single year uncertainty.

4.6 Annual cycle of GHI

Figure 7 and Table 4 show the long-term annual cycle of GHI of best estimate in comparison to adapted CMSAF, CMSAF, on-site measurements, DLR-ISIS, NASA-SSE, SolarMed and MN7 data sets. It can be seen from the comparison of the annual cycle of measured values and the best estimate that seasonal variations of GHI match quite well.

All satellite-derived data products overestimate the more precise ground-based measurements in the available months September until May. Especially in December and February decisively lower GHI values were measured compared to monthly average values from satellite data sets. Note that those values represent only a specific month and year while the other data sources represent long-term averages. Therefore, the CMSAF data set is combined with ground-based measurements to get information on long-term solar conditions, but corrected for the general overestimation of GHI. The corrected CMSAF dataset, i.e. $\text{CMSAF}_{\text{adapted}}$ or in the graphic $\text{GMS}_{\text{adapted}}$, best represents reasonable seasonal cycle of GHI.

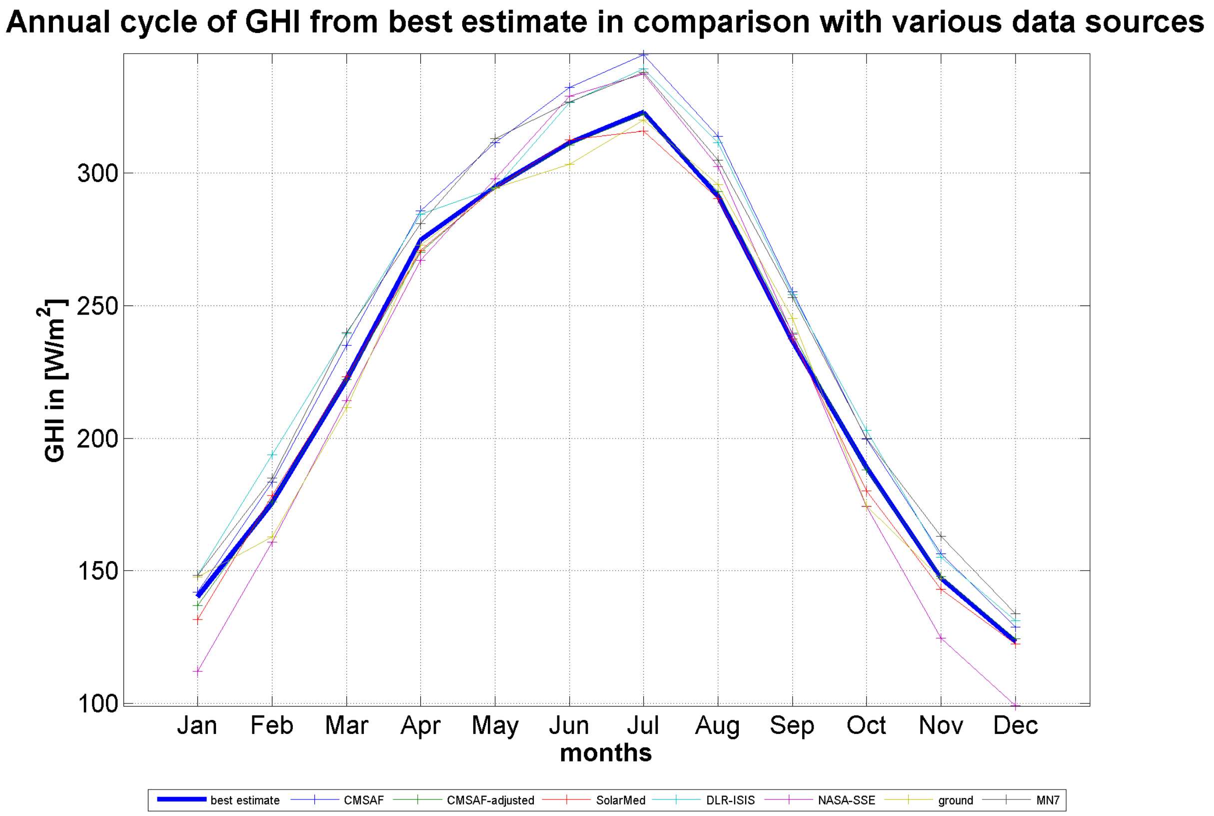


Figure 7: Long-term monthly averages of GHI best estimate in comparison to $CMSAF_{original}$, $CMSAF_{adapted}$, on-site measurements, SolarMed, DLR-ISIS, NASA-SSE, SolarMed and MN7 datasets.

	CMSAF	$CMSAF_{adap}$	DLR-ISIS	NASA-SSE	SolarMed	ground	MN7	best estimate	P75 my	P90 my	P75 sy	P90 sy
	[W/m^2]	[W/m^2]	[W/m^2]	[W/m^2]	[W/m^2]	[W/m^2]	[W/m^2]	[W/m^2]	[W/m^2]	[W/m^2]	[W/m^2]	[W/m^2]
Jan	142	137	148	112	132	148	148	140	137	134	137	134
Feb	183	176	194	161	178	163	185	176	172	168	172	168
Mar	235	222	239	214	223	212	240	222	217	213	217	213
Apr	286	270	284	267	271	273	281	275	269	263	269	263
May	311	295	294	298	294	294	313	295	289	283	288	282
Jun	332	311	327	329	313	303	327	311	305	299	304	298
Jul	345	322	339	338	316	320	338	323	316	310	316	309
Aug	314	293	311	303	290	296	305	291	285	279	285	279
Sep	255	240	254	239	238	245	253	236	231	227	231	226
Oct	200	188	203	174	180	174	200	189	185	181	185	181
Nov	156	148	155	125	143	147	163	147	144	141	144	141
Dec	129	124	131	99	122	-	134	123	121	118	120	118
year	241	227	240	222	225	-	241	228	223	218	222	218

Table 4: Long-term monthly average values of GHI.

4.7 Description of resulting TMY (P50) and MYs (P75 and P90)

4.7.1 Global Horizontal Irradiance

For the TMY (P50) the annual mean Global Horizontal Irradiance is 228 W/m^2 equal to an annual sum of 1996 kWh/m^2/a. This is 0.04 % above the P50 value of 1995 kWh/m^2/a. For the MY75 with respect to multiple year uncertainty the annual mean Global Horizontal Irradiance is 224 W/m^2 equal to an annual sum of 1963 kWh/m^2/a. This is 0.5% above the P75 value. For the MY90 with respect to multiple year uncertainty the annual mean Global Horizontal Irradiance is 220 W/m^2 equal to an annual sum of 1924 kWh/m^2/a. This is 0.6% above the P90. These relatively low differences between the P-values and the yearly best estimates of the TMY/MY data sets are caused due to the applied concatenating method where complete days inside a month are interchanged and upsampled to fill gaps.

Figure 8 shows the monthly values, the hours over the year, as well as the cumulative frequency distribution of GHI & DHI for the TMY. The corresponding monthly values for the TMY are listed in Table 5 and Table 6.

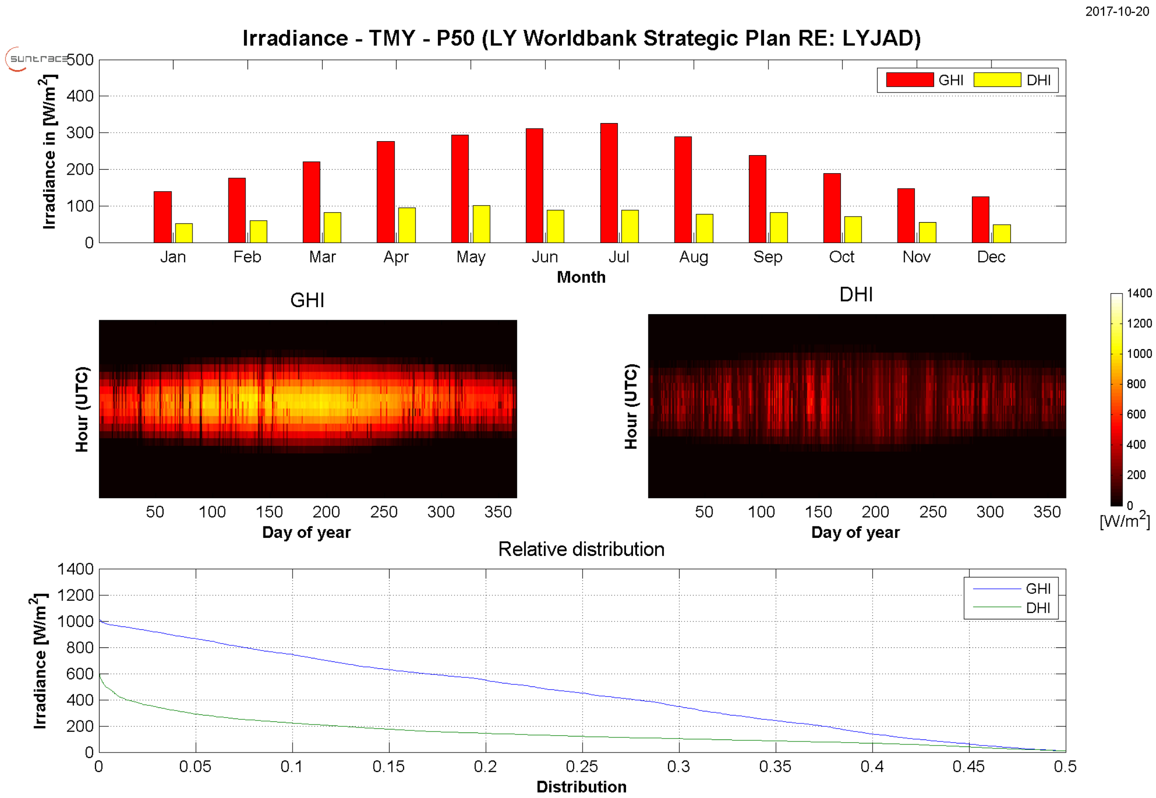


Figure 8: TMY - monthly values (top), hours over the year (middle) and distribution (bottom) of GHI and DHI.

Global Horizontal Irradiance

	average [W/m²]	min [W/m²]	max [W/m²]	sum [kWh/m²]
Jan	139	0	664	103
Feb	176	0	828	118
Mar	221	0	919	165
Apr	276	0	1012	198
May	294	0	1029	219
Jun	312	0	992	225
Jul	326	0	1017	243
Aug	288	0	975	215
Sep	239	0	917	172
Oct	189	0	823	140
Nov	147	0	700	106
Dec	124	0	609	93
Year	228	0	1029	1996

Table 5: TMY - monthly values of GHI

Diffuse Horizontal Irradiance

	average [W/m²]	min [W/m²]	max [W/m²]	sum [kWh/m²]
Jan	52	0	408	38
Feb	60	0	475	40
Mar	82	0	544	61
Apr	95	0	597	69
May	102	0	644	76
Jun	89	0	525	64
Jul	88	0	476	66
Aug	77	0	494	57
Sep	82	0	432	59
Oct	70	0	499	52
Nov	55	0	394	40
Dec	48	0	399	36
Year	75	0	644	658

Table 6: TMY - monthly values of DHI

5 Conclusions

In the context of this study, long-term best estimate of GHI for the site LYJAD with the associated uncertainty is provided. A Typical Meteorological Year (TMY) representing the long-term best estimate of GHI is created using site-specific satellite data obtained from CMSAF, which are adapted to on-site measurement data. Since the location of the on-site measurement station is 60km away from the project site, the correction function for adapting the satellite data is determined by comparison with additional satellite data of the location of the on-site measurement station. Then, the correction function is applied to the satellite data from the project site LYJAD. In the region of the project site the geographical characteristics are quite homogenous and thus nearly don't change with distance. Therefore, the additional uncertainty due to the relatively high distance of the measurement station from the project site is evaluated to be low since the geographical characteristics of both locations are very similar.

The TMY is provided in hourly resolution and includes site-specific auxiliary meteorological parameters obtained from on-site measurements. Similarly, Meteorological Years (MYs) in hourly time resolution representing P75 and P90 case of GHI are also provided along with the current assessment.

5.1 Main findings

The quality of obtained satellite-derived data is found to be good. The on-site measurements are taken with good instrumentation in form of a Rotating Shadowband Irradiometer (RSI). No documentation of the sensors and the meteorological measurement stations is available, thus it is not known if the radiation instruments had been regularly recalibrated and cleaned. However, in comparison to a thermopile pyranometer equipped with a glass a glass dome, the RSI is quite insensitive against soiling.

The length of the measurement period is in total 12 months which is long enough to achieve reasonable results. Using one complete year assures that all seasons are included for the adaption resulting in a low uncertainty for the adaption methodology of 2.0 %. In addition, having on-site measurements of at least one year available allows using these measurements for creating the TMY and MY data sets. Using measured data instead of model-derived data has the advantage that the resulting TMY and MY-data sets are well representing the ambient meteorological conditions at the site. Also the GHI data are more realistic because also ground-corrected satellite-derived irradiance data do not show the same temporal patterns as measurements. This is especially valid for 1 min data, which today only can be derived from satellite images using interpolation techniques, because the highest temporal resolution of available satellite data sets is 15 min. For satellite data before 2004 only 30 min repetition rate is available.

The long-term best estimate for GHI at this site amounts to **228 W/m^2**, which is equivalent to **1995 kWh/m^2** per year or **5.5 kWh/m^2** per day.

The inter-annual variability is analysed on the basis of the CMSAF data set. A year-to-year volatility of 0.9 % is calculated for GHI, which is very low compared to many other regions worldwide. The assessment of uncertainties takes into account the length of record of various data sets, uncertainty of the on-site measurements close to the site LYJAD and the methodological uncertainty of the adaption process. Accordingly, the above given long-term average for GHI is assumed to have an uncertainty of 3.2 % associated with the inter-annual variability related to multiple years and 3.3 % related to a single year.

For the long-term average (P50), a characteristic meteorological year in hourly time resolution is provided. Besides GHI, this data set also provides Diffuse Horizontal Irradiance (DHI) and auxiliary meteorological parameters, such as air temperature, wind speed, and wind direction derived from the on-site measurements, where auxiliary parameters support site-specific plant layout and performance calculations.

For risk assessment of the solar power project, P75 and P90 Meteorological Years are created based on the P50 value. The multiple years P75 value of GHI at this site is estimated to be 2.2 % below the long-term best estimate (P50). This leads to a long-term average P75 value for GHI of 223 W/m^2 or 1952 kWh/m^2 per year or 5.3 kWh/m^2 per day. The single year P75 value of GHI at this site is estimated to be 2.3 % below the long-term best estimate (P50). This leads to a long-term average P75 value for GHI, based on a single year uncertainty of 222 W/m^2 or 1950 kWh/m^2 per year or 5.3 kWh/m^2 per day.

5.2 Recommendations for further improvement

On-site measurements directly at the project site would help to reach even better characterisation of local conditions and reducing importantly the uncertainty of the long-term best estimate GHI since local effects maybe could be identified. This would bring greater authenticity to the resource information. Having two years of on-site measurements available would allow to identify possible inter annual effects. In an optimum case, it is better to have two years of on-site measurements, as they provide more robust results and significantly decrease the uncertainty of the site-adapted data.

6 References

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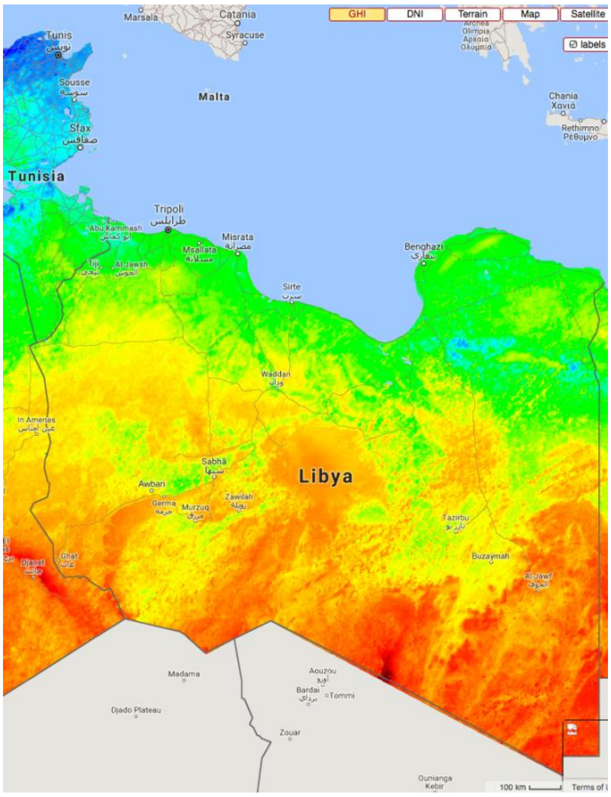
Annex 4: Technology Configurations for PSP Pilot

Libya - Supporting Electricity Sector Reform (P154606)



Contract No. 7181909 - Task D:
Strategic Plan for Renewable Energy Development

Feasibility Study for a PV Plant at Jadu Site
Annex 4 - Technology Configurations for PSP Pilot
18th December 2017

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1. High-Level PV Technology Assessment

The application of PV power plants has changed distinctly in recent years. Starting with mainly small rooftop installations in rich countries the market has now reached maturity also within the market of big utility scale power plants, which arise almost all over the world.

This section describes the major technology trends focussing on the main components (modules, inverters and mounting systems) and deals with the qualitative aspects of photovoltaic technologies.

Solar photovoltaic plants use the global irradiation (GI), which is converted into electric energy in the solar generator. The solar generator consists of PV modules connected in series to form strings, which are connected in parallel and deliver DC power to the inverters. The inverter converts the DC power to AC power before transforming to the required voltage level allowing evacuation of power to the grid as shown in Figure 1-1 below.

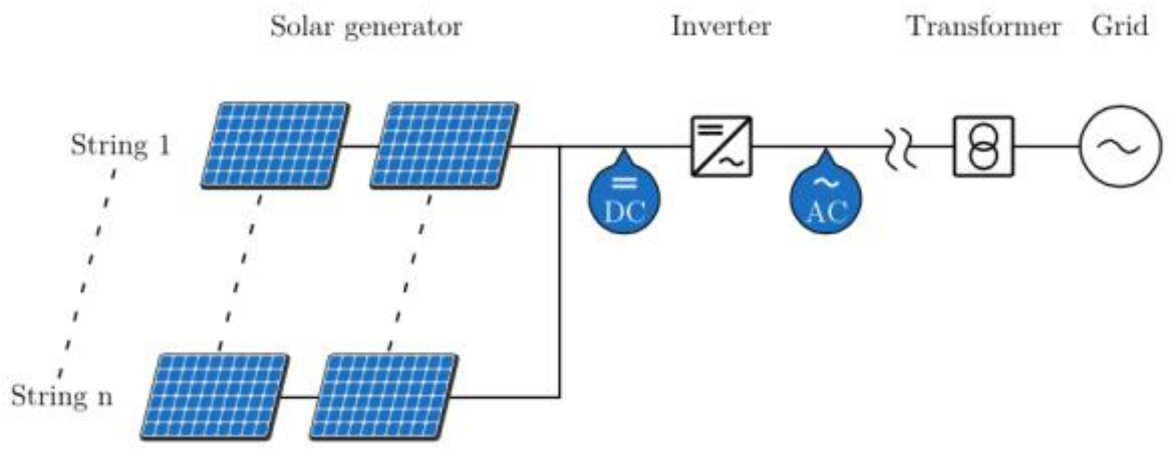


Figure 1-1: General principle of a possible setup for a PV array (source: Suntrace GmbH)

2. PV Module Technologies

The photovoltaic module technologies differ primarily by the type of technology, which leads to different manufacturing processes, price ranges, manufacturing cost and performance. Photovoltaic module technology is based on the photoelectric effect, in which the photons emitted by the sun impact a semiconductor surface and are absorbed to produce electricity. Different module technologies are described hereafter. With respect to the Libyan energy market situation, major technologies should be favoured providing a long track record with best practice industrial standards and sufficient suppliers for competitive bidding.

Silicon wafer based PV technology accounted for about 93 % of the total production in 2015. The share of multi-crystalline technology is now about 68 % of total production. In 2015, the market share of all thin film technologies amounted to about 7 % of the total annual production.

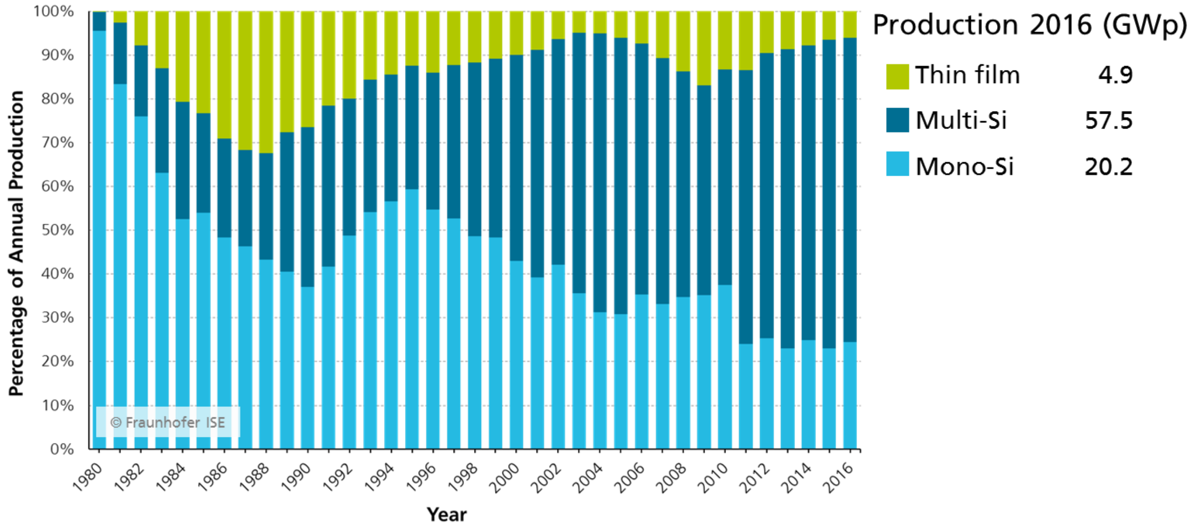


Figure 2-1: Percentage of global annual PV module production (source: Fraunhofer ISE, Photovoltaics Report, July 2017)

The multicrystalline technology has existed since 1981. Its manufacturing process is simpler than the one of monocrystalline technology, which requires more effort. However, the monocrystalline modules offer higher efficiency – typically within 15-20%.

For the thin film technology the semiconductor material is placed on a substrate material, with only nanometre of thickness. Hence, very low amounts of material are needed. The main semiconductor materials in use are

- Amorphous Silicon (a-Si);
- Cadmium Telluride (CdTe);
- Copper Iridium Gallium Selenide (CIS / CIGS); and
- Gallium Arsenide (GaAs).

Depending on the technology, thin film module efficiencies have reached 11-17%.

In the following table, the different main PV module technologies are compared.

Table 2-1: Comparison of different technologies

Module Technology	Advantage	Disadvantage
Multicrystalline	• Mature and commercially proven technology • Long lifetime of panels • Low degradation of about 0.5% per year • Low installation costs • Low production costs compared to monocrystalline modules • Crystalline cells are not harmful to the environment. • Established global competitions and high number of tier 1 companies	• Lower efficiency in comparison to monocrystalline technology, due to lower purity of the cell material: 14-18%. • Because of the lower efficiency, a larger surface is required to reach the same capacity. • Higher risk of cracks during transport or mounting in comparison to thin film technology.
Monocrystalline	• Mature and commercially proven technology • Long lifetime of panels • Low degradation of about 0.5% per year • High efficiencies typically within 15-20%.	• The initial investment costs are higher compared to multicrystalline modules. • Higher risk of cracks during transport or mounting in comparison to thin film technology.
Thin film	• Easier to manufacture and lower production cost compared to crystalline modules. • Homogenous appearance. • Flexible, hence for use at different applications and surfaces. • Less affected by high temperatures and shadowing.	• **Very few market players,** with only First Solar having a significant market share (CdTe modules). • Faster degradation compared to crystalline modules. • Higher cost for mounting, installation, cabling compared to crystalline modules. • CdTe modules use cadmium telluride as semiconductor layer. Under extreme conditions, e.g. high temperatures, it might happen that CdTe breaks into Cd and Te. As Cadmium is a toxic metal, the recycling of the modules by the manufacturer has to be secured to avoid emissions to the environment at the end of the lifecycle. • Thin Film technologies have faced technical problems with degradation in the last decade. A special accuracy is needed in the selection of the product.

3. Inverter Technology

Inverters convert the direct current (DC) produced by the solar modules into alternating current (AC) that can be fed into the grid. In general, there are two different types of inverters, the string inverter and central inverter.

String inverter concept
The individual PV modules are connected in series to form strings. When using string inverters, the DC power from a few strings runs directly into a string inverter where it is converted to AC power. The string inverter is a small unit and can eventually be mounted underneath the PV mounting system. This concept offers higher modularity and flexibility of the system configuration compared to the central inverter concept and is typically applied for PV plants < 1 MW and systems with different array angles and/or orientations. The nominal DC capacity of string inverters is typically below 100kW.

Central inverter concept
When using central inverters, the strings are connected in parallel through combiner boxes and are then connected to the central inverter, which summarize typically between 500 kW to 2.5 MW of DC PV power. In utility scale PV plants, the PV field is generally divided into more parts (subfields), each of them served by an inverter of its own. This configuration is optimal for large systems where production is consistent across arrays. Moreover, the central inverter concept offers lower capacity specific costs and fewer component connections compared to the string inverter concept.

State of the art inverter technology offers a broad range of operational stages, being able to fulfil international grid codes in terms of fault-ride-through and reactive power provision. Moreover, a SCADA system (Supervisory Control and Data Acquisition) is typically incorporated allowing fully remote operation.

The inverter concept selection needs to be made for each project taken into account the market situation, system cost and expected energy production. Certain central and string inverters can be used as statcoms and provide reactive power. Requirements for reactive power supply are typically arranged in either the grid code, grid connection agreement or potentially the PPA.

4. Fixed Mounting Structures and Tracking Systems

The photovoltaic panels may be installed on fixed structures or on structures that are tracking the sun's course during the day, the latter may be of one axis or two axes.

Fixed structures in the northern hemisphere are generally tilted towards the south with an inclination between 10° and 40°. The fixed position of the modules leads to a generation curve with a strong peak at midday on cloudless days. Under certain conditions (e.g. high lease costs, proximity to the equator) east-west facing solar modules can also be an option. The specific yield is lower compared to south-facing power plants, but efficient surface use and a more balanced energy yield in the course of the day are two interesting advantages of this variant. In addition, the specific cost for the mounting structure is lower compared to the south or north orientated fixed-tilt system.

For tracker solutions, the aim is to follow the sun and maintain the panels perpendicular to the axis of incidence of the sun. Thus, a greater efficiency in converting solar energy into electricity can be achieved. The Two-Axis-Tracking can follow the sun both in azimuth and angle - both to the east and west, and depending on the season, follow the inclination during the day and the time of the year.

Advantages of tracking systems compared to fixed-tilt systems:
In general, the tracking systems can harness more energy, making them a very attractive alternative in areas of high solar irradiation. Tracking systems are able to keep shading to a minimum but typically require more space for the same power output as compared to a fixed-tilt system. One of the most important aspects of tracking systems is the increased energy yield during the morning and evening hours, which helps to deliver a more constant electricity supply, which helps to deliver a more constant electricity supply.

Disadvantages of tracking systems compared to fixed-tilt systems:
One of the disadvantages of tracked systems compared to fixed-tilt PV power plants is that "moving" or "rotating" parts are needed for or within the power plants. In general, tracking systems are more susceptible to failure, due to the number of moving parts and therefore, they also require more maintenance and maintenance costs can be around 15% higher. Trackers are more susceptible to high wind loads and in areas of high wind speeds the limited warranty for tracker systems may be reduced.

The decision to choose any of the three types of mounting structure is based on a technical and economic evaluation. Extra energy generation must be assessed in comparison to the energy price and to the investment required.

5. Maturity of Technology – Track Record

Though since the 1950s in the focus of research and development, PV technology did not achieve market maturity until the 1990s supported by renewable energy policies in Germany and USA. As of today, the PV industry can look back on a long track-record and more than a decade of experience in utility-scale power utilisation in international markets. Until recently, the demand for PV installations was concentrated in the OECD countries but the technology has managed to enter several emerging markets in recent years and also for Libya PV technology stands out as a promising option for renewable energy.

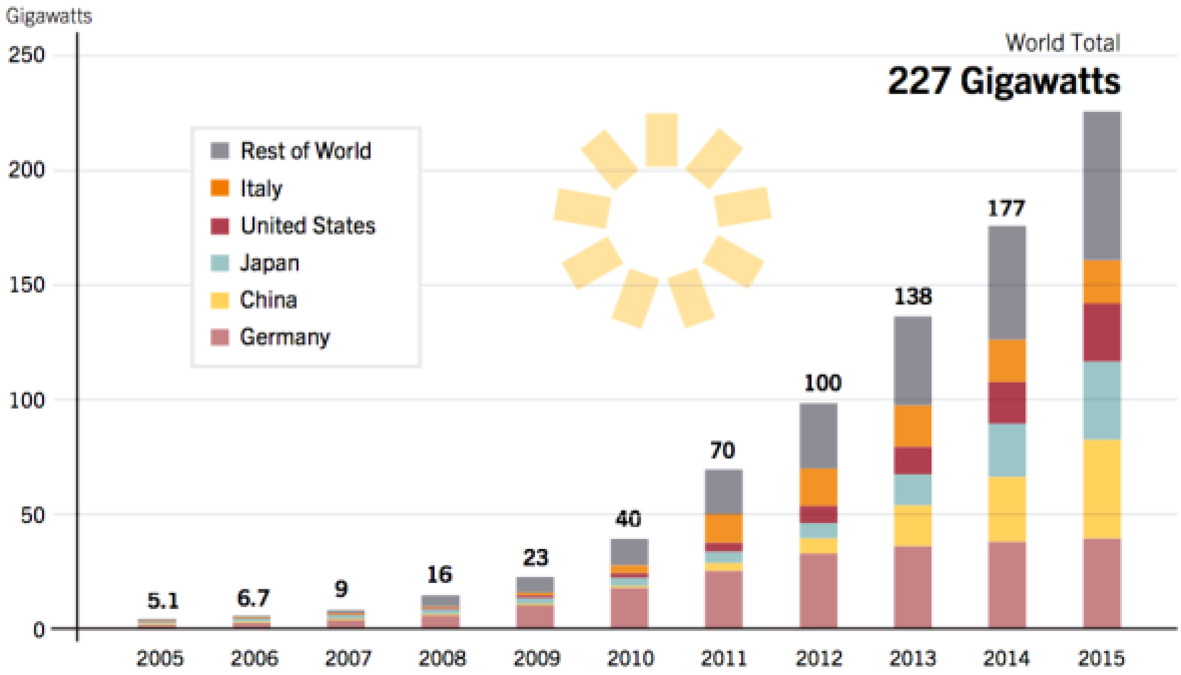


Figure 5-1: Solar PV Global Capacity by Country/Region 2005-2015 (source: REN21, GSR 2016)

Market expansion in most of the world, including the Gulf region, Jordan and Morocco for instance, is due largely to

- the increasing competitiveness of solar PV,
- new government programmes,
- the relatively simple nature of PV technology compared to others,
- rising demand for electricity and improving awareness of solar PV's potential

as countries seek to alleviate pollution and CO2 emissions. The technology is bankable i.e. favourable interest rates due to reduced risks.

6. Market Outlook of PV Technology

Though photovoltaic is mature from a technological and commercial point of view, the potential for further cost reduction is still considered to be high.

The experience curve shows that in the last 36 years the module price decreased by 24 % with each doubling of the cumulated module production (see Figure 6-1; source: Fraunhofer ISE). Cost reductions result from economies of scale and technological improvements.

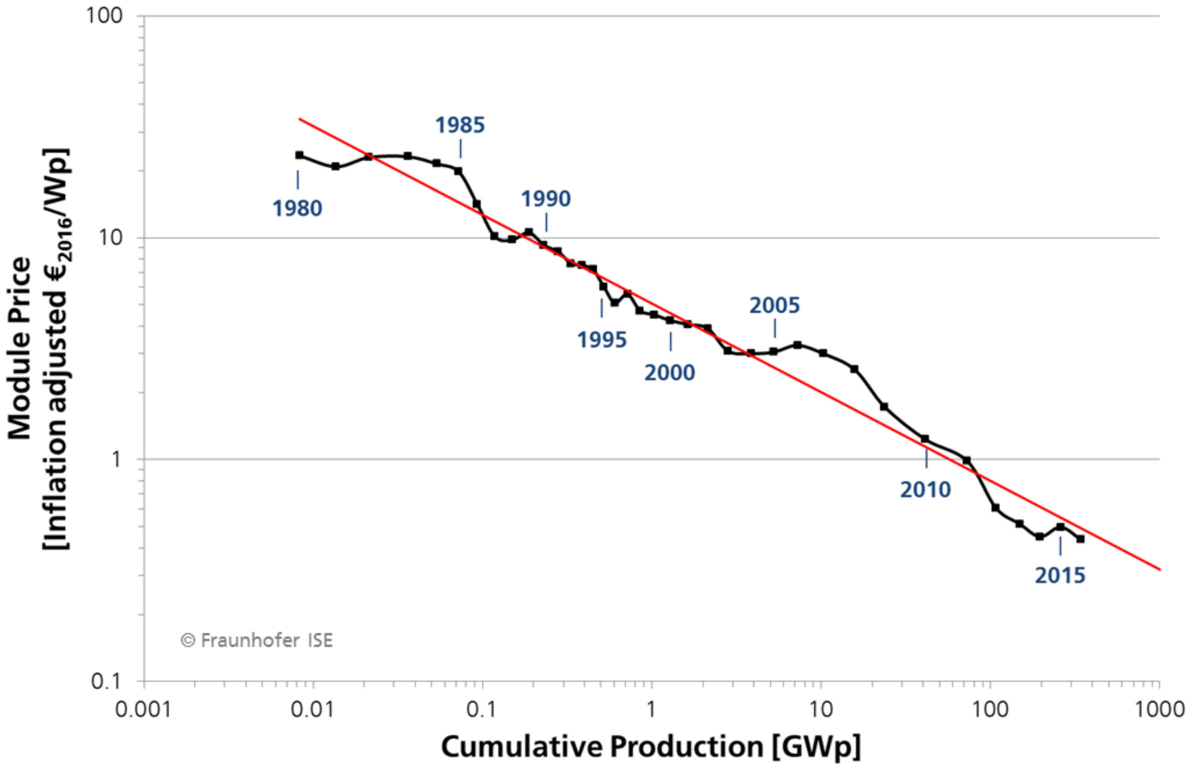


Figure 6-1: Price Learning Curve (Includes all commercially available PV technologies); (source: Photovoltaics Report, Fraunhofer Institute for Solar Energy Systems, July 2017)

Massive market growth is expected in the next years. The IEA developed three different scenarios for the energy consumption and generation until 2050, based on assumptions about population growth and energy consumption behaviour. Based on these assumptions the authors of the International Technology Roadmap for Photovoltaic (ITRPV) calculated three scenarios. The following cumulative installed PV power in 2050 have been determined:

- low scenario: 4.5 TWp;
- medium scenario: 6.85 TWp; and
- high scenario: 9.17 TWp

The medium scenario is shown in Figure 6-2 below. In the figure, cumulative installed PV module power and annual market calculated with a logistic growth approximation and assuming 6.8 TWp installed PV module power in 2050.

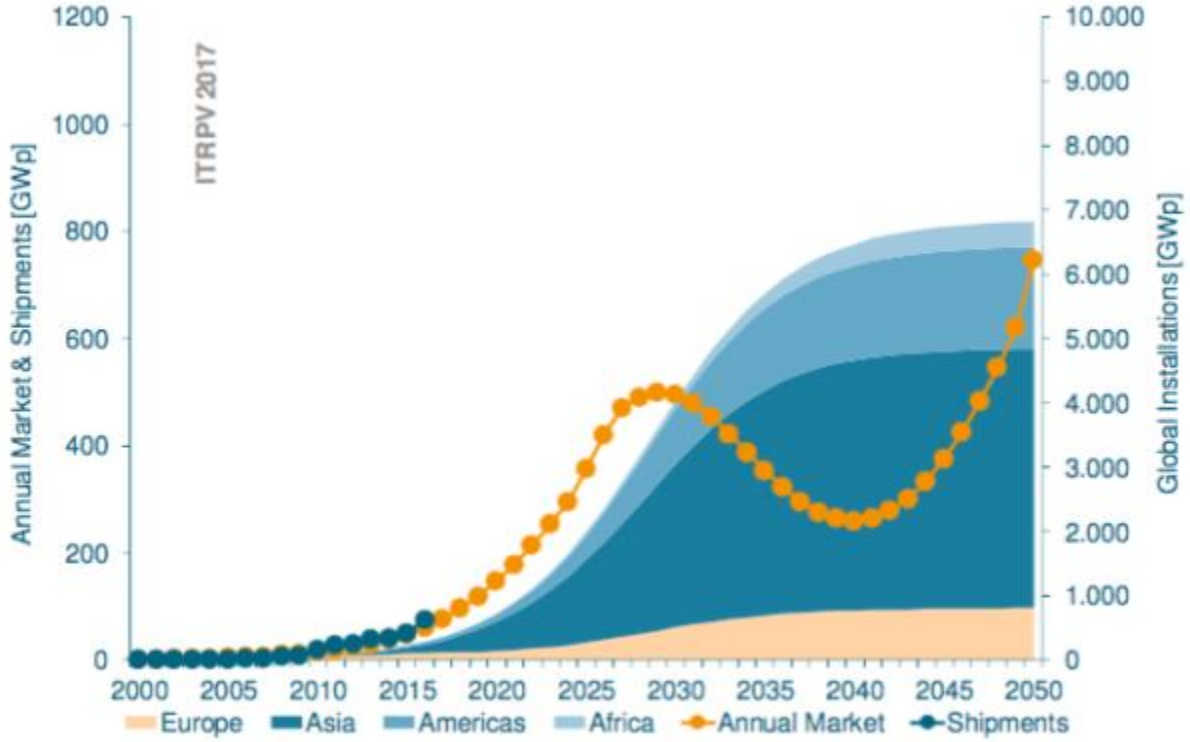


Figure 6-2: Installation forecast: Medium scenario; (ITRPV), 2016 Results, Eighth Edition, March 2017

Major market drivers in the next years will be:

- cost reduction and resulting electricity price
- technological improvements
- environmental concerns (e.g.: air pollution, health impacts, global climate change)
- social benefits (e.g.: improved energy access, security and reliability of supply)
- growing interest in citizen control over energy production
- Scalability and simplicity of the technology

7. Technology Risks

Compared to other energy production technologies photovoltaic with its relatively simple and repetitive technology faces comparatively low risks. In the following the focus will be on the main risks regarding completion, operation, function and resource.

Completion risk
The most common constructional problems are:

- Complex ground conditions;
- Delayed or wrong delivery of components;
- Bad weather conditions; and
- Incorrect design.

These risks may lead to a cost and/or time overrun in construction or to a completed plant that may not meet the pre-defined performance levels.

Operational and Management risks
All threats during the operating phase that disrupt the production or lead to higher operational costs can be pooled as operational and management risks. Causes for an operational and management risk include poor planning, organization or execution of operational procedures. Hence, the experience of the management personnel is crucial. Possible limitations of production have a negative impact on the output quantity and consequently on generated income. The key consequence in the model is a lower cash flow, i.e. revenues.

Functional risk – PV plant
The functional risk includes the risks that the output is less in quantity or quality. This risk is significant as it can lead to lower revenue and hence, to lower cash flow.

Main risks are:

- Module/Cell quality (e.g. Potential Induced Degradation (PID), Light Induced Degradation (LID), cell or module array mismatch);
- Inverter quality (e.g. insufficient meteorological design (dust, salty air), low efficiency, high malfunctioning rate);
- Design errors (e.g. Inverter design, DC/AC ratio, cable dimension); and
- Grid connection adjustments (e.g. provision of reactive power).

Resource risk – PV plant
The resource risk can be described as the risk that the solar irradiation (the resource) does not meet with respective assumptions/projections. Solar irradiation is (almost) linearly related to projected income and return on investment. Seasonally adjusted solar resource assessments (preferably combined with on-site measurement campaigns) can provide a higher element of certainty.

8. Scalability

PV power plants offer an almost unlimited scalability. The smallest energy generator would be a module (of e.g. 200Wp) with micro inverter, bigger utility scale power plants exceed these smallest device a million times (>200MWp). The wide range of available inverters (micro, string and central) and their repetitive application permit almost every plant size desired, so that the scalability of PV power plants is limited mainly by the area available and the grid connection conditions.

9. Costs and Potential of Cost Reduction

The impressive cost reduction of PV modules already has been shown in section 6 and further significant cost reductions are expected in the next decades. Cost reductions will be mainly driven by in increasing economies of scale and technology improvements. Higher module efficiencies in turn reduce the area required and also mounting costs.

The Figure 9-1 shows the relative development of system costs for large systems (>100 kWp).

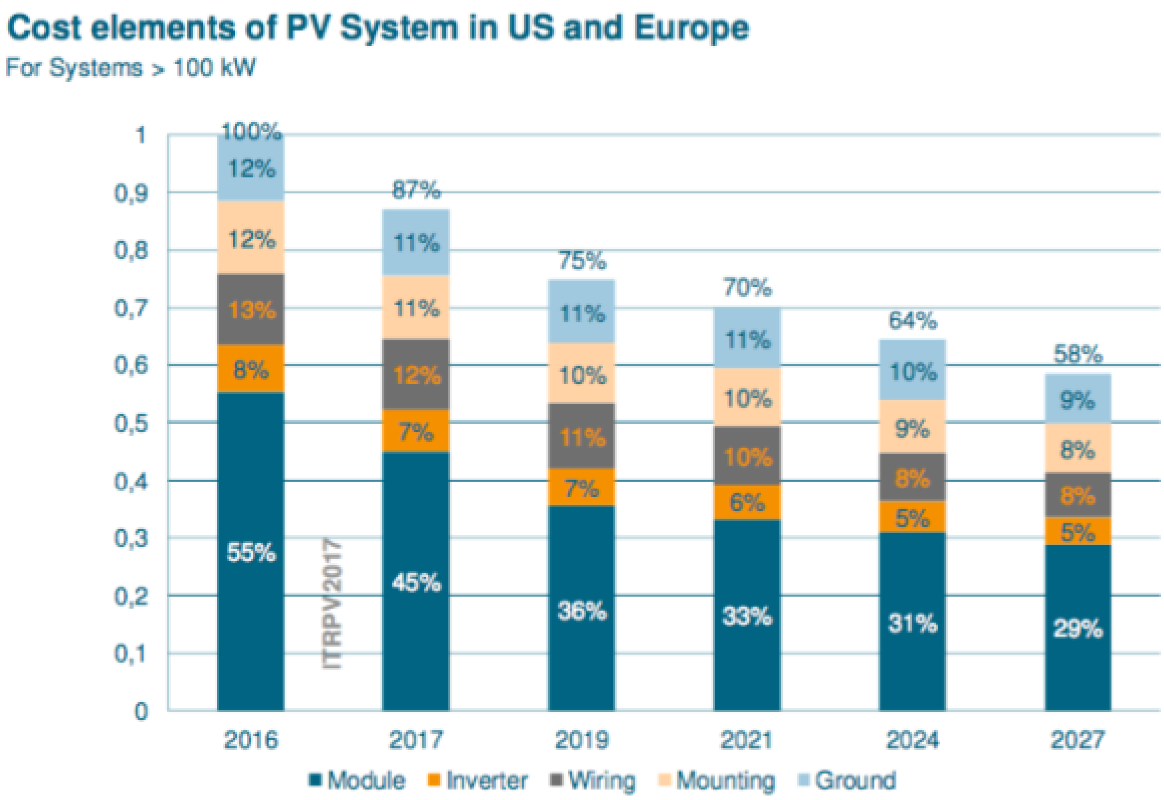


Figure 9-1: Relative system cost development for systems > 100 kW in the US and Europe (2016 = 100%); no soft costs, such as costs for permits or costs for financing, are included; source: ITRPV; eighth edition, March 2017

In addition, as equipment costs keep falling, balance of system costs and costs for operations and maintenance (O&M) will rise in importance as cost reduction drivers. Approach towards best practice levels will therefore play an important role in the future and even in new markets. Competitive pressures are driving down costs rapidly.

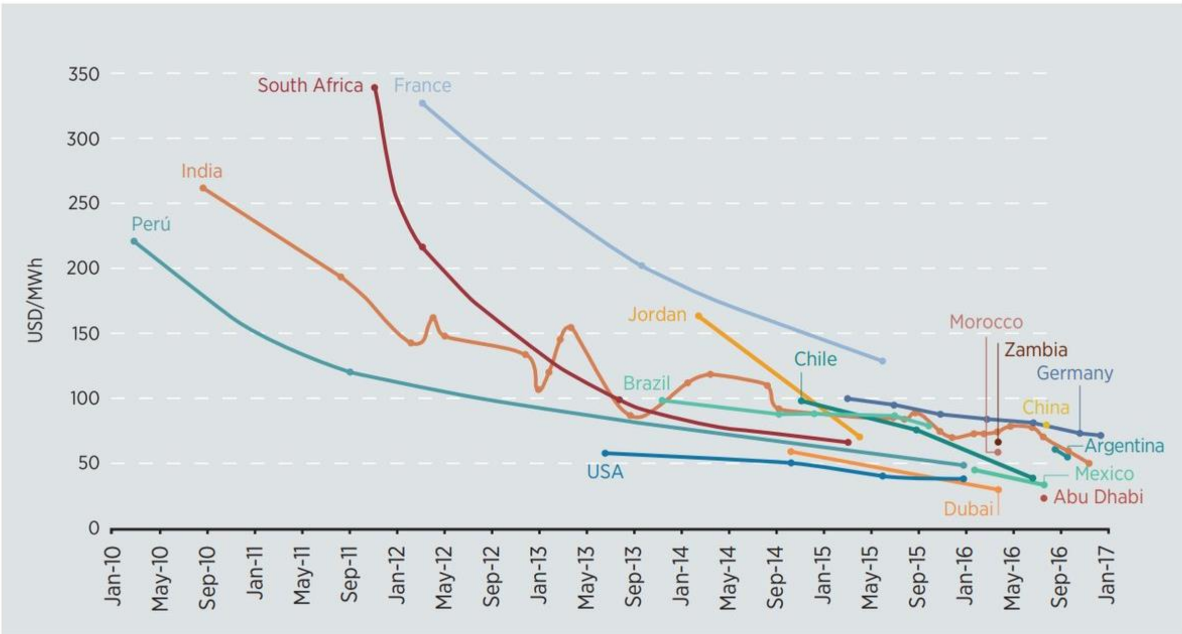
O&M expenditures vary depending on the applied technology (fixed vs. tracked mounting system, string inverter vs. central inverters), site-specific factors like used surface (mowing) or soiling (module cleaning), accessibility, wages and others. Hence, it is difficult to estimate average O&M costs. O&M costs for utility-scale plants in the United States for example have been reported to be between USD 10 and USD 18/kW per year (Lawrence Berkeley National Laboratory, 2015b; Fu, *et al.*, 2015) and in some OECD markets, such as Germany and the United Kingdom, the O&M costs now account for 20-25% of the LCoE (STA, 2014; deea, 2016).

The operation and maintenance expenditures consist of fixed and variable costs and include the following items:

- Administration and management;
- O&M staff;
- Service contracts;
- Materials;
- Maintenance reserve account payments;
- PV module cleaning; and
- Greenkeeping.

The LCoE depends substantially on the plant size and local irradiance conditions. Apart from these factors local market conditions influence the costs. The variation will decrease with the maturing of the emerging markets, lower capital costs and the expansion of best practice solutions worldwide.

Figure 9-2 shows the LCoE of individual projects in the years 2010 to 2015 with the weighted average and the projected LCoE range till 2025.



Notes: Prices are averages. On the rare occasion when multiple auctions occurred within the same month, the average price of those auctions is shown. In case of ambiguity regarding the auction's date, the date when the winning bids were selected and announced was taken as the main reference.

Sources: Based on data from BNEF (2016 a, b,c), ANEEL (2016), BnetzA (2017a), Bridge to India (2017a), Coordinador Eléctrico Nacional (2016), Eberhard and Kåberger (2016), Elizondo-Azuela, Barroso et al. (2014), IFC (2016), Mahapatra (2016 a,b), MINEM (2016a, b), MNRE (2010), MNRE (2012), Ola (2016), Osinergmin (2016), Santiago and Sinclair (2017a, b), Shahan (2016).

Figure 9-2: Evolution of average auction prices for solar PV, January 2010-February 2017

The projection of Figure 9-2 is in line with the recent power purchase agreement and tender results in Mexico and Dubai, where bids reached prices as low as USD 0.03/kWh, even if it has to be taken into account that those prices are not necessarily directly comparable with an LCoE calculation. An LCoE calculation is a cost and yield based discounting whereas a competitive tariff is determined based on detailed financial modelling with specific investment return targets.

10. Consumptions of Media

Depending on the technology applied for module cleaning, water may be needed for the cleaning process. However, dry cleaning technologies are available in the market, helping to reduce the consumption of additional media of the PV power plant to zero.

11. Efficiency

The efficiency of a PV plant can be determined by referring to different parameters:

- Performance Ratio - to assess the quality of the applied technology and design (PR depends on temperature but not on irradiation) [-];
- Capacity factor – utilization of available plant power – [-];
- Specific yield – Power output per installed DC power – [kWh/kWp]; and
- Space consumption - installed DC Power per hectar – [kWp/ha].

The results of the different parameters depend on various site and technology specific factors. Main site-specific factors are the geographical location and the meteorological parameters like irradiation and temperature. Technology specific factors are determined by component selection (fixed vs. tracking mounting system, efficiency of inverters, cable dimensioning) and plant design (row distance, module tilt, DC/AC ratio).

Capacity factor
PV capacity factors are determined primarily by the quality of the solar resource and whether single or two-axis tracking is used. Other less important factors are module technology and system design. Preliminary analysis suggests that the shift to higher irradiation locations and the effect of increased use of tracking seem to have outweighed other factors influencing the global weighted average capacity factor of new utility-scale solar PV, which is estimated to have risen by around one-fifth between 2010 and 2015 (see Figure 11-1).

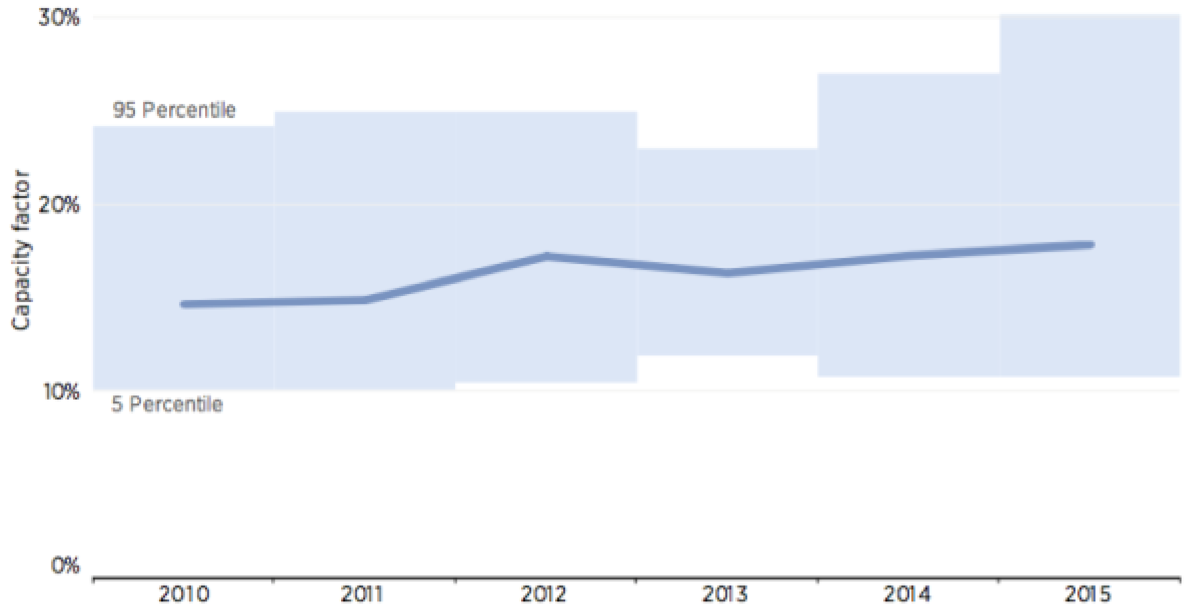


Figure 11-1: Global weighted average capacity factor for utility-scale systems, 2010-2015; source IRENA Renewable Cost Database

12. Applicability under Prevailing Climate Conditions

Temperature, irradiation, latitude, distance to the sea, air pollution and extreme weather events are the main parameters that have to be considered when selecting the components and determining the plant design.

Ambient temperature and altitude might have an important influence on the inverter and transformer performance, which is why an approval of the manufacturer for the site-specific conditions might be necessary. Corrosion is the main subject that has to be considered when a site is located close to the sea or near to agricultural or industrial used areas. It is advisable to conduct appropriate measurements and to ask for approval from the concerned manufacturers. Extreme weather conditions like for example sand storms might lead to an adjusted selection of components (e.g. IP code of inverters) or the adaption of O&M activities (soiling – module cleaning frequency).

13. Standalone Capabilities and Load Follow Capability

Power generation of PV plants directly depends on solar irradiation and therefor standalone applications are only feasible in combination with other technologies.

In recent years, hybrid solutions with diesel generators have reached commercial maturity without gaining big market share. This solution is mainly applied to reduce the operating costs of diesel generators that are used by industrial consumers in remote regions.

Apart from this application, 100% autonomy is only achievable with large battery systems and therefore only economically viable in remote regions, where a connection to the grid is very expensive.

PV systems, due to their flexible scalability, can be sized in such a way that they consider the consumption, but they have no load follow capability without adding an energy storage system.

Storage systems are currently still very capital intensive and the economic efficiency of a storage system to increase self-consumption (up to the achievement of complete autonomy) is to be examined in individual cases. For the next few years a significant reduction in the cost of storage systems is expected from technical development and mass production. First larger storage systems (e.g., Lithium-ion batteries, redox flow batteries) with storage capacities of over 1MWh have been built over the last years and a satisfactory market maturity is expected to be achieved over the next five to ten years.

14. PV Technology Alternatives for the Feasibility Study

Because of the good irradiation conditions, Libya offers an interesting framework to go for solar energy. The good scalability and the relatively simple nature of PV are important advantages of this technology. Referring to the applicability of the technology under the prevailing climate conditions it is important to mitigate functional risks especially regarding the inverter and mounting structure selection.

Fixed structures are the most reliable mounting option. As discussed within section 4 two-axis tracking systems have decisive disadvantages regarding reliability due to the number of moving parts. Their market share especially in utility-scale PV power plants is negligibly small. 1-axis tracking systems instead have reached a significant market share and meanwhile are widely deployed also in desert-like areas. Nevertheless, the newly developed systems still have to prove reliability for the lifetime of a PV power plant. The reduction in the LCoE makes the single-axis tracking system an interesting option and a further analysis is recommended if the additional risks are kept in mind.

A central inverter concept for PV power plants > 10 MW is recommendable. For smaller and/or more complicated sites string inverters are a good option.

Regarding the different module technologies, crystalline modules stand out concerning maturity, track record and market share. From the thin film PV modules, only First Solar as manufacturer of cadmium telluride (CdTe) modules has a significant market share. Thin Film modules are less affected by high temperatures.

The application of energy storage systems for PV installations is still very capital intensive and an implementation of large-scale storage systems as a back-up for PV power plant is still uncommon. An extensive use will only be economically viable in the future.

According to the technology alternatives so far selected and the resource available in potential areas the Consultant, for the effects of the feasibility study, has selected the following technology configurations for PV:

- Capacities 50 and 100 MW_{ac} in order to capture the effects of economies of scale while installing capacities large enough to support the current supply gap in Libya;
- Combination of fix mounted and 1-axis tracked will also capture the gains on electricity yield Vs. higher OPEX costs by tracking in one axis; and
- Central inverter concept as recommended for the proposed capacities.

Annex 5: PVSYST report on the simulation of selected site in Jadu

PVSYST V6.47		09/11/17	Page 1/5

Grid-Connected System: Simulation parameters

Project :	**Libya_FS_Jadu**			
Geographical Site	**Lyjad**		Country	**Libyan Arab Jamahiriya**
Situation	Latitude	32.1°N	Longitude	12.1°E
Time defined as	Legal Time	Time zone UT+2	Altitude	141 m
	Albedo	0.20		
Meteo data:	**Lyjad**	NREL NSRD : TMY3 - 2015		

Simulation variant :	**p-Si_100MWac_1.35_20171109**	
	Simulation date	09/11/17 15h15

Simulation parameters

Collector Plane Orientation	Tilt	17°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Imported
Horizon	Free Horizon			
Near Shadings	Linear shadings			

PV Array Characteristics

PV module Si-poly	Model	**TSM-320PD14**		
Original PVsyst database	Manufacturer	Trina Solar		
Number of PV modules	In series	20 modules	In parallel	21100 strings
Total number of PV modules	Nb. modules	422000	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**135040 kWp**	At operating cond.	121231 kWp (50°C)
Array operating characteristics (50°C)	U mpp	665 V	I mpp	182291 A
Total area	Module area	**818829 m²**	Cell area	739547 m²

Inverter	Model	**Sunny Central 1000CP XT**		
Original PVsyst database	Manufacturer	SMA		
Characteristics	Operating Voltage	596-850 V	Unit Nom. Power	1000 kWac
			Max. power (=>25°C)	1100 kWac
Inverter pack	Nb. of inverters	100 units	Total Power	100000 kWac

PV Array loss factors

Array Soiling Losses			Loss Fraction	2.0 %
Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	0.061 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	1.0 %
Module Quality Loss			Loss Fraction	0.0 %
Module Mismatch Losses			Loss Fraction	0.4 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

System loss factors

AC loss, transfo to injection	Grid Voltage	220 kV		
	Wires: 3x2500.0 mm²	9000 m	Loss Fraction	0.0 % at STC
External transformer	Iron loss (24H connexion)	132638 W	Loss Fraction	0.1 % at STC
	Resistive/Inductive losses	3649.0 mOhm	Loss Fraction	1.0 % at STC
Unavailability of the system	3.6 days, 3 periods		Time fraction	1.0 %

Grid-Connected System: Simulation parameters (continued)

User's needs :	Unlimited load (grid)			
Auxiliaries loss	Constant (fans)	190000 W	... from Power thresh.	77000.0 kW

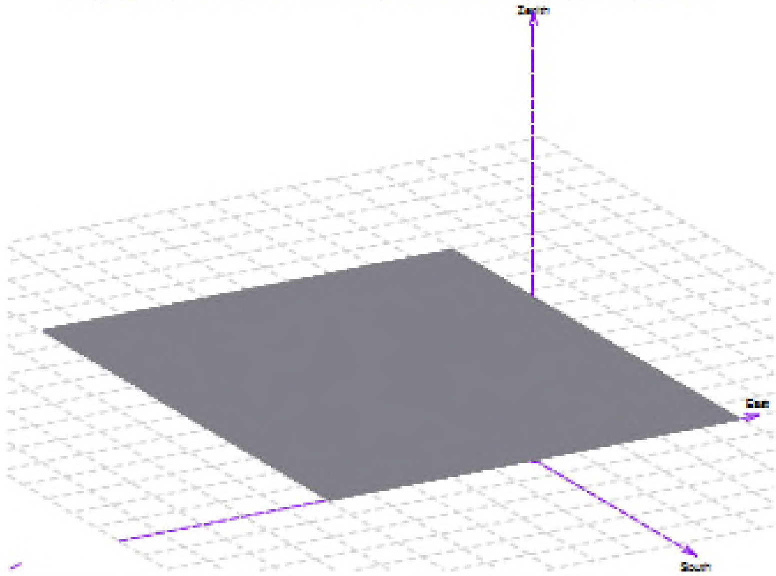
Grid-Connected System: Near shading definition

Project : **Libya_FS_Jadu**

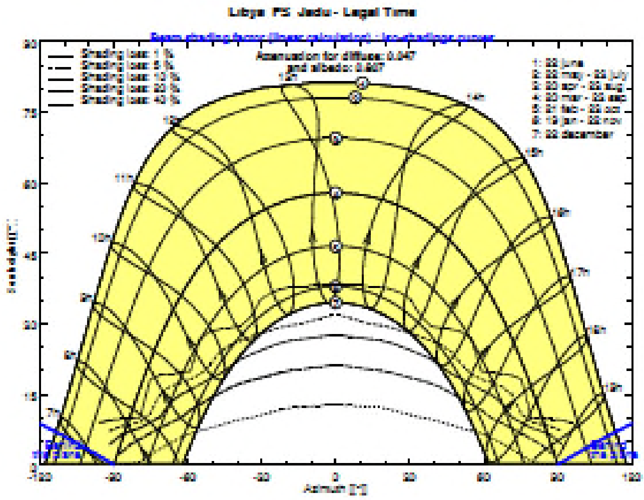
Simulation variant : **p-Si_100MWac_1.35_20171109**

Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	17°	azimuth	0°
PV modules	Model	TSM-320PD14	Pnom	320 Wp
PV Array	Nb. of modules	422000	Pnom total	**135040 kWp**
Inverter	Model	Sunny Central 1000CP XT	Pnom	1000 kW ac
Inverter pack	Nb. of units	100.0	Pnom total	**100000 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



PVsyst Licensed to Suntrace GmbH (Germany)

Grid-Connected System: Main results

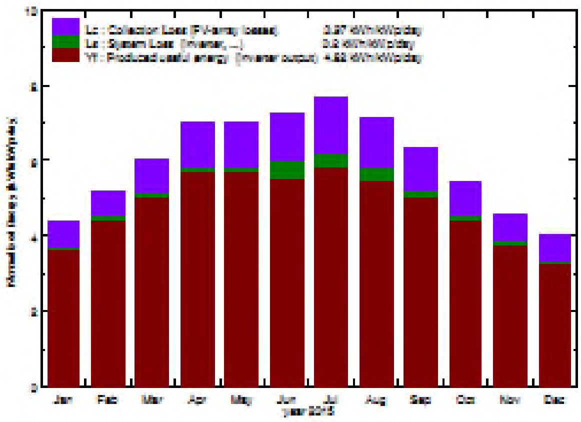
Project : **Libya_FS_Jadu**

Simulation variant : **p-Si_100MWac_1.35_20171109**

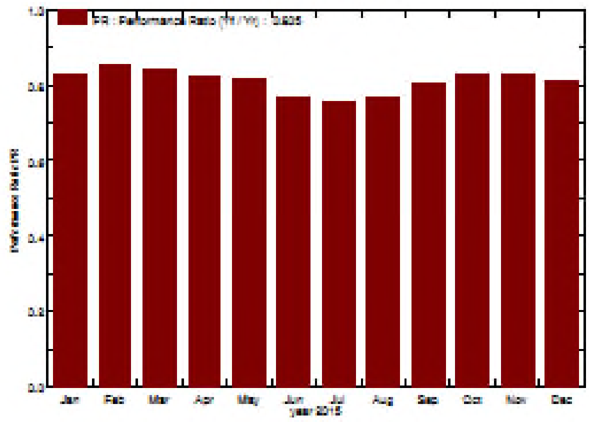
Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	17°	azimuth	0°
PV modules	Model	TSM-320PD14	Pnom	320 Wp
PV Array	Nb. of modules	422000	Pnom total	**135040 kWp**
Inverter	Model	Sunny Central 1000CP XT	Pnom	1000 kW ac
Inverter pack	Nb. of units	100.0	Pnom total	**100000 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**237718 MWh/year**	Specific prod.	1760 kWh/kWp/year
	Performance Ratio PR	80.48 %		

Normalized productions (per installed kWp): Nominal power 135040 kWp



Performance Ratio PR



p-Si 100MWac 1.35 20171109

Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	EffArrR %	EffSysR %
Jan. 15	103.1	12.91	135.3	121.7	15635	15179	14.11	13.70
Feb. 15	118.2	12.34	145.4	134.5	17222	16725	14.47	14.05
Mar. 15	164.5	15.29	186.0	173.5	21685	21054	14.23	13.82
Apr. 15	198.4	19.13	209.1	195.5	23799	23141	13.90	13.52
May 15	219.1	21.86	217.9	203.8	24589	23906	13.78	13.40
June 15	224.6	24.91	217.0	203.3	24283	22471	13.67	12.65
July 15	242.6	29.57	238.4	223.9	25912	24385	13.27	12.49
Aug. 15	214.5	28.49	221.1	207.9	24351	22877	13.45	12.64
Sep. 15	171.8	26.94	189.1	177.0	21062	20509	13.61	13.25
Oct. 15	140.4	21.47	167.0	155.1	19157	18618	14.01	13.62
Nov. 15	106.1	17.98	136.7	124.5	15660	15214	13.99	13.59
Dec. 15	92.6	14.97	124.4	110.2	14052	13639	13.80	13.39
Year	1995.0	20.54	2187.2	2031.0	247407	237718	13.81	13.27

Legends: GlobHor Horizontal global irradiation; T Amb Ambient Temperature; GlobInc Global incident in coll. plane; GlobEff Effective Global, corr. for IAM and shadings; EArray Effective energy at the output of the array; E_Grid Energy injected into grid; EffArrR Effic. Eout array / rough area; EffSysR Effic. Eout system / rough area

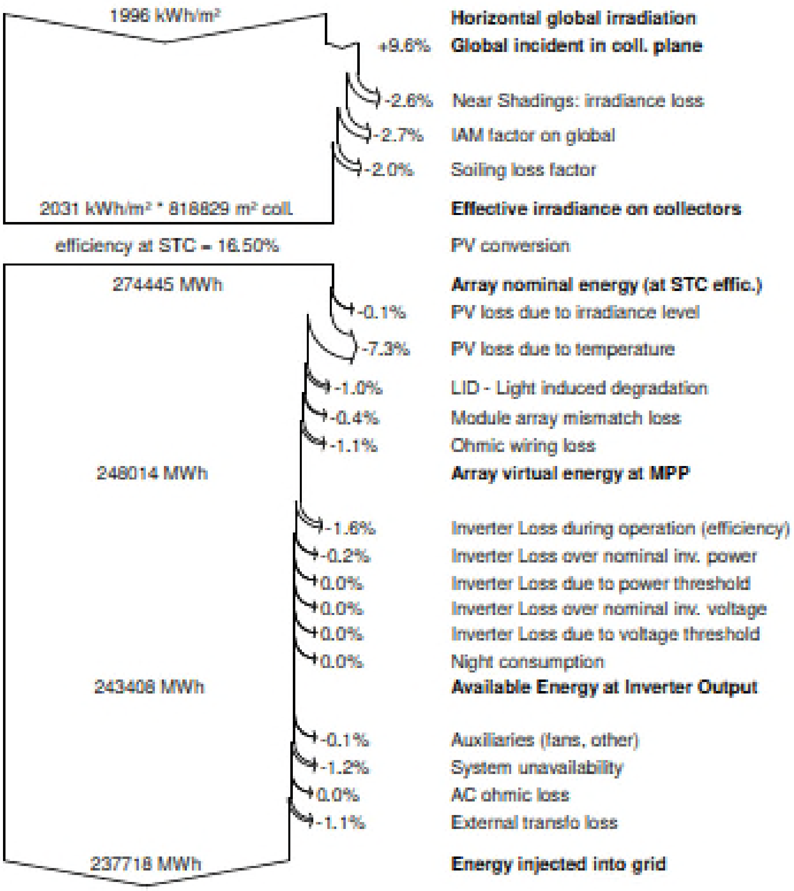
Grid-Connected System: Loss diagram

Project : **Libya_FS_Jadu**

Simulation variant : **p-Si_100MWac_1.35_20171109**

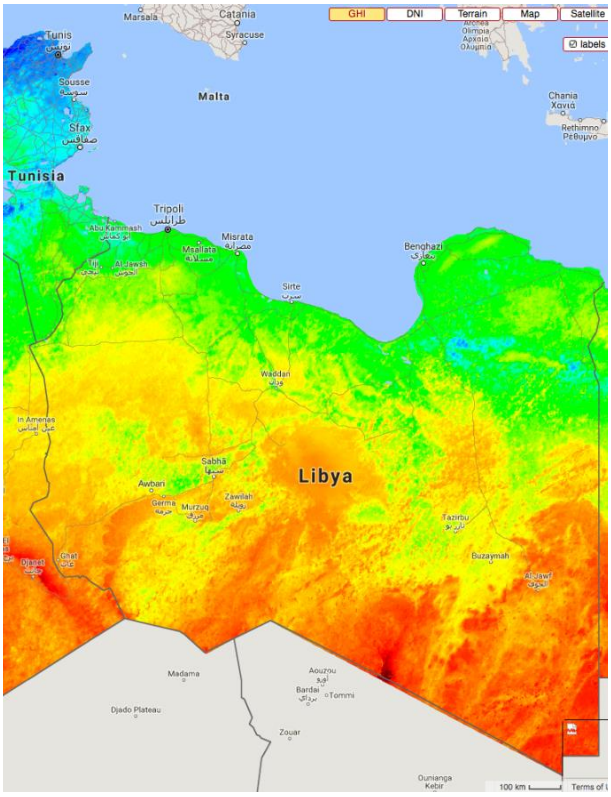
Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	17°	azimuth	0°
PV modules	Model	TSM-320PD14	Pnom	320 Wp
PV Array	Nb. of modules	422000	Pnom total	**135040 kWp**
Inverter	Model	Sunny Central 1000CP XT	Pnom	1000 kW ac
Inverter pack	Nb. of units	100.0	Pnom total	**100000 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Annex 6: Environmental Screening

Libya - Supporting Electricity Sector Reform (P154606)



Contract No. 7181909 - Task D:
Strategic Plan for Renewable Energy Development

Feasibility Study for a PV Plant at Jadu Site
Annex 6 - Environmental Screening
18th December 2017

Client:

THE WORLD BANK IBRD • IDA

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1. Environmental Screening

Libya is located in the North Africa region between longitude 9°-25° east and latitude 18°-33° 18 north. The Libyan territory spreads from the Mediterranean coast in the north to the Sahara with a total surface area of approximately 1.750 million km^2. Libya has borders on the east with Egypt, on the west with Tunisia and Algeria and on the south with Chad, Niger and Sudan[1].

Currently, about 65% of power generation in Libya is from natural gas, 12% without fuel (combined cycle), and the rest is from liquid fuels. On the other hand, Libya has a high potential of Renewable Energy which can be used to generate electricity from wind and solar (photovoltaic and CSP). The regulatory framework to promote private investments in the sector is not very attractive as so far there has been no significant private interest. Development barriers facing RE sector in Libya include economic, institutional, legal and regulatory, and financial obstacles. The legal and regulatory framework still lack essential legislations and regulations and other critical elements for the country to realize its ambitious goals and targets on renewables. Lack complete information, with respect to RE resource availability, energy use patterns also hinders greater private sector participation. Further, there remains an insufficient enabling environment to support the renewable energy market, mainly lack of awareness, low technical capacity, no standardized contracts and protocols, underdeveloped financing modalities, etc. that further constraining accelerated sustainable energy investments.

The main objectives of this initial environmental screening/scoping are:

- To support with environmental regulation aspects in technology assessment in the form a general description of Libyan environmental regulation and effects on solar and wind power technologies;
- To support on the desktop selection of potential areas according to environmental restrictions in the form of a general check of environmental aspects for solar and wind in potential areas selected; and,
- To assess environmental aspects for a pilot project in Libya.

2. Regulatory Framework Related to ESIA in Lybia

The following laws form the regulatory framework for environmental impacts assessment in Libya, with focus on renewable energy projects:

2.1 The Law No. 15 of 2003[2]

The Law No. 15 of 2003 on protection and improvement of the environment is the main EIA related legislative framework in Libya. The law has 12 chapters and 79 articles. The law stipulates responsibilities of the public authorities and the projects proponents towards preserving the environment in the following fields:

1. General Provision (Articles 1 – 9);

[1] https://sustainabledevelopment.un.org/content/documents/2136Country_intervention_on_drought_Libya.pdf
[2] Law 15 (1371) ; 2003 on protection and improvement of environment

2. Air Pollution (Articles 10 – 17);
3. Protection of Sea and Marine wealth (Articles 18 – 38);
4. Protection of Water Sources (Articles 39 – 47);
5. Protection of Foodstuffs (Articles 48 – 50);
6. Environmental Hygiene (Article 51);
7. Protection from Common Animal Diseases (Article 52);
8. Protection of Soil and Plants (Article 53 – 55);
9. Protection of Wildlife (Article 56 – 57);
10. Biological Safety (Article 58 – 63);
11. Penalties (Articles 64 – 76); and,
12. Final Provisions (Articles 77 – 79).

2.2 National Oil Corporation's Environmental Impact Assessment Guidelines

The National Oil Corporation's Environmental Protection Department's "Environmental Impact Assessment Guidelines for Seismic Operations" was published in 2006 and constitute the guidelines for conducting environmental impact assessments in Libya. The guide defines the following steps as being required:

1. Scoping: defining the geographical area to be surveyed, ecosystems, land-use and an indication of the area likely to be affected;
2. Assessment: identification of potential impacts, anticipation of their scale, duration and severity followed by recommendation of mitigation measures presented within an Environmental Management Plan;
3. Key stakeholders consultation: usually discussions with the NOC and department of antiquities; and,
4. Follow up: ensuring that mitigation measures are being implemented, usually through independent audits and monitoring.

On the other hand, The National Oil Corporation's has also set HSE guidelines. The National Oil Corporation acts as ministry, regulatory agency, and state-owned company[3].

2.3 Law No. 426 Establishing the Renewable Energy Authority of Libya[4]

The Libyan government created, the Renewable Energy Authority of Libya (REAOL) in 2007. The main goal of the REAOL is to implement proper policies so as to meet the governmental target of a 10% share of the total energy mix coming from renewable energy sources by 2020. The REAOL implements renewable energies projects, encourages and supports related industries, proposes supporting legislation and regulations and evaluates Libyan renewable energy potentials to identify priority areas. REAOL also has the mandate to assess in developing regulatory and industry infrastructure, and assess and conducting renewables resources mapping.

[3] http://www.resourcegovernance.org/our-work/country/libya
[4] http://www.iea.org/policiesandmeasures/pams/libya/name-24772-en.php

2.4 Other Relevant Laws:

The following laws are also relevant for EIA studies in Libya:

1. Law No (5) of 1969 on the organization and planning of towns and villages amended by law No. (3) of 2002;
2. Law No (38/39) of 1975, concerning municipalities organizing actions, defining in details concerned with environmental protection;
3. Law on the Protection of Agricultural Lands (No. 33 of 1970);
4. Law on Range and Forest Protection (No. 5 of 1982);
5. Decision no (81) for 1976: Model regulation to Regulate the Water and Drainage Utility at the Municipalities (28 April 1976);
6. Decision no (94) for 1976: Model Regulation Related to Public Cleanliness (16 May 1976);
7. Decision no (142) for 1976: Rules for Disposal of Waste Materials at the Municipalities (19 May 1976);
8. Law on Water Use (Law No. 3 of 1982);
9. Law on Protecting Animals and Trees (No. 15 of 1989);
10. Health Law No. 106 (1973) – Details aspects of environmental protection including water pollution and sampling;
11. Labour Law (No. 58 of 1970);
12. General Peoples Council Decision No. 8 of 1974 – Protection and Security of Employees;
13. Law on Industrial Security and Labour Safety (No. 93 of 1976); and,
14. Law No. (13) of 1984 on provisions relating to general hygiene

2.5 International Conventions Signed by Libya

Libya is a part of a number of international environmental protection initiatives and treaties. It is a signatory to the Barcelona Convention, which aims to protect the Mediterranean Sea against pollution[5]. The following conventions are ratified by Libya:

- Convention on Preservation of Fauna and Flora in their Natural State (London , 1933);
- African Convention on the Conservation of Nature and Natural Resources (Algeria , 1968);
- Convention on Wetlands (Ramsar , 1971);
- World Heritage Convention (Paris , 1972);
- Convention on International Trade in Endangered Species of Fauna and Flora (CITES Washington, 1973);
- Convention for the Protection of the Mediterranean Sea against Pollution (Barcelona, 1976);
- Convention on the Conservation of Migratory Species of Wild Animals (Bonn, 1979);
- United Nations Convention on the Law of the Sea (UNCLOS) (Montegoby, 1982);
- The Basel Convention on the Transboundary Movement of Hazardous Wastes and their Disposal (Basel, 1989);
- Bamako Convention on the Ban of the Import Into Africa and the Control of Transboundary Movement and Management of Hazardous Wastes Within Africa (Mali,1991);
- Convention on Biological Diversity (Rio, 1992);
- 16th November 1994. Libya has signed but not yet ratified the convention;
- Cartagena Protocol on Biosafety to the convention on biological diversity (Montreal , 2000);
- UN Framework Convention on Climate Change, Climate Change-Kyoto Protocol;

[5] http://ec.europa.eu/smart-regulation/evaluation/search/download.do;jsessionid=L1hvTTNJxCC6ZBh4ZLGYwJF2Gq16DJh0vKh0sQPT1HJ6QxvHcxhy!1601440011?documentId=3999

- UN Convention on Combating Desertification; and,
- Vienna Convention for the protection of the Ozone Layer.

2.6 The World Bank Environmental Safeguard Policies

The World Bank (WB) has ten (10) major social and environmental safeguards that are applicable in development projects. The WB considers these policies to be the cornerstones of its support to sustainable poverty reduction. The objective of these policies is to prevent and mitigate undue harm to people and their environment in the development process. These policies provide guidelines for bank and borrowers in the identification, preparation, and implementation of programs and projects. In essence, the safeguards ensure that environmental and social issues are evaluated in decision-making, help reduce and manage the risks associated with a project or program, and provide a mechanism for consultation and disclosure of information. The safeguards are listed in Table 2-1 below:

Table 2-1: Summary of the WB Environmental Safeguard Policies

Safeguard	**Policy Objectives**
Environmental Assessment*	Help ensure the environmental and social soundness and sustainability of investment projects. Support integration of environmental and social aspects of projects in the decision-making process
Natural Habitats*	Promote environmentally sustainable development by supporting the protection, conservation, maintenance, and rehabilitation of natural habitats and their functions
Pest Management	Minimize and manage the environmental and health risks associated with pesticide use and promote and support safe, effective, and environmentally sound pest management.
Physical Cultural Resources (PCR)*	Assist in preserving PCR and in avoiding their destruction or damage. PCR include resources of archaeological, paleontological, historical, architectural, and religious (including graveyards and burial sites), aesthetic, or other cultural significance.
Involuntary Resettlement*	Avoid or minimize involuntary resettlement and, where this is not feasible, assist displaced persons in improving or at least restoring their livelihoods and standards of living in real terms relative to pre-displacement levels or to levels prevailing prior to the beginning of project implementation, whichever is higher.
Indigenous Peoples*	Design and implement projects in a way that fosters full respect for indigenous peoples' dignity, human rights, and cultural uniqueness and so that they (1) receive culturally compatible social and economic benefits, and (2) do not suffer adverse effects during the development process.
Forests*	Realize the potential of forests to reduce poverty in a sustainable manner, integrate forests effectively into sustainable economic development, and protect the vital local and global environmental services and values of forests.
Safety of Dams	Ensure quality and safety in the design and construction of new dams and the rehabilitation of existing dams, and in carrying out activities that may be affected by an existing dam.
Projects on International Waterways	Ensure that the international aspects of a project on an international waterway are dealt with at the earliest possible opportunity and that riparians are notified of the proposed project and its details.
Projects in Disputed Areas	Ensure that other claimants to the disputed area have no objection to the project, or that the special circumstances of the case warrant the Bank's support of the

	project notwithstanding any objection or lack of approval by the other claimants.

* Safeguards most likely to apply in post-disaster situations

The following safeguards are of great importance: environmental assessment; natural habitats; physical cultural resources; and, involuntary resettlement.

2.7 IFC Guidelines

The International Finance Corporation (IFC) belongs to the WB Group and promotes sustainable development of the private sector in developing countries. Its mission also covers reducing poverty and improving living conditions. IFC expects project promoters to manage risks related to the social and environmental impacts. The IFC Environmental, Health and Safety (EHS) General Guidelines of April 2007 are technical reference documents with general and industry-specific examples of Good International Industry Practice (GIIP).

The EHS guidelines contain the performance levels and measures that are normally acceptable to IFC and that are generally considered achievable in new facilities at reasonable costs by existing technology.

For IFC-financed projects, application of the EHS Guidelines to existing facilities may involve the establishment of site-specific targets with an appropriate timetable for achieving them. The environmental assessment process may recommend alternative (higher or lower) levels or measures, which, if acceptable to IFC, become project or site-specific requirements.

When the host country regulations differ from the levels and measures presented in the EHS Guidelines, projects are required to achieve, whichever is more stringent.

The following performance criteria are important for the ESIA:

- assessment and environmental and social management plan;
- workforce and working conditions;
- prevention and reduction of pollution;
- health, security and community safety;
- land acquisition and forced displacement;
- biodiversity conservation and sustainable management of natural resources;
- indigenous peoples; and,
- Cultural heritage.

3. Institutional Framework

Major institutions engaged in environmental protection in Libya are:

3.1 Environment General Authority

The Environment General Authority (EGA) is the major environmental competent authority in Libya which was first established in 1982 as the Technical Centre for Environmental Protection and then upgraded to become the EGA. It was established under the General People's Committee for Health and Environment in 2000 in accordance with resolution No. 263 of the General People's Committee. The

Environment General Authority is an independent autonomous institution which exercises its duties in accordance with the Environmental law No. 15 of 2003 to protect and improve the environment. EGA is the advisory body concerned with environmental affairs with respect to the protection and conservation of natural resources, to prevent environmental degradation and to achieve safe treatment of contaminants and pollutants. It operates on three different levels: national, regional and local. At the national level, EGA is responsible for formulating an integrated and comprehensive national environmental policy for sustainable development and integrated planning. It also acts in formulating and developing specific strategies, standards and priorities for environmental protection and natural resource conservation. At the regional level, seven brunches were established in order to be responsible for the implementation of the national environmental policy.

EGA main duties can be listed as follows:

- Preparation of studies and research on the environment within Libya to protect and conserve its biological resources, in collaboration with research centers and other specialized national and international institutions;
- Awareness campaigns to advertise rules and guidelines to protect environment from pollution and its causes if any.
- Monitoring and recording of species imported to or exported from Libyan in implementation of the CITES Convention.
- Granting authorizations for activities which may have adverse effects on the environment including import or export of chemicals. The Authorization states the rules and conditions and requires the beneficiary to comply with the conditions contained therein.
- Recording of all types of chemicals that may result in contamination of the environment including pesticides used for the purposes of public health and agriculture.
- Expression of opinions on the environmental impact of projects of various kinds before their inception;
- Follow-up of conventions, treaties and international developments in the field of environment, and coordination with the national committees and the competent authorities to implement the relevant obligations to those conventions;
- Cooperation with international groups to remove the causes of pollution in coordination with the national authorities concerned.
- It is also responsible for state of environment (SoE) reporting and assessments. The SoE and EIA are both mandated by the Libyan national law. In addition to that it is responsible for both water and Air quality.

3.2 General Water Authority

General Water Authority (GWA) was established in 1972. The organization works under the Secretariat of Agriculture, Livestock and Fisheries and is the national body responsible for all water assessment, planning, and water resources management and monitoring. It provides advices to water users, formulates water legislation, designs water structures and supervises their construction, and monitors and implements water legislation. GWA is responsible for management of conventional water, both surface and groundwater, but not Great Man-Made River water desalination and wastewater.

3.3 National Centre of Statistics and Documentation

This Central Bureau of Statistics is the national body responsible for the collection, processing and publication of official statistics on the population and its activities in society and on the economy. It is affiliated to the Ministry of planning.

3.4 The Ministry of Local Government

This ministry is responsible for drinking water quality, water quality, the quality of wastewater treatment and reuse of the treated wastewater in agriculture in cooperation with the Ministry of agriculture. It is also responsible for solid waste collection through the national company for cleaning, safe management of toxic waste from hospitals and construction and operations of landfill. The ministry is involved in the protection of public health including measures to encourage waste recycling and development of green areas and the so called the cities green belt.

3.5 EGA and Municipalities

All local governments at the municipality level have their own environmental protection units separate from EGA. They appropriately deal with municipal priorities or water supply and quality, wastewater treatment and reuse, solid waste disposal, landfills operations, recycles of waste and other related issues.

3.6 Ministry of Electricity and Renewable Energies

Ministry of Electricity and Renewable Energy is responsible for integration of renewable energy and energy efficiency into the national development agenda via policies, programs, plans and strategies designs and implementation.

3.7 General Electricity Company of Libya

General Electricity Company of Libya (GECOL) is a state-owned company and solely responsible for power generation, transmission and distribution in the whole country. It is the electric utility of Libya.

3.8 The Renewable Energy Authority of Libya

Renewable Energy Authority of Libya (REAoL) is the agency mandated to promote and develop the use of renewable energies for electricity generation. REAoL was established by the Libyan Government in 2007, its main objective is applying appropriate policies to achieve the Government's goal of obtaining 10% of the energy demand from renewable energy sources by 2020. The specific objectives include: implementation of renewable energy projects and exploitation of renewable energy resources; mapping of renewable energy sources in Libya; performance of studies to determine the current and future market scenarios and trends; assessing renewable energy resources in all regions of Libya; promotion and support local renewable energy industries and assure dissemination of knowledge related to renewable energy; propose legislative and regulatory decision for supporting and facilitating the widespread of renewable energy technologies; and increase the contribution of renewable energy in the national energy mix.

4. Socio-Economic and Natural Environments of Lybia

Libya is the 3rd largest country in Africa with a surface area about 1.76 million km^2. The country has a population of 6,278438 million[6]. Presently the labor force comprises around 1.3 million people, of whom 31% work in industry, 27% in services, 24% in government and 18% in agriculture. Officially unemployment stands at 13%.

Approximately 85 % of the total population lives in the coastal area particularly in the major cities such as Zawia, Gherian, Tripoli, El-Khoms, Misrata, Sirte, Benghazi, El-Baida Derna and Tobruk.

4.1 Agriculture

Only 1% of Libya's land is considered arable due to poor water conditions[7], but the sector contributes to almost 12% of the national GDP and gives employment opportunities to 18% of the workforce.

4.2 Energy

Libya has the highest proven oil reserves in Africa at 41.5 billion barrels. Oil is sold on a term basis, the majority of which is exported to Europe. The oil industry itself is controlled by NOC, which in turn runs a number of subsidiary companies[8].

Proven natural gas reserves meanwhile are at 46.4 trillion cubic feet, ranking 14th in the world. The Western Libya Gas Project dominates gas production, and pumps gas from Libya's southern border to Sicily and mainland Italy. Natural gas is also used for power generation.

4.3 Commerce

The retail market in Libya is strongly dominated by local shops and an informal sector of souks. Some small supermarkets and shopping centers are developing in the country; however, most "modern" retailing is non-existent. Retailing is largely under state control via a number of subsidies from Libya's National Supply Company and policies to restrict foreign enterprising.[9] Wholesale and retail trade, and hotels and restaurants are an important source of employment in major urban areas, accounting for 5.6% of GDP in 2006.[10]

[6] http://www.doingbusiness.org/~/media/wbg/doingbusiness/documents/profiles/country/lby.pdf

[7] Doing Business in Libya , US Department of Commerce, 2008

[8] http://ec.europa.eu/smart-regulation/evaluation/search/download.do;jsessionid=L1hvTTNJxCC6ZBh4ZLGYwJF2Gq16DJh0vKh0sQPT1HJ6QxvHcxhy!1601440011?documentId=3999

[9] Libya Country Profile 2006, Egyptian Export Promotion Center, accessed February 2008

[10] Libya Country Report 2008, Oxford Business Group

4.4 Access to social services

Public health is strengthened by the high rate of sanitation of over 97% (2002). Only 72% of Libyans however enjoy access to safe water,[11] though 100% of the population enjoys access to electricity, compared to 87% in the region and 83% among similar income countries[12].

4.5 Education

Male literacy rates are traditionally higher than those of women, 92.4% compared to 72% (2003). This ratio is a positive change from the 1980's when male literacy rates were similar while the female rate was as low as 35%.[13] The cost of private and tertiary education has declined by 19.2%, increasing access to educational opportunities since 1999.[14] While all women over the age of 15 have lower literacy rates than men, in recent years women are more likely to continue their education to the tertiary level.[15]

4.6 Natural environment of Libya

4.6.1 Temperature[16]

Table 4-1 presents registered average annual, winter and summer temperature in different meteorological stations across Libyan territory. Maximum registered average temperature is 30.8 °C; and the lowest registered average temperature is 10.1 °C.

Table 4-1: Registered average temperature in different meteorological stations

Station	Annual [°C]	Winter (Dec.-Feb.)	Summer (Jun.-Aug.)
El-Kufra	23.3	14.2	30.8
Sebha	23.4	12.8	30.6
Jalo	22.4	14.1	29.8
Jaghboub	21.3	12.9	28.8
Ghadames	21.9	11.8	31.4
Agedabia	20.5	13.5	26.5
Sirt	20.5	13.4	25.5
Nalut	19.1	10.5	27.2
Benina	20.1	13.4	26.1
Misurata	20.4	14.1	26.2
Tripoli	25	14	26.4
Derna	20.0	14.8	25.1
Shahat	16.5	10.1	22.8

[11] Country Snapshots – Libya, Private Participation in Infrastructure Database, World Bank Group, July 2008
[12] http://ec.europa.eu/smart-regulation/evaluation/search/download.do;jsessionid=L1hvTTNJxCC6ZBh4ZLGYwJF2Gq16DJh0vKh0sQPT1HJ6QxvHcxhy!1601440011?documentId=3999
[13] Country Study: Libya, Library of Congress, Federal Research Division, April 2005
[14] The Socialist People's Libyan Arab Jamahiriya: Statistical Appendix, IMF, May 2007
[15] Libyan Arab Jamahiriya, The Human Development Index, United Nations Development Programme, accessed September 2008
[16] http://ubm.opus.hbz-nrw.de/volltexte/2005/794/pdf/diss.pdf

Zuara	19.8	13.3	25.8

4.6.2 Rainfall

Rainfall in Libya is characterized by its inconsistency as a result of the contrary effects of the Sahara from one side and the Mediterranean from the other. Intensive thunderstorms of short duration are fairly common. About 96% of Libyan surface receives annual precipitation of less than 100 mm. The heaviest rainfall occurs in the northeastern region (Jabal al Akhdar) from 300 to 600 mm and in the northwestern region (Jabal Nafūsah and Jifārah plain) from 250 to 370 mm.

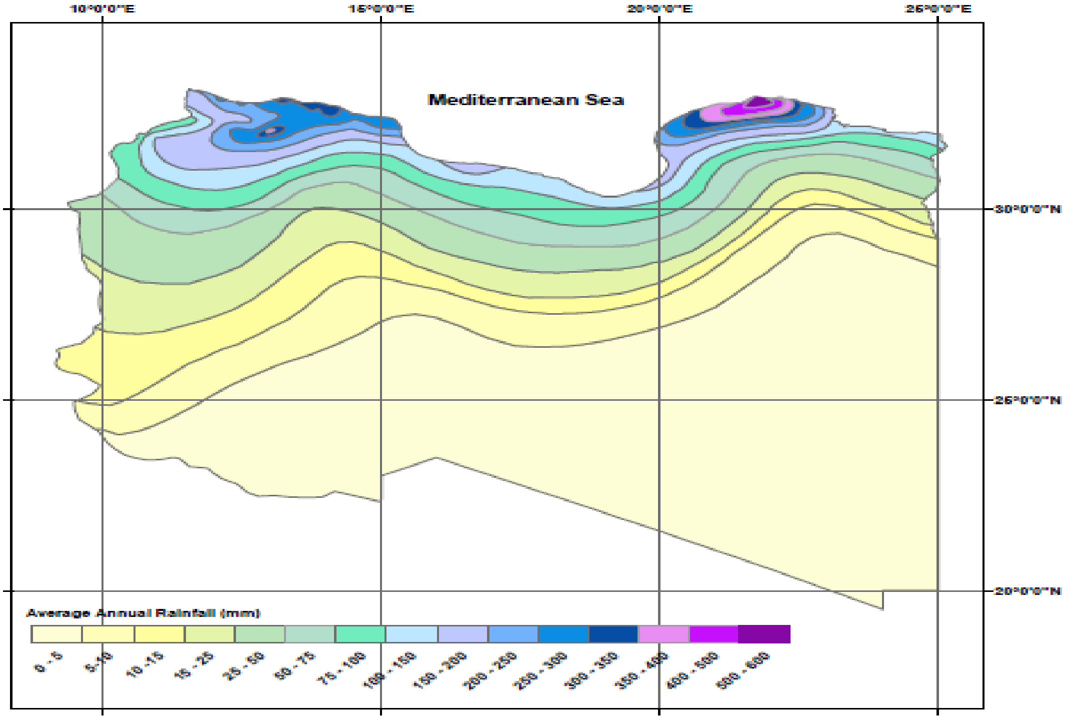

Figure 4-1: Average annual rainfall 1956 - 2000

4.6.3 Water Resources

The surface water resources are very limited and contribute only by a small amount (less than 5%) to the total water consumption. 18 dams[17] have been already built on the main wadis to control periodic floods, divert the retained water to irrigation projects and recharge the local groundwater aquifers. The total storage capacity of these dams is about 389 Mm^3 with an average annual volume of water retained behind these dams of about 61 Mm^3.

Groundwater forms the only available source of potable, industrial and irrigation water supply covering more than 80% of the total water demand in the country. The groundwater occurs within 6 main groundwater basins. These basins are consisting of several groundwater aquifers which vary in their depth, thickness, geologic age, and hydraulic and hydro-chemistry properties[18].

[17] https://sustainabledevelopment.un.org/content/documents/2136Country_intervention_on_drought_Libya.pdf
[18] https://sustainabledevelopment.un.org/content/documents/2136Country_intervention_on_drought_Libya.pdf

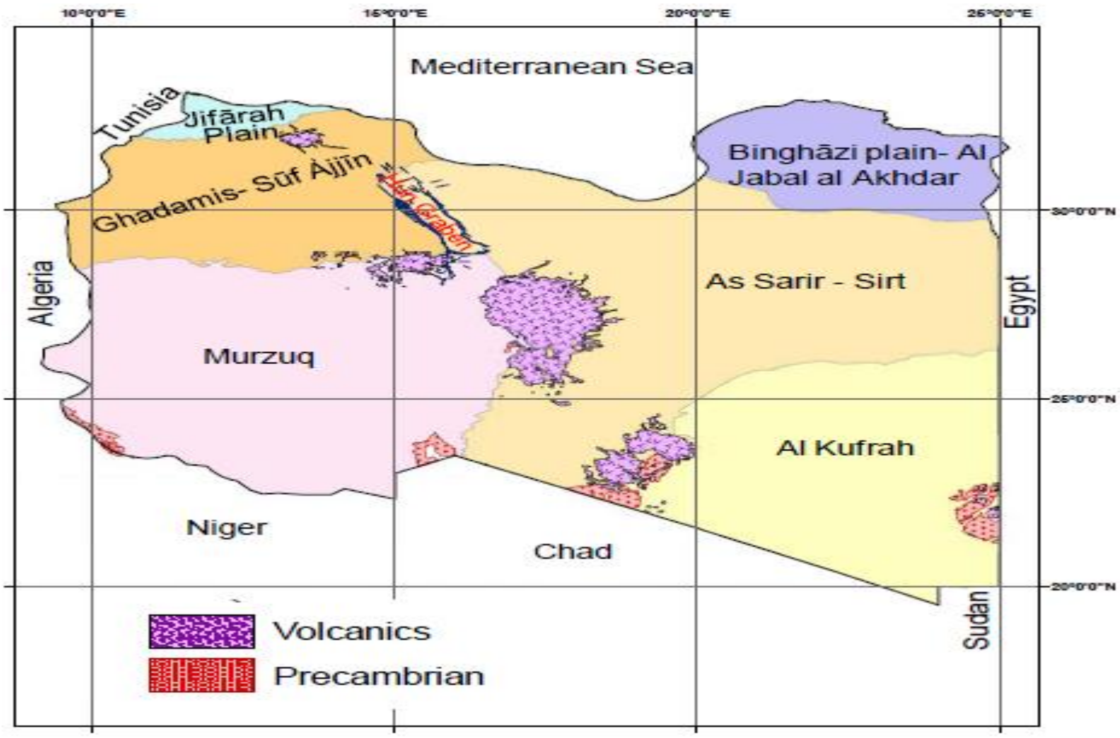

Figure 4-2: Groundwater basin in Libya

4.6.4 Biodiversity

Biodiversity in Libya consists of a recorded presence of 1570 plant species and 4590 animal species. The diversity of vegetation in Libya varies according to the quality of ecosystems, and the fertile coastal strip represents only a fraction of the population. Four different ecosystems can be distinguished[19]:

- Coastal Ecosystem;
- Semi-health ecosystem;
- Mountain ecosystem; and,
- Environmental Health System

There is a fairly low level of endemism in Libya, because only about 75 taxons (4%) are endemic. The areas of Jabal Al Akhdar, the Coastal Strip, the central part of the Sahara and the south of Libya including Jabal Al Awaynat, Tibesti and the Ghat Plateau (Qaisar and El Gadi), are home to 50% of the country's endemic species.

Forests are to be found in the area of Jabal Al Akhdar in the north-east*;* forests in semi-arid regions*;* and forests to the south of Jabal Al Akhdar[20]. The following table lists protected areas in Libya with their size and location.

[19] http://medomed.org/2010/libya-biodiversity-conservation-data/
[20] http://medomed.org/2010/libya-biodiversity-conservation-data/

Table 4-2: Protected areas in Libya[21]

Parks and Reserves	Surface area (ha)	Location
Bir Ayad Reserve	12,000	150 km south-west of Trípoli
Hiesha Jadida Reserve	100,000	300 km east of Trípoli
Abu Ghilan Park	4,500	60 km south of Trípoli
Surman Park	1,450	51 km west of Trípoli
Gharabouli Park	8,500	60 km east of Trípoli
Wadi El- Kouf Park	8,000	1.200 km east of Trípoli
Total	134,450 ha	

5. Project Technology: PV Technology

PV technology has reached several year ago a mature status, passed grid parity in almost all countries and became one of the highly competitive technologies for power generation. Prices of main components have dropped dramatically during the last years. The global PV industry has already passed a strong learning curve with plenty of innovations and efficiency increase.

The main component in solar PV power plants is the PV module. A module consists of several cells that have the capacity to convert the solar radiation into electrical energy. The most dominant cell technologies are made of crystalline silicon and thin films. Each module, independent of the technology, has to be certified with clearly defined and guaranteed performances over a period of 5-20 years. PV modules are mounted on fixed structures or on tracking systems that follow the sun. The tracking systems require a higher investment and result in increased O&M cost, but they offer an energy yield gain of up to 35%.

Energy produced from PV technology cannot be stored at economic price levels today because batteries are too expensive, thus the produced energy has to be fed into the grid at the time of generation.

Another key component in a solar PV power plant is the inverter that changes the electric current from DC to AC. Large-scale power plants can utilize both small and large inverters. The largest inverters have power outputs of more than a megawatt and they often represent the cheapest solution. However, the large-scale inverters are also very heavy; their implementation, therefore, relies on special equipment for heavy transportation and lifting. In addition, any maintenance on these inverters has to be performed by people certified by the supplier. On the other hand, by using smaller inverters of approximately 20-60 kW each (string inverter concept) would reduce the risk of long downtime during malfunctions. Downtime of one single inverter would only affect a small part of the plant; in addition, the inverter can be exchanged by a trained electrician.

5.1 Project Activities

The main project activities that are needed to implement a solar project could be divided in:

[21] Khatabi, K. 1993. The National Report about Biodiversity in Libya. Presented at the Conference on Biodiversity in North Africa Countries. Tunis.

5.1.1 Design and Mobilization Phase

Once all permits and development processes are completed, the project implementation starts. The following key activities form the essential milestones of the mobilization and design phase:

- Preparation of a temporary campsite;
- Establishing fences around the project site;
- Transportation of materials, equipment and machinery to project site;
- Storing materials;
- Mobilization and hiring workers and employees;
- Preparation of site construction materials; and,
- Setting security and safety rules, procedures and deploying staff.

5.1.2 Construction Phase

Generally, a solar PV project construction phase consists of the following key activities:

- Construction of an adequate access infrastructures to the site;
- Site clearance, including earth movements, clearing works, excavations and stockpiling of excavated materials;
- Transportation of construction materials from extraction areas, commerce and storage areas to the project site;
- Transportation of equipment, machineries and workforce to the project site;
- Civil work;
- Mechanical and electrical work;
- Installing the mounting structures;
- Mounting solar panels, collectors, etc.;
- Installing pipes, cables, modules, etc.;
- Erection and installation of inverters, transformers, power plants central units, etc.; and,
- Connecting the solar power plants to the power transmission / evacuation lines.

5.2 Operation Phase

Generally, the operation phase consists of the following:

- Operating, cleaning and maintaining the solar panels;
- Operating the automated machines in the power plant;
- Periodic examination and maintenances of the solar panels and related equipment in the power plant; and,
- Monitoring and repairing the transmission/distribution lines.

To build the project, there would be need for construction materials, construction water and for drinking water and sanitary water. This process should respect environment. The selection of the site from where to source construction materials such as stones, gravels, etc. should respect environmental conditions and Libyan regulations as well as international best practices.

The construction and operation phases will need qualified and unqualified workforce. Operation phase will create fewer, but skillful, jobs compared to construction. This labor shall be sourced locally in order to generate positive impacts on local employment, however, realistic and tangible measures should be created in order to train on jobs and hire locally.

Waste generation is expected during construction phase and will consist of construction wastes and domestic wastes. At the same time, solid wastes will be generated by workers in forms of food packaging, cans, bottles, etc. Waste management should be handled carefully as the local ecosystems are so fragile and would be very sensitive receptors.

Liquid wastes will be also generated by workers. Septic tanks should be installed on sites to collect this waste and they should be emptied in regular basis and transferred to an authorized liquid waste treatment station.

6. Anticipation of Impacts

The initial environmental screening has identified the following environmental impacts at Jadu site.

Table 6-1: Identification of possible impacts at Jadu site

Impacts	
Land use	Although the land is not arable and there is almost no vegetal cover, the installation of a PV power plant in this site might affect flora mostly inhabited by small reptiles, insects, etc. However, the effect of this impact will be limited. On the other hand, it is recommended that the detailed ESIA considers assessing the use of this site for pastoralism.
Landscape and visual impacts	The nearest town is 11 km from this site and it is anticipated that the project will have very limited visual impact during construction and operation. Meanwhile, only during construction the presence of construction machineries and quite large number of vehicles might give negative visual impacts.
Hydrology	For this initial screening, the site is considered to have ground water at a depth of 100 m; therefore, it is recommended to check in details the use of ground water by the adjacent communities during ESIA, and that during construction and operation, proper measures are adopted in order to avoid any contamination.
Biodiversity	There are no protected areas adjacent to the site. Furthermore, the site soil is sporadically covered by vegetation. It is anticipated that most sensitive receptors would be small reptiles. Project construction activities could destroy habitats and their flora and fauna. However, the ESIA shall consider assessing the use of site by birds or existence of any endemic Saharan vegetal species.
Archeology	The initial screening demonstrated that there is no evidence on the existence of an archeology site, which might be impacted by the construction of the solar project.

Air quality	The nearest town is 11 Km from this site and it is anticipated that the project will have very limited impacts on the adjacent communities with regards to air quality; however, workers shall wear the adequate personnel protective equipment during construction. It is anticipated that during construction activities, particles will be emitted as consequence of combustion exhaust gases from generators, machineries and vehicles; dust from soil during land clearance and movement of vehicles and machineries.
Noise	The nearest town is 11 Km from this site and it is anticipated that the project will have very limited impacts on the adjacent communities with regards to noise; however, workers who will operate machineries generating noises, shall wear the adequate personnel protective equipment during construction such as ear muffins. In case, materials transportations to the site will pass closed to villages, machineries and vehicles shall observe safety measures and limited speed in order to avoid any potential damage on residents.
Traffic and Transportation of materials	In case, materials transportations to the site will pass closed to villages, machineries and vehicles shall observe safety measures and limited speed in order to avoid any potential damage. From this initial screening, it could be stated that there is already a paved road that could be used for accessing the site; so, there would be no need to build an access road and assess potential impacts.
Soil and Land degradation	The construction of a solar project will need the clearance of soil vegetation; however, given that the vegetal cover is very limited; Land degradation will be very limited. On the other hand, specific measures shall be taken in order to maintain soil. It is also anticipated potential soil contamination from accidental spillage.
Wastes	During construction and operation, solid and liquid wastes will be generated by workers engaged. Liquid waste will be in form of grey and black water. Solid wastes will be in form of canes, cartons, food packages, etc. During construction, construction wastes such as rocks, stones and other materials will be generated in addition to woods, pellets and cartons from components packaging.
Community safety, security and health	The nearest town is 11 Km from this site and it is anticipated that the project will have very limited impacts on community safety, security and health.
Occupational health, security and safety	Workers will need to observe safety and security measures, and wear the proper personnel protective equipment.
Water	For this initial screening, the site is considered to have ground water; therefore, it is

	recommended to check in details the use of ground water by the adjacent communities during ESIA, and that during construction and operation, proper measures are adopted in order to avoid any contaminations through accidental spillages. During construction, there will be need for construction water, sanitary water and drinking water.
Vibration	During construction, workers will have to observe the safety and security measures and wear the proper personnel protective equipment in order to avoid any incidents. Meanwhile, the use of machineries, which generate vibration, shall follow the guidelines and norms to avoid any incident.
Jobs and business opportunities for local population and firms	The construction, operation and maintenance of solar project will create job and business opportunities for local people. However, there would be need to assess local skills offer and projects needs and work in cooperation with local authorities and population representatives to avoid any unrealistic expectation with regards to project positive impacts on local population.

7. Recommendations

Based on this initial screening, it is concluded that the Jadu site is adequate for solar PV installations. However, it is recommended to conduct an ESIA for the site. The ESIA shall mainly respond to the national requirements, the World Bank Environmental Safeguard Policies, IFC Environmental, Health and Safety (EHS) General Guidelines, as well as other international best practices such as Equatorial Principles.

The ESIA shall establish baseline environmental and social information at a level of detail necessary to conduct the analysis and assessment of potential impacts, and anticipate an assessment of solar module glint on the basis of technical design that would be initially set.

In the ESIA, a special focus shall be given to waste disposal and waste management, which shall comply with local standards. Developer(s) shall present a waste management plan, where hazardous and toxic wastes such as paints, adhesives and resins or lubricants shall be managed and disposed in full respect of the local regulations.

Developer shall also set an EHS where general frame of guidelines for health and safety standards for solar projects, as well as for the associated infrastructure and activities outside the site. ESH shall cover safety rules on site and during transportation to the site, emergency plans, access to site, setting HSE management program; provision of sanitary services and welfare amenities on site; identify critical health and safety relevant activities; access only to qualified personnel undertaking activities relevant to their duties and provision of suitable personal protection equipment.

ESIA shall propose mitigation measures for impacts that are considered significant. Furthermore, ESIA shall develop a comprehensive Environmental and Social Management Plan, which will describe and prioritize the actions needed to implement mitigation measures, corrective actions and monitoring measures necessary to manage the identified impacts. ESIA shall also include environmental monitoring plan with allocation of duties and timeframes in order to implement the mitigation measures. Environmental and monitoring plan will also include reporting requirements and schedules for periodic reports on the implementation of the environmental and social management plan.

It is strongly advised that the developer(s) consider(s) and implement(s) an adequate stakeholder's engagement. The stakeholders' engagement shall include: a comprehensive description of the project, its components, its potential impacts and the standards that govern its development and implementation; engagement planning activities to be carried out. These activities will define the objectives, the modes of engagement of the stakeholders in the activities, the appropriate methods of communication (adapted to the cultural characteristics and the corresponding language(s) and in prior consultation with the participants), the support to be used, timing and engagement activities of stakeholders.

Stakeholder consultation to support the ESIA process specifically aims to achieve the following objectives:

- To provide information about the project and its potential impacts to those interested in or affected by the project, and gather their views in this regard;
- To provide opportunities to stakeholders to discuss their expectations and concerns;
- To manage expectations and concerns regarding the project;
- To discuss significance of anticipated environmental and social impacts;
- To discuss the process of developing appropriate mitigation measures;
- To build a continuous communication with stakeholders;
- To adequately integrated the views and concerns of stakeholders with regard to the proposed project;
- To discuss the environmental and social management plan.

Annex 7: Checklist for environmental screening at Jadu site

Possible Environmental/ Social Impacts	Baseline Environment	Comments
✓ Consistency with land use	Current land use within 5 km radius: ☐ Residential (Please specify if it is Urban / Rural areas) ☐ Commercial ☐ Public / Institutional ☐ Industrial ☐ Agricultural ✓ Protected Areas / Natural Parks ☐ Others, please specify ___________________	Mostly pastoral
☐ Potential disturbance to wildlife due to vegetation clearing	Existing vegetation in the area: ☐ Forest ☐ Others, specify ____________________	There is no existing vegetation in the area
✓ Topography	Slope: ✓ flat (0-3%) ☐ gently sloping (3-18%) ☐ steep (>18%)	
✓ Soil	Soil type in the area: ☐ sandy ✓ clay ☐ sandy-loam ☐ Others, specify ____________	
☐ Visual / Landscape	Presence of visually significant landforms/landscape/structures? ☐ Yes ☐ No Description: Almost flat	
✓ Water	Distance to nearest/receiving water body: ☐ 0 to less than 1 km ☐ 1 to 3 km ✓ More than 3 km If nearest/receiving water body is fresh water, specify classification: If nearest/receiving water body is coastal or marine water, specify classification: Current Water Use:	It is fresh water but not suitable for human drinking. At the site, the depth of water is not so high within about 100 meter depth. From the

Possible Environmental/ Social Impacts	Baseline Environment	Comments
	☐ Fishery ☐ Tourist Zone / Park ☐ Recreational ☐ Residential ☐ Industrial ✓ Agricultural Distance of project area to the nearest well used: ☐ 0 to less than 1 km ✓ 1 to 3 km ☐ More than 3 km Use of the nearest well: ☐ Drinking/Domestic ☐ Industrial ✓ Agricultural	feasibility point of view it is better to drill the well for using water at the site.
✓ Water use	Size of population using receiving surface water: ☐ ≤ 500 persons ✓ >500 and ≤ 5,000 persons ☐ >5,000 persons Available/nearest water source. ✓ Well ☐ Water district ☐ Surface water ☐ Others, specify	
☐ Risk of flooding	Is the project site located in an area with potential of flooding ☐ Yes ✓ No Description: The land is far away from any valley	
☐ Air quality degradation	Distance to nearest community: ☐ 0 to less than 1 km ☐ 1 to 3 km ✓ More than 3 km	

Possible Environmental/ Social Impacts	Baseline Environment	Comments
☐ Noise	Distance to nearest community: ☐ 0 to less than 1 km ☐ 1 to 3 km ✓ More than 3 km	
☐ Glare effect	Distance to nearest community: ☐ 0 to less than 1 km ☐ 1 to 3 km ✓ More than 3 km	
✓ Traffic and transportation, Increase in traffic volume and worsening of traffic flow	✓ Existence and states of roads and physical infrastructures: There is a main road not so far from the site which reach to Tripoli ✓ State of traffic flow : There is high traffic flow	
☐ Displacement of residents in the project site and within its vicinity	Size of population of project wide area: ✓ ≤ 500 persons ☐ >500 and ≤ 5,000 persons ☐ >5,000 persons	
☐ Displacement of Indigenous People	Size of population of project wide area: ✓ ≤ 500 persons ☐ >500 and ≤ 5,000 persons ☐ >5,000 persons	
✓ Enhanced employment and/or livelihood opportunities	Size of population of project wide area: ☐ ≤ 500 persons ✓ >500 and ≤ 5,000 persons ☐ >5,000 persons	
☐ Reduced employment and/or livelihood opportunities	Size of population of project wide area: ✓ ≤ 500 persons ☐ >500 and ≤ 5,000 persons ☐ >5,000 persons	
✓ Disruption/Competition in delivery of public services	Size of population of project wide area: ☐ ≤ 500 persons ✓ >500 and ≤ 5,000 persons ☐ >5,000 persons	
✓ Enhanced delivery of public services	Size of population of project wide area: ☐ ≤ 500 persons ✓ >500 and ≤ 5,000 persons ☐ >5,000 persons	

Possible Environmental/ Social Impacts	Baseline Environment	Comments
✓ Increase of population due to immigration	Size of population of project wide area: ☐ ≤ 500 persons ☐ >500 and ≤ 5,000 persons ✓ >5,000 persons	
☐ Impacts on community health and safety	Project wide area is: ☐ Urban ✓ Rural Available services within/near Project wide area: ☐ Schools (e.g. elementary, high school, college) ☐ Health facilities (e.g., clinics, hospitals, etc.) ☐ Security and order (e.g., police outpost, brgy. Tanod, etc.) ✓ Recreation and sports facilities ☐ Others, specify	
☐ Power transmission lines	Availability of land for the construction of power transmission lines: ✓ YES ☐ NO	The power transmission lines already exist