First Libyan International Conference on Engineering Sciences & Applications (FLICESA_LA)
13 – 15 March 2023, Tripoli – Libya

A Comprehensive Study About Evaluating And Comparing Two Solar (PV And CSP) At The Al-Kufrah Desert Region

Basher A. Matari
Sustainble and Renewable Energy, Faculty of Engineering OMU University
Al-Kufrah, Libya
basher.buamtary@gmail.com

Tarek Hamad
Sustainble and Renewable Energy, Faculty of Engineering OMU University
El-Beida, Libya
tarek.hamad@omu.edu.ly

Assia Hansas
Electrical, Faculty of Engineering, OMU University
El-Beida, Libya
assia.hanzaz@omu.edu.ly

***Abstract*—This paper gives an in depth concept of computing and utilizing two main solar power technologies Photovoltaic(PV) and Concentrated solar power (CSP). there is no doubt that solar power will play a major role in the near future in the energy sector specially in Libya, since solar energy is considered to be abundant but yet poorly harnessed, every study point contributes of making solar energy a reliable and feasible option to be considered, especially hot arid desert regions. Therefore, the idea of simulating the leading solar technologies (PV and CSP) was proposed, the Al-Kufrah region was considered due to the high solar hours per year. The system advisor model (SAM) is used to predict the performances of the proposed plants, and the comparison was both from the design and the simulation results, with respecting the validation of the software from previous papers to insure acquiring reliable results all leading to the question, which technology has a better future in the Libyan energy sector.**

Keywords— Solar Power; CSP; PV; SAM; Simulation; Al-Kufrah; Single power tower.

I. INTRODUCTION

Global energy consumption has been increasing since the Industrial Revolution and is expected to increase for the coming decades. In order to meet the environmental challenge in the 21st Century, certainly, renewable energy must play an important role. Solar energy is one of the most promising renewable energy sources. Libya located in North Africa between 26 latitudes north and 17 longitudes east, extends over 1,759,540 km^2 [1]. It is bordered by the Mediterranean Sea to the north, Egypt to the east, Sudan to the southeast, Chad and Niger to the south, and Algeria and Tunisia to the west. Both the Mediterranean Sea and the desert affect Libya's weather. In the winter, the weather is cold, with some rain on the coast. The Sahara is very dry and hot in the summer and cold and dry in the winter [1]. More than 80% of the land is unused. This land might not be used for either agriculture or any other foreseeable purpose than solar energy collection [1]. For the last two decades, Libya had depended on fossil fuels, petroleum, and natural gas for its income, energy, industrialization, and development. Although some efforts have been made to diversify the sources of income, to a large extent, fossil fuels have continued to play a major role in the country's economy. Unfortunately, the fossil fuels available in this area are becoming depleted as shown in Fig. 1.

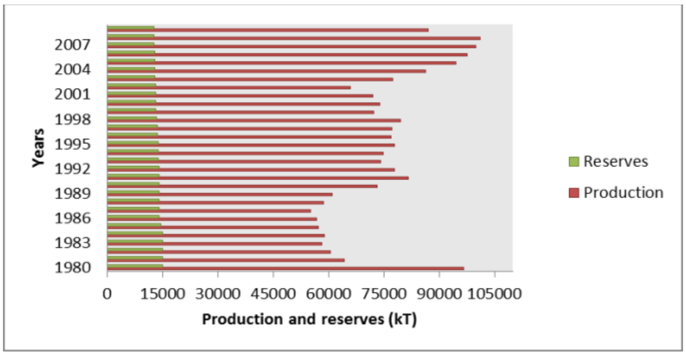


Fig. 1. Fossil Fuel reserves and production of Libya vs. time [1,2]

So new sources of energy need to be utilized to cover the ever growing need of the Libyan economy.

II. SITE ASSESSMENT

Solar energy stands out as the most promising. Libya experiences, on 3400 h of sunshine per year; it maintains an average insulation of approximately 2200kWh/m2 annually as shown in Fig. 2. [2].

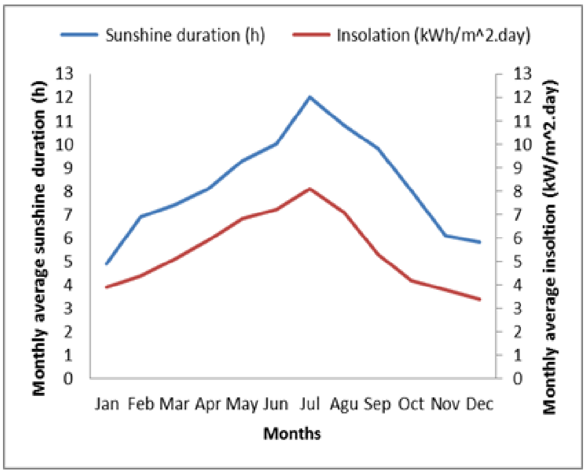


Fig. 2. Sunshine duration and insolation for Libya [2]

Global horizontal irradiation in Libya is shown in Fig. 3.

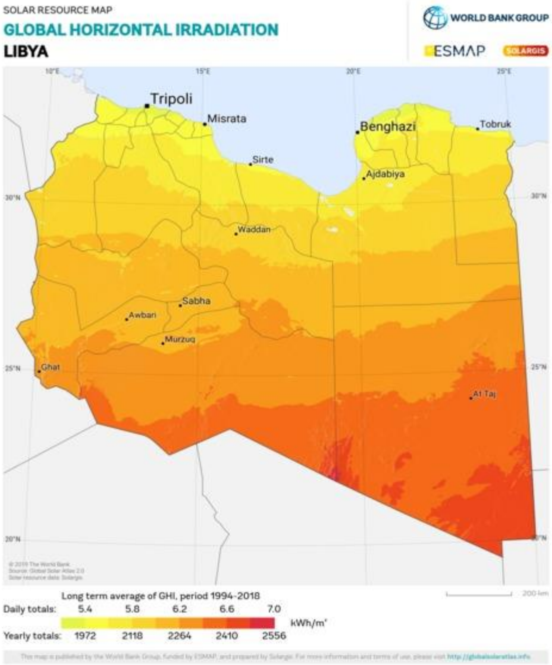


Fig. 3. Global horizontal irradiation in Libya [9]

and The well-known hot Sahara Desert comprises more than 80% of the country's area. A study conducted by the German Aerospace center, reveals that every 1 km2 of this region is exposed to solar radiation per year, equivalent to 1.5 million barrels of crude oil plant [4]. Direct normal irradiation is shown in Fig. 4. [9].

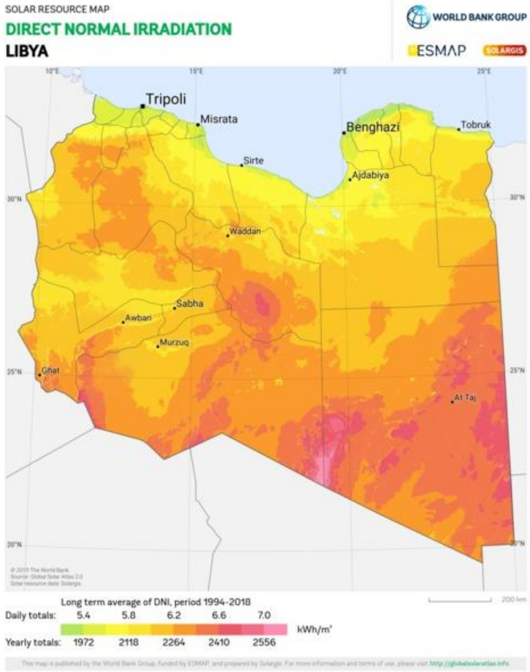


Fig. 4. Direct normal irradiation (DNI) [9]

In Fig 5 the photovoltaic potential is shown

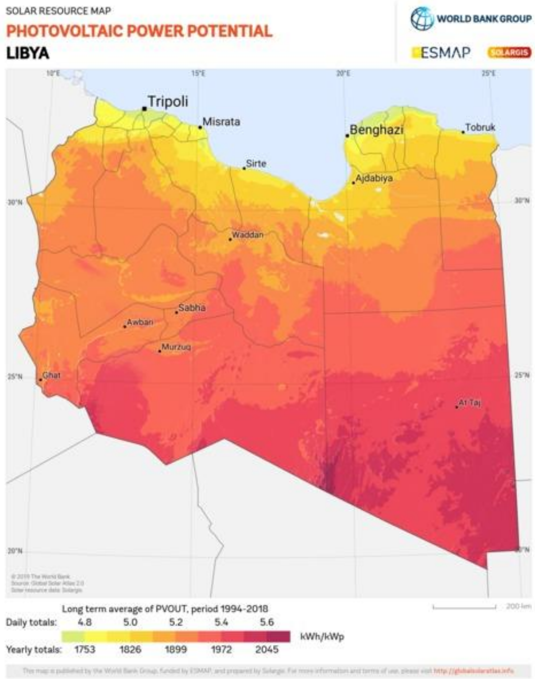


Fig. 5. Photovoltaic power potential [9]

As shown in the figures such an unexploited large land is a good candidate for large-scale solar systems plants. Thus, the Al-Kufrah region was considered due to the high solar hours per day for hosting such large projects. The region is located south-east of the country Latitude/Longitude (22.7, 23.6). The performance of solar technologies is dependent on the meteorological conditions at the specific location of the plant.

III. Methodology, Validation and the Solar Technologies

A. Work Flow Chart Processes

the Work flow is shown in Fig. 6.

Fig. 6. Work flow

B. Weather data

The breakdown of the weather data and configuration have been made with utility software, since the Libyan Region of Al-Kufrah has very little weather data hourly through the year some weather assumptions have been taken and are linked to the weather sources presented by NREAL [9].

The site and weather data is presented by System Advisor Model(SAM) software[9]. The potential of the solar power is presented through the months as shown in Fig. 7.

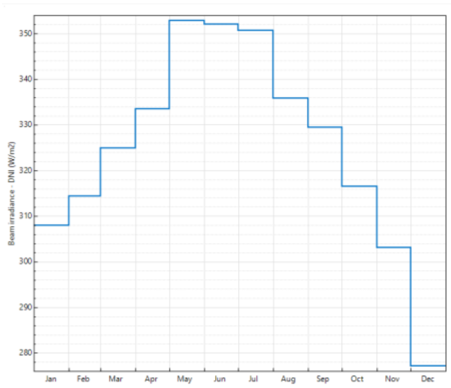
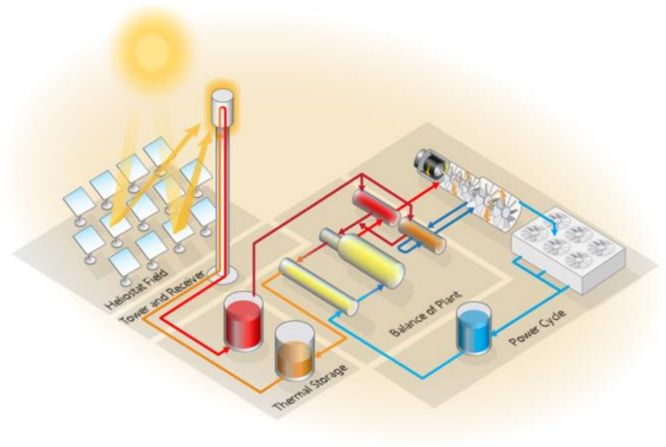


Fig. 6. Beam irradiance

Diffuse and Global irradiances are shown in fig. 7.



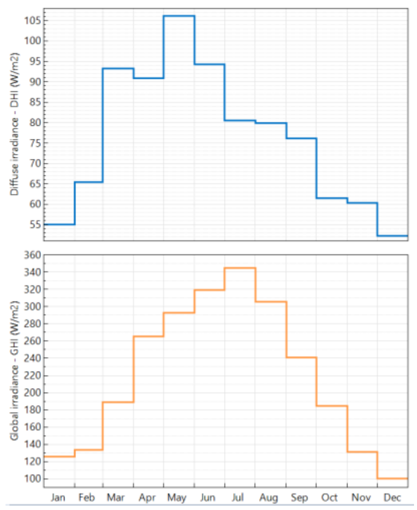


Fig. 7. Blue Diffuse Irradiance. Orange Global Irradiance

the figure has demonstrated that the highest potential of diffuse and global irradiance is on summer months, unlike winter months.

D. SAM Modeling and Validation

Here, the goal is to first develop validated models of existing facilities, then to use one validated model to compute the performances that a similar plant could potentially have in Al-Kufrah region. The design simulations are conducted on the system advisor model (SAM) simulations. SAM, which is widely used within fields of policy-making, engineering, and other techno-economic fields, it is free software [10]. SAM can simulate several renewable energy systems, including concentrating solar power (PV and CSP) systems for electric power generation. Additionally, the software is capable of simulating industrial process heat from the singler power tower. A more detailed description of SAM can be found in [10] Sample CSP PT models are readily available in SAM [28]. To establish a baseline for the proposal of new plant design, modeling existing plants, and leveraging their experimental data for validation can certainly enhance the trust in the proposed design simulated results. In general, there is a huge reliability issue and thus confidence in the results of the created models without referencing them to real models. The error between SAM simulation and real plants are varying between 8% to 12% depending on the size of the simulation and certain circumstances, a detailed validation can be shown referenced in [10]. the following Fig 8. shows the results of comparing the Genesis (Blythe) power plant with the (Genesis SAM simulation)

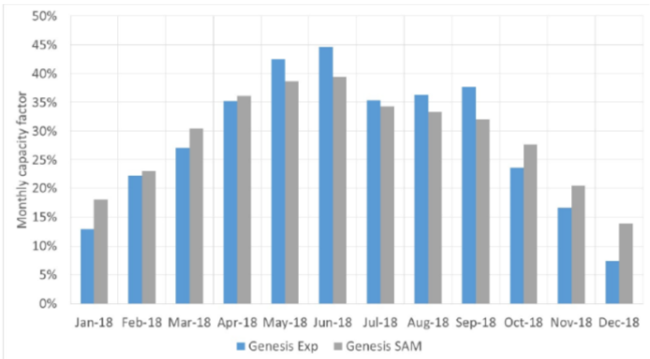


Fig. 8. comparing Genesis (Blythe) power plant with the (Genesis SAM simulation) [10]

E. *Solar energy technologies*

The development in both PV and CSP can be tracked up in the following sub-section.

1. *Concentrated Solar Power Technology.*

- In a general, CSP power plants produce electricity by converting concentrated direct solar irradiation into energy. Unlike photovoltaic cells or flat plate solar thermal collectors, CSP power plants cannot use the diffuse part of solar irradiation which results from scattering of the direct sunlight by clouds, particles, or molecules in the air, because it cannot be concentrated. shown in Fig. 9. [6,12]

Fig. 9. CSP plant

- Solar Field:

mirrors; receivers; support structures; collector systems; HTF; heat exchanger; HTF pump; tracking; piping. [6,12]

- Power Block:

turbine condenser, superheater, pump, optional boiler, generator, heat exchangers, cooling tower, balance of the system. [6,12]

- Thermal Storage Unit:

storage media, encapsulation methodology, HTF, storage tank, heat exchanger, tank insulation. [6,12]

The process of energy conversion consists of two parts:

- The concentration of solar energy and converting it into usable thermal energy.
- The conversion of heat into electricity.
- The conversion of heat into electricity is generally realized by a conventional steam turbine (Rankine cycle). [7]

the design parameters of the CSP model was inspired by the Ourzazate solar power station in the Kingdom of Morocco [16], and must of the design references were from NREAL sources.

Additionally, the technology for the CSP plants was (single power tower) for various good reasons. Single towers have the following advantages over other CSP technologies:

- Higher efficiency
- Minimal piping
- Fixed receiver unit
- Flat mirrors
- Proof of concept at first generation sites
- Ideal for hybrid plants
- Field set-up flexibility

Other technologies have disadvantages like the Durability of piping/ball joints and utilizing more expensive curved mirrors, and they suffer from relatively low thermal to electric conversion [12].

d. *Photovoltaic Solar power.*

The PV system converts the sun's radiation, in the form of light, into usable electricity. It comprises the solar array and the balance of system components. PV systems can be categorized by various aspects and are summarized as follows [8]:

1.Solar PV Module 2. Solar charge controller 3. Inverter 4. Battery 5. DC-DC Converter 6. Load 7. String sizing 8. Inverter Sizing

The most important parameters that were selected based on the location of the plant, since the region is considered very hot through the year, the plant should be robust and resistant to temperatures, specially the PV panels. Therefore, the temperatures coefficient of the panels had a good value of (-0.299 %/Celsius).

IV. Results and Discussion

After finishing the design of the both plants, the results are shown in the following tables, table 1 shows the PV results, Fig. 10. shows the power generated through June, July, August and November. And table 2. Shows the CSP results followed by Fig. 11. Showing the power generated through June, July, August and November

A. *PV results*

TABLE 1. PV RESULTS

Metric	Value
Annual energy (year 1)	286,766,016 kWh
Capacity factor (year 1)	28.5%
Energy yield (year 1)	2,494 kWh/kW

Performance ratio (year 1)	0.77
Battery roundtrip efficiency	88.05%
Net capital cost	$211,663,472
total cost installed per capacity	$ 1.74/Wdc
Area	664.7 acres, 2.689 km^2

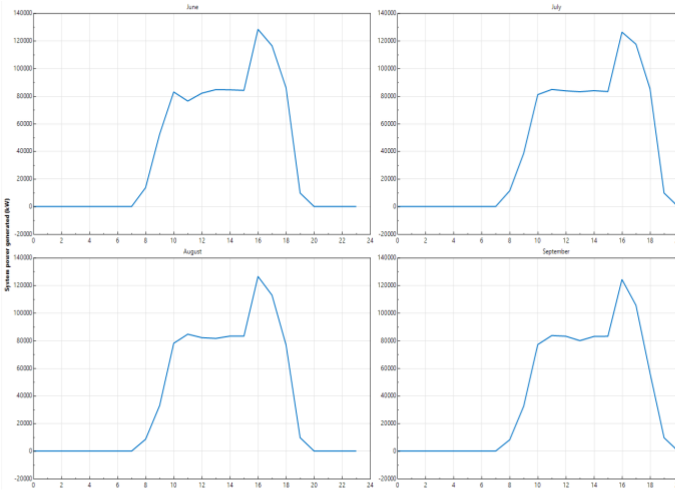


Fig. 10. PV plant power generated through June, July, August and November

B. CSP results.

TABLE 2. CSP RESULTS

Metric	**Value**
Annual energy (year 1)	489,955,584 kWh
Capacity factor (year 1)	68.4%
Annual Water Usage	80,435 m^3
Net capital cost	$ 532,435,808
Estimated total installed net capacity per ($/kw)	$ 6,188.30
Total land area	1,540 acres, 6.233km^2

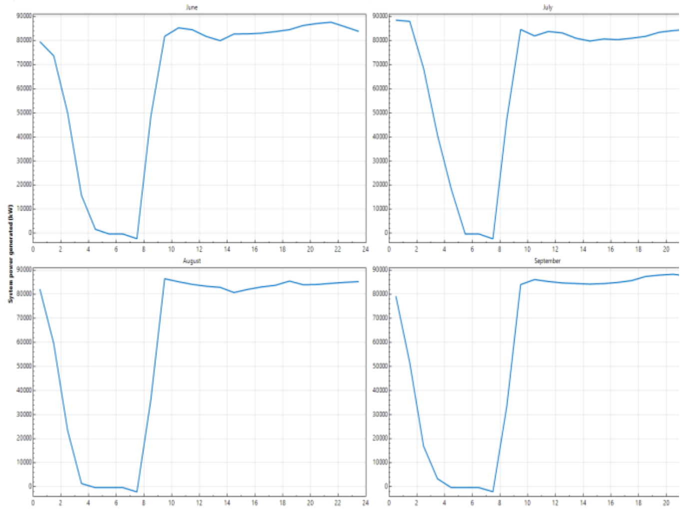


Fig. 11. CSP plant power generated through June, July, August and November

C. Comparison between PV and CSP Metrics.

Table 3. shows the comparison between both the simulation results

TABLE 3. PV AND CSP COMPARISON

Metrices	PV	CSP
Capacity (MW)	90 MW	90 MW
Capacity factor	28.5%	68.4%
Annual energy (kWh)	286,766,016 kWh	489,955,584 kWh
Total cost (million $)	$211,663,472	$ 532,435,808
Total area (km^2)	2.689	6.233

D. Discussion

The results of the simulation were very promising, both plants can power the average of 30,000 homes without any defect. However, the technical differences need to be evaluated to make a detailed comparison between the two choices. The discussion of the technicalities is taken in the following section.

1. Efficiency:

   In terms of energy storage and efficiency, CSP was superior since it stored energy with the help of thermal energy storage (TES) technologies. PV, on the other hand, is incapable of producing or storing thermal energy since it directly generates electricity. Aside from that, it's also difficult to store electricity, and battery storages are quite expensive and have a short life span.
2. Technical simplicity:

   A PV system is like a quartz watch, whereas a CSP system is like a mechanical watch. The former revolves around the solar cell, while the latter is a combination of equally critical components. This has allowed the PV industry to focus on solving one issue driving down the cost per Watt while the CSP industry is spread across multiple challenges e.g., improving the optical efficiency of collectors, researching new heat transfer fluids or procuring higher efficiency turbines [15].
3. Efficiency of Land use:

   it can be seen from the results chapter that PV has a more efficient land use. in the other hand CSP land use efficiency scales exponential when higher capacities of MWe is desired. However other aspects are to be considered in terms of land use are the shape, slope and site preparation. The geometry of the solar field is not important for PV plants whilst it should (ideally) be square for CSP facilities [7]. CSP systems are also more sensitive to slopes, requiring reasonably flat terrain (preferably less than 1.5°- 3°) whereas PV easily tolerates 5 ° - 10 ° slope [7]. Furthermore, in some circumstances the preparation of the site to reduce land disturbance can require more effort for CSP plants, whereas it can be easier for PV arrays.

4. Cost:

The levelized cost and per unit cost of CSP system is higher compared to the PV system. but that's due to the fact CSP system are more economically viable when aiming for higher power capacities and have better energy utilization. Additionally, CSP have a better energy storage. The installation costs are shown in fig.12. [9].

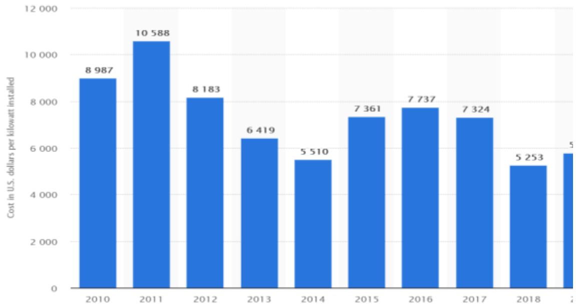


Fig. 12. Costs of installing CSP power tower over the years [9]

5. Grid flexibility:

CSP has the advantage that it can be equipped with low-cost thermal energy storage. This allows CSP to provide dispatchable renewable power. CSP therefore can offer advantages, such as allowing for generation to be shifted to times when the sun is not shining or to maximizing generation at peak demand times. CSP with integrated storage can thus be a cost effective. total installed costs for CSP plants that include thermal energy storage tend to be higher than those without, but storage also allows for higher capacity factors [15].

6. Hazardous:

According to NREL [9] CSP should have a safe perimeter, since sunlight tends to attract insects and insects attract wildlife, wild life can complicate the security of the plant if unobserved at the same time CSP plants are considered hazardous like a conventional power plant, because they are emitting heat and have in some cases leakage.

7. Use of the sunlight:

CSP can exclusively use the Direct Normal Irradiation (DNI) whereas PV uses the whole Global Horizontal Irradiation (GHI) [9]. The two quantities are not the same and as a rough indication DNI can typically vary between 65% and 85% of the overall GHI [9]. As an immediate consequence PV system can also work with diffused light, conversely from CSP which requires direct irradiation. However, at least in the current state of technology, heat is much easier to store than electricity itself. Therefore, CSP plants implementing thermal energy storage (TES) systems mitigate this potential problem whereas PV plants are significantly affected by clouds.

8. Temperature:

Heat can "severely reduce" the ability of solar panels to produce power, depending on where they're installed, hot temperatures can reduce the output efficiency of solar panels by 10%-25% Meanwhile [14], CSP system can handle high temperatures and heatwaves without losing any efficiency. Additionally, during extreme temperatures, solar batteries may malfunction and stop working. The capacity of batteries increases when the temperature rises, and decrease when the temperature goes down. Although at higher temperatures, the capacity of batteries is higher, they have a shorter battery life span, and are prone to overheating and fire [14].

E. Feasability

Considering the results and the discussion in the previous section with the location of the plants (Al-Kufrah region) which is a hot arid desert region in the Sahara Desert, it can be stated that both plants have promising results to achieve the desired goal of 90MW. Additionally, the results compared to other regions around the globe were outstanding [9]. Anyway, when it comes to efficiency and the power capacity and grid flexibility CSP tends to be more superior, although the PV plant was cheaper in every term it has many disadvantages when operating in high temperate regions and storing a large quantity of energy in batteries. Finally, the CSP plant is the best choice when installing a solar technology plant in desert regions in must circumstances.

V. CONCLUSION

In this paper, the comparison, study and the performance analysis of two different solar power technologies at the Al-Kufrah region were considered. The two proposed systems at the site were both 90MW (PV, CSP). Using SAM software, the performances of the two systems were evaluated during the summer and winter seasons but just 4 months were illustrated. The results obtained for the two systems were compared to each other. Finally, the feasibility of using the solar power systems in the region was discussed.

IV. APPENDIX

A. The PV module parameters are illustrated in Table 4

TABLE 4. PV MODULE PARAMETERS

Modules	
SunPower SPR-A395-BLK	
Cell material	Monoi-c-Si
Module area	1.870 m^2
Module capacity	399.740 Wdc
Quantity	287,680
Total capacity	114,997.203 kWac
Total area	537,961.6 m^2

B. The inverter parameters are shown in Table 5

TABLE 5. INVERTER PARAMETERS

Inverters

Yaskawa Solectria: SGI 750XTM [400V]	
Unit capacity	1250 AC Kw
Input voltage	400-800 VDC DC V
Quantity	114
Total capacity	1263.77AC Wac
DC to AC Capacity Ratio	1.34
AC losses (%)	0.25

C. The PV array parameters are depicted in Table 6

TABLE 6. PV ARRAY PARAMETERS

Array	
Strings	17,980
Modules per string	16
String voltage (DC V)	769.6
Tilt (deg from horizontal)	30
Azimuth (deg E of N)	180
Tracking	1 axis
Backtracking	no
Self-shading	no
Rotation limit (deg)	45
Shading	no
Snow	no
Soiling	yes
DC losses (%)	3.6

D. THE CSP DESIGN PARAMETERS THE TECHNICAL DESIGN PARAMETERS FOR THE PROPOSED AL-KUFRAH REGION CSP PLANT IS PRESENTED IN TABLE 7

TABLE 7. CSP PARAMETERS

OMU CSP design parameters	**Value**
Total Capacity	90 MWe
Total estimated land area	6.233km^2
Cycle thermal efficiency	0.412
Cycle thermal power	218.45
HTF hot temperature	570°C
HTF cold temperature	280°C
Ful load of hours storage	10 hours
Solar field hours of storage	4.2 hours
Heliostats	7209
Single heliostat area	144.37m^2
Design-point DNI	800 W/m^2
Solar multiple	2.4
Receiver thermal	524.3MWt
HTF	Solar Salt
Material type	Stainless AISI316
Tower height	175.65 m
Receiver diameter	17.16 m
Number of panels	20
Thermal storage Capacity	218.4 MWt
Full load hours of TES	10hours
Storage type	Two Tank

References:

[1] Tarek A Mohammed., System integration of hydrogen energy technologies using renewable energy resources". 2384.pp., (2,3), (2015).

[2] Ahmad Belkhair., Tarek Hamad., Estimating the Amount of Methane Gas Generated from the Feedstock: A Case Study of El-Beida City, Libya. The International Renewable Energy Congress, pp (1-8), (2019).

[3] belgasim y., aldali m., g hashem., k. hossin, "the potential of concentrating solar power (csp) for electricity generation in Libya", renew. sustain. energy rev., vol. 90, pp. (1–15), ((2018).

[4] Trieb F., "Concentrating Solar Power for Seawater Desalination". Stuttgart, Germany:German Aerospace Center (DLR), (2007).

[5] Mohamed Ahmed., Al-Habaibeh Amin., Abdo Hafez.," An investigation into the current utilization and prospective of renewable energy resources and technologies in Libya. Renewable Energy". Elsevier solar energy. vol.50, pp732–740, (2013).

[6] Dagoberto Calamateo., Dongmei Zhou., "A Pre-Feasibility Study of a Small-Scale Concentrating Solar Power Plant for an Industrial Application in Sacramento", California. Proceedings of the 2nd International Conference on Fluid Flow, Heat and Mass Transfer. pp.180, (2015).

[7] Carrizosa E., "A heuristic method for simultaneous tower and pattern-free field optimization on solar power systems". Computers & Operations Research. 57: p. 109-122., (2015).

[8] Emery, Keith., "The rating of photovoltaic performance. Electron Devices", IEEE Transactions on. 46, (2009).

[9] Photovoltaic research (2017, April 12).: http://www.nrel.gov/pv/

[10] Al-Kouz, Wael & Almuhtady, Ahmad & Abu-libdeh, Nidal & Nayfeh, Jamal & Boretti, Albert. "A 140 MW Solar Thermal Plant in Jordan". 8. 1-24, (2020).

[11] "Project Ourzazate Solar Power Station – Phase I, Country: Kingdom of Morocco, Project Appraisal Report, Date: April ,(2012).

[12] Busse, K. T., & Dinter, F. "Overview of predictive CSP spread prospects and its opportunities". *Journal of Energy in Southern Africa*, *27*(2), 50–59, (2016).

[13] T. Jamasb, W.J. Nuttall, M.G. Pollitt, Eds., "Future Electricity Technologies and Systems". Cambridge (UK): Cambridge University Press, (2006).

[14] shim Gurung, Qiquan Qiao, "Solar Charging Batteries: Advances, Challenges, and Opportunities", Joule, Volume 2, Issue 7, Pages 1217-1230, ISSN 2542-4351,(2018).

[15] Stekli, J., L. Irwin, and R. Pitchumani, "Technical Challenges and Opportunities for Concentrating Solar Power With Thermal Energy Storage". *Journal of Thermal Science and Engineering Applications*, 5(2): p. 021011-021011, (2013).

[16] "Project Ourzazate Solar Power Station – Phase I Country: Kingdom of Morocco Project Appraisal ReportDate: April (2012)".