Advanced research in solar energy: Malaysia, UAE and Nigeria

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Abstract: Solar energy was studied intensively by many researchers due to several advantages such as it creates zero pollution, low operation cost, and less maintenance. Therefore, solar energy grows rapidly and power plant was successfully built in many countries. In UAE, the use of solar energy could be classified into short-term, mid-term and long-term. These plans include financial incentives on photovoltaic panels. In Nigeria, the zones with the most favorable solar energy potential for electrical power generation are the North East and North West geo-political zones if compared to southern region. In Malaysia, solar energy seems not so popular even though received enough sun irradiation. Because of low efficiency (less than 10 % efficiency), and lack of awareness. However, government has implemented a lot of policies or programs to promote solar energy.

Keywords: solar energy, renewable energy, sun, green chemistry

INTRODUCTION

Nowadays, there are some renewable energies such as wind energy (Vogel et al., 2018; Esmaeili and Ahmadian, 2018), hydropower (Marquez et al., 2010; Jawahar and Prawin, 2017; Nor et al., 2017), solar energy, biomass energy (Moonmoon et al., 2014; Mustafa and Hasan, 2012) and geothermal energy (Ruggero, 2016; Chandrasekharam and Jochen, 2008) were intensively investigated by many researchers. They are looking for great improvement in order to produce electricity and better living conditions (Agmar et al., 2018). Each renewable energy has its own advantages as indicated in Table 1. Here, solar energy will be selected and discussed. Basically, it does not create pollution and produce harmful substance (Kamat, 2007). It could be classified as green energy and grows very quickly in the global market. Researcher explains that solar energy comes from sun, then produced electricity. Low operation costs could be achieved due to less maintenance is required (Nathan, 2007). There are many solar power plants have been successfully built in the world up-to-date because of vast availability and certainty of sunlight. The global renewable generation capacity (in 2017) was 2179 GW. Hydro energy contributed for 53 % while solar energy accounted for 397 GW, which took third place or 18 % (Table 2).

Table 1: Advantages of various renewable energies

<table>
<thead>
<tr>
<th>Renewable energy</th>
<th>Advantages</th>
</tr>
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</table>
| hydropower       | • It does not cause air pollution, and called as clean energy (Tang, 2016).
|                  | • It’s production could be constant, and is considered as efficient |
|                  | • It is inexpensive, and required low operating cost (Charles, 2014).
|                  | • It can produce electricity continuously. |
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- Dam could be tourism destination and for irrigation.

**Wind Energy**
- It does not release greenhouse gas (Vaughn, 2009)
- It does not pollute air
- It is sustainable and cost effective (Kris, 2016)

**Geothermal Energy**
- It is emission free (Ingrid and Kurt, 2013)
- It is little (air, water) pollution
- Deployment cost is low.
- Geothermal reservoir is replenished (Harsh and Roy, 2006)
- The power plant has high capacity.

**Biomass Energy**
- It can be used to replace fossil fuel to produce electricity (Carol, 2013)
- It is available (renewable energy)
- Growing biomass increases oxygen content, and reduces carbon dioxide (Klass, 1998).

<table>
<thead>
<tr>
<th>Renewable energy</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>53 %</td>
</tr>
<tr>
<td>Wind</td>
<td>23 %</td>
</tr>
<tr>
<td>Solar</td>
<td>18 %</td>
</tr>
<tr>
<td>Others</td>
<td>6 %</td>
</tr>
</tbody>
</table>

Table 2: Renewable generation capacity by energy source (Renewable capacity highlights, 2018)

In this work, the implementation of solar energy in Malaysia, Nigeria and UAE will be studied. The development and challenging issues were highlighted.

**Literature survey**

**Solar energy in Nigeria**

Nigeria is located north of the equator. Therefore, sunlight could be converted to produce electricity and for heating purpose through photovoltaic panel. Nigeria is one of the oil producing country, however, renewable energies such as solar energy, hydro power and biomass has been explored also. In this country, development of solar energy seems to be part of the national energy policy. The policy motivated researchers to embark on research related to solar energy. In recent years, the number of scientists have focused on solar thermal devices for producing thermal energy transferred to the desired tools. For example, solar thermal tools including solar cookers, solar driers, solar stills and desalination, solar water heaters, solar water pumping, solar incubators and chicken brooders.

Recent research on solar energy in Nigeria has focused on solar resource measurement through modeling and simulation, and the use of geo-satellite database (Ohunakin et al., 2015; Adaramola, 2014; Njoku, 2016). From recent findings, the global solar irradiation (GSI) in Nigeria is specific to the country's geo-political zones. The zones with the most favorable solar energy potential for electrical power generation are the North East (5.6-7 kWh/m²/day) and North West geo-political zones (Figure 1) if compared to southern region (3.5-5.5 kWh/m²/day) due to the relatively high GSI in these areas (Ajayi et al., 2014; Fadare, 2009).
Meanwhile, solar resource data collection has been a challenge in previous investigations. To address this challenge, a detailed solar resource estimation on inclined surfaces in Nigeria have been estimated recently (Okoye et al., 2018). This estimation involved the use of solar trackers to model the hourly data of solar resources for nine different locations in Nigeria. The diffuse part of the radiation was first estimated using the accurate and well-known Perez anisotropic and Koronakis isotropic models before trackers were integrated. This model included single, dual as well as full tracking. The nine locations selected included Onitsha, Katsina, Wamba, Magama, Potiskum, Bursari, Bauchi, Gusau and Kaduna. The locations were selected based on (i) abundance of GSI and (ii) population density because highly populated areas (with less land area to spare) will only be suitable for decentralized generation options and less populated areas will be the perfect choice for large scale power development (Figure 2). It was found that the annual solar resource potential for selected areas increased from 1,621 to 2,279 kWh m$^{-2}$; using solar trackers, it will vary between 1,664 and 2,983 kWh m$^{-2}$.

**Fig 1:** Nigeria solar radiation map (Adaramola, 2014).
A recent study has attempted to recalibrate previously established solar energy correlations to address the challenge of gaps in solar resource data collection (Ozoegwu, 2018). Missing data points degrade the quality of the overall data especially when available data is for a short period. A critical review of about 50 years of solar energy resource calculations and quantification was carried out and the missing gaps were recalibrated by testing the previous correlations with recent data for Enugu (South East Nigeria) metropolis. The recent data was obtained from Nigeria Meteorological Agency (NIMET). It was observed that sunshine models and mixed-weather parameter models is the best model to be employed for solar energy resource forecast. Also, the critical review revealed that solar assessments studies in Nigeria are stymied by narrow use of artificial intelligence and time series approaches. It was inferred that neural time series was capable of predicting current Nigeria solar resource from past data, as well as forecasting up to one-year of data for the location studied. The predictions were validated with one-way ANOVA.

Aside the challenge of unavailability of detailed data faced in previous investigations on solar energy, the influence of varying climatic parameters on solar irradiance in different regions has also been sparsely studied. Due to increasing changes in global climatic conditions, it is important to establish how this variation influences the projections required for the planning and implementation of solar energy projects in Nigeria. A recent study has investigated the variability of solar irradiance with weather parameters such as temperature, and rainfall in Nigeria using the Regional Climate Model version 3 (RegCM3) software designed by the International Centre for Theoretical Physics (ICTP) (Ohunakin et al., 2015a). RegCM3 is capable of measuring climate change, thus it can as well measure solar irradiance variability. Seasonal and inter-annual variation in GSI were simulated for Nigeria for a 10-year period (1997-2007) using the RegCM3. The simulations showed that during rainy season, over-estimate was inherent in the southern zones but high accuracy was observed for the middle belts and northern climate regions. It was concluded that RegCM3 model was capable of forecasting inter-seasonal GSI and mean temperatures across Nigeria.

The same model was used in conjunction with ECHAM5 in another study (Matthew et al., 2015). The name “ECHAM5” was derived from the combination of its origin. The ‘EC’ was the abbreviation for European Centre for Medium-Range Weather Forecasts (ECMWF) and ‘HAM’ was the abbreviation for Hamburg, the place where its parametrization package was developed. The combined model was used to simulate the effect of increasing atmospheric concentration on solar irradiation on the ground level in Nigeria. Dataset was obtained from NIMET to train the models. 30 % maximum error range was estimated between the model values and the data collected from NIMET. The predictions indicated that the mean temperature across Nigeria was increasing due to global warming. The predictions also indicated that the global solar radiation in Nigeria would decrease by up to 3.27 % in the period 2011-2040 due to climate change. This observation was in agreement with the increase in concentration of CO$_2$. 
As a result of this trend, the southern region is expected to experience more reduction in GSI due to increasing cloudiness in this area (Figure 3).

Fig 3: Prediction of change in solar radiation in Nigeria during 2011–2040

The influence of solar irradiance on climatic variability was studied by using multivariate model (Ajayi et al., 2014). This multivariate model increases the sensitivity of the model to climate and weather variabilities. The model is different from previous works in the sense that it is a more robust model capable of estimating daily GSI anywhere in Nigeria with minimal error. It was built from NIMET data covering 12 sites spread across the geo-political zones in Nigeria for a period of 1987–2010. Furthermore, some zone-specific studies on the influence of climatic parameters on GSI have been carried out recently. They (Giwa et al., 2017) reported that such studies covered the 6 geo-political zones across Nigeria. In the South West zone, it has been established that turbidity or cloudiness has a significant potential to block solar radiation incident on the area. It was observed that GSI reduced drastically during Harmattan season in Lagos, the most populous state in the zone. The sources of turbidity were reported to come from the moist winds migrating from the Atlantic Ocean. These moist winds consisted of dissolved sodium chloride (NaCl) and organic compounds. Therefore, the use of bright sunshine hours only to make GSI predictions in Lagos would be erroneous. Bright sunshine hours will only give accurate estimation to a certain degree; but when correlated with Global horizontal irradiance (GHI), bright sunshine hours would give much more accurate predictions of hemispherical solar radiation in Lagos. In Akure (7.25 °N, 5.2 °E), another state in the South West, a study has determined the GHI by developing a simple correlation from a 22-year solar radiation data (Adaramola, 2012). However, the average GHI can be partly over-estimated and heavily over-estimated between July-September by using the correlation. It was concluded that Angstrom-Page model is a better predictor of average global radiation for Akure than the developed correlation.

From Angstrom-Page model, an empirical model has also been developed (Yohanna et al., 2011) for the estimation of GHI in Makurdi, a state located in the North central zone of Nigeria. Data on bright sunshine hours and cloudiness were collected everyday between 6 am and 6 pm for exactly 18 months. The Angstrom equation is shown in Eq. (1).

$$\frac{H}{H_o} = a + b\left(\frac{N}{N^*}\right)$$

(1)

$H$ is measured solar radiation, $H_o$ is mean daily radiation, $N$ is sunshine hours between sunrise and sunset, and $n$ is the bright sunshine hours. $H_o$ was determined from Eq. (2).

$$H_o = \frac{24}{\pi} l_o \left[ 1 + 0.033 \cos \left(\frac{360N^*}{365}\right) \left(\cos \phi \cos \delta \sin \omega + \frac{2\pi}{360} \omega \sin \phi \sin \delta\right)\right]$$

(2)
\( I_o \) is solar constant, \( \varphi \) is latitude, \( \delta \) is declination angle, \( \omega \) is hour angle. By plotting \( \frac{H}{H_o} \) against \( \frac{n}{N} \), constants “a” and “b” were obtained. These constants denoted the diffused and direct/beam radiation, respectively. The results showed average GHI and bright sunshine hour of 224 W/m\(^2\) and 6.6 h, respectively for this location. The maximum and minimum GHI and bright sun hours in Makurdi were observed in March (264 W/m\(^2\) and 7.7 h) and August (169 W/m\(^2\) and 4.8 h), respectively. Aside Angstrom-Page model, Sayighr universal formula has also been used by researchers to estimate GHI across Nigeria. Researchers (Chineke and Okoro, 2010) estimated the GHI for Niger Delta (South, Nigeria) and Umudike (South East, Nigeria) using Sayighr universal formula. GHI values ranging from 1.99-6.85 kWh were estimated. It was observed that the estimations were in agreement with previously published values in literature. It was proposed that the formula can be used for the estimation of GHI in locations where GHI measurements cannot be carried out.

Quite a number of recent research efforts have been made towards improvement of solar power conversion efficiencies in Nigeria. The incorporation of silver nanostructures (nAg) in dye sensitized solar cells (DSSC), immobilization of nAg on top of TiO\(_2\) or on fluoride doped tin-oxide (FTO) substrate, and life cycle assessments are the recent approaches. Solar PV cells have been enhanced recently (Eli et al., 2016) through the incorporation of nAg in DSSC via SILAR deposition technique. Comparison was made between configurations which are immobilizing nAg on top of TiO\(_2\) semiconductor (FTO/TiO\(_2\)/nAg) or on FTO substrate (FTO/nAg/TiO\(_2\)). Higher power conversion efficiencies and photocurrent generation could be reached in the FTO/TiO\(_2\)/nAg (36 %, 49 %) and FTO/nAg/TiO\(_2\) photoanodes (25 %, 22 %). The results from plasmonic effect quantification of the solar device showed that there was enhanced visible range absorption for both configurations, but absorption was higher when nAg was deposited on TiO\(_2\) (Fig. 4). The enhanced absorption might be as a result of Surface-Plasmon resonance (SPR) effect of added nAg which enhanced the surrounding electromagnetic fields. Consequently, photocurrent generation was increased. However, it was stressed that the device had poor fill factor value.

Similarly, researcher (Eli et al., 2017) investigated the effect of varying diameter (40, 80 and 120 nm) of nAg on the performance of DSSC through the use of SILAR (successive ion layer adsorption and reaction). Device with nAg of diameter 40 nm showed the most desirable results. However, decrease in photovoltaic efficiency was observed with increasing nAg diameter from SILAR cycle 1 through 2.

![Figure 4](image_url)
Interesting efforts have also been directed towards the determination of peak energy levels of solar systems via 2-axis tracking in various locations in Nigeria (Njoku, 2016). System performance ratio ($R_p$) was investigated based on insolation level and temperature. This approach was different from the fixed value of 0.75 commonly used. The obtained results highlighted that seasonal and annual energy generation potentials were reached maximum value in December-February ($446-648$ kWh/kWp) if compared to June-August ($249-590$ kWh/kWp).

The life cycle impact (LCI) of a 1.5 kW solar PV system when installed in 6 different geo-political zones (one location per zone) was described (Akinyele et al., 2017). Using performance ratio of 0.8, photovoltaic life span of 20-30 years, module efficiency of 15.4 %, solar irradiation of 1,493-2,223 kWh/m$^2$/y, life cycle emission rate of 37.3-72.2 g CO$_2$/kWh and cumulative energy demand of 3,800-8,700 MJ eq, the following indices were obtained: global warming potential of 1,907-5,819 kg CO$_2$-eq, EPT of 0.83-2.3 years and net energy ratio of 7.08-36.17. The lowest and highest values of the ranges corresponded to the location with the lowest (South South) and highest (North East) solar resource potentials, respectively. The findings from this study provided insights into the effect of location-specific solar resource potential on the environmental performance of a photovoltaic system. The findings are useful for energy analysis, planning and decision making purposes in Nigeria.

The social impact of solar PV system correlates with its increasing developments. Positive end user perception of this technology will go a long way in its incorporation in the Nigeria energy mix. In this study (Wojuola and Alant, 2017), the public perception of renewable energy technology in Nigeria, including knowledge, beliefs, and attitude towards utilization was explored. It was observed that there were high positive correlations between perceived usefulness and intention to use it. In addition, negative perceptions about the government-owned electricity company, lack of information on how the technologies works, cost and lack of financial transparency contributed to negative outlook about renewable energy technologies among the public. Therefore, adequate education will go a long way in improving public perception about solar energy in Nigeria.

National Renewable Energy and Energy Efficiency Policy (NREEEP) and the Nigerian Feed-in Tariff for Renewable Energy Sourced Electricity (Nigerian Electricity Regulatory Commission (NERC), 2015) were implemented in order to increase the use of renewable energy, and discouragement of the use wood based fuel in rural areas. These policies (FMP, 2015) were employed to ensure that solar energy industry was rapidly increased from 3 % to 6 % by 2020 and 2030, respectively through public sensitization campaign, research and development.

The Nigeria feed-in tariff policy supersedes the Multi-Year Tariff Order (MYTO) II, which had been in existence since 2012 (Giya et al., 2017). This policy aims to increase the utilization of abundant renewable energy resource and attract investors into the renewable energy sector of Nigeria. A notable objective of this policy is to guarantee increase in electricity generation by 2 GW from renewable energy sources, by 2030. In order to achieve this, the policy compels the electricity distribution companies to source at least 50 % of their procurements, and the other from the Nigerian Bulk Electricity Company as well. The policy also differentiates clearly between small and large plants generating electricity; a plant with capacity between 1 MW and 30 MW is regarded as small and will get automatic integration as renewable energy whereas plant with more than 30 MW capacity is large and would require competitive bid submission according to the guidelines provided in the policy.

A recent review (Ozoegwu, 2018) explained that the policies were in form of incentives to encourage renewable energy investment and integration in Nigeria. These incentives can be categorized as follows: (1) Feed-in Tariffs (2) grants (3) Reduction in tax (4) public investment. Excessively high feed-in tariff for solar energy plants (N 92, 192 per MWh) was identified as the barrier to the poor implementation of solar energy projects in Nigeria. Therefore, the removal of subsidy from fossil fuel products was recommended. The monies obtained from subsidy removal could be diverted to the payment of feed-in tariffs for solar energy. Also, various pledges in terms of subsidies and financial rebates from the Nigeria government towards swift integration of solar energy into the country’s energy mix were identified. An example of these pledges is provide rebates to on-grid customers who substantially modified their equipment for higher energy efficiency. However, the pledges do not provide any quantitative figure to show the amount of subsidy, rebates, or soft loans that will be given. Therefore, it was recommended that this policy be modified by including quantitative estimates of incentives. There are several pilot projects which belong to the government and managed by Rural Electrification Agency (REA). REA is in charge of carrying out feasibility studies on utilization of electricity from renewable sources especially solar energy for remote and off grids areas. In terms of tax credits, government’s contributions towards tax exemption are laudable. However, more tax credits should be allocated to potential investors in solar energy.
technologies for increased deployment of solar energy across Nigeria. In general, swift integration of solar energy into the energy supply mix of Nigeria would be effectively catalyzed by the government’s involvement through implementable and stable policies.

On the other hand, another review (Giwa et al., 2017) summarizes the barriers, prospective drivers, and proposed policies to encourage solar energy project development in Nigeria. This review identified (1) high dependency of GSI on zone and climatic parameters—with bright sun hours varying from 4h (in the south) to 9 h (in the zone); (2) poor and dilapidated grid system that cannot accommodate electricity generator like solar PV technologies; (3) high capital, and operating and maintenance cost of solar PV systems; (4) harsh government policies for interested investors solar energy projects etc. as the barriers to smooth implementation of solar projects.

As the population of Nigeria continues to grow at an alarming rate, about 3 GW of electricity is available to over 170 million people and 45% of the entire population still lack access to regular electric power. Therefore, solar energy played important role, if appropriate energy policies are put in place and implemented. With the abundant solar energy resource in Nigeria that remains hugely untapped (18 GJ/day of incident solar energy on the total surface area of Nigeria), the potential to tap this useful resource for sustainable electricity generation is high. In order to understand the future solar energy development in Nigeria, it is imperative to analyze all factors impeding it. Another critical barrier to solar energy development is the huge subsidy on fossil fuel products. This subsidy gives fossil fuel products an edge based on cost per energy produced. Fossil fuel products are the major source of energy for most Nigerians in most part of the country. These products are used in electrical generators, gas power plants, and even in hydropower plants for electricity production. It is generally believed that the removal of subsidy from fossil fuel products might lead to inflation and rise in the prices of basic items (Siddig et al., 2014; Soile et al., 2014). In addition, recent fluctuations in the amount of subsidy on fossil fuel products have further removed any possible competitive edge solar energy might have.

Even if the government removes the subsidy on fossil fuel products, another obstacle that must be addressed is the cost of solar electricity production. Researchers (Emodi and Boo, 2015) recently presented the MYTO II (2012-2016) feed-in Tariffs (in naira per MWh (N/MWh)) from various electricity generation sources (Figure 5). The feed-in tariff of ground-mounted solar PV system is more than double of the price of the most expensive fossil fuel source in Nigeria.

![Fig 5: MYTO II FiTs for different electricity generation sources for period of 2012 to 2016 (Emodi and Boo, 2015)](image)

Therefore, for solar PV technology market to become economically competitive in Nigeria, it is recommend that: (1) the government should give incentives to investors or a form of financial plan; (2) the payment options for solar PV electricity should be adjusted such that rural customers are attracted; (3) the government should encourage local production of solar PV systems through appropriate legislations and policies in order to remove cost constraints and ensure affordability; (4) Subsidy on solar PV electricity can then be easily be withdrawn after a specified period, as the global cost of solar PV system become cheaper; (5) the government should finance and give incentives to research and development.
oriented institutions. These recommendations would accelerate the deplorability of solar power technology across Nigeria.

The future of solar energy in Nigeria is promising. Several efforts have obviously been made towards development of solar energy market in Nigeria but the effects of these efforts are yet to be widely seen. To attain the future goals of solar power deplorability in Nigeria, the following have been proposed in recent studies: (1) creation and institution of stable policies for solar energy development to attract potential investors; (2) sensitization and education of the public (using traditional and social media) on solar power technologies and applications as well as their benefits; (3) citizens whose lands may have been lost through solar energy development should be entitled to compensation either in form or financial compensation or solar application skill empowerment; (4) the solar equipment to be installed or used (either imported or manufactured locally) should be of high quality standards; (5) there should be adequate funding for advanced R&D for production of adequate and reliable meteorological data; (6) there should be sufficient funding for research on the solar equipment or devices; (7) the training and education of appropriate personnel on the technical know-how of solar applications should be put in place; (8) an organization in charge of monitoring the progress of solar projects should be put in place (Ohunakin et al., 2014).

The first West African solar panel manufacturer is National Agency for Science and Engineering Infrastructure (NASENI), located in Karshi, Abuja (North Central, Nigeria). There are 2,800 pieces of solar panels were successfully produced since 2011 (Akinyele et al., 2015) and has a capacity of about 7.5 MW per year (National Agency for Science and Engineering Infrastructures (NASENI), 2015). This is an opportunity that should be utilized and developed. One of the solar panels produced by NASENI is shown in figure 6.

![NASENI’s Type 1 module with a capacity of 190 W at STC having 72 cells.](image)

**Fig 6:** NASENI’s Type 1 module with a capacity of 190 W at STC having 72 cells.

**Solar energy in United Arab Emirates**

The abundance of renewable energy especially solar energy could be identified (Griffiths, 2017) in the United Arab Emirates (UAE). The exploitation of the solar energy in the UAE has been prompted to fill up the energy demand-supply dichotomy because of rapidly economic growth. Recent research on solar energy in UAE has been focused on the measurement of solar irradiance, application of solar energy in desalination, and space heating and cooling.

Prior to the development of solar power technologies for electricity production, the solar irradiance in the UAE has been extensively researched in accordance with the geographical area, time and type of solar cell that can give better power output and with higher lifetime. Three main irradiance data were measured including diffuse horizontal irradiation (DHI), global horizontal irradiation (GHI) and direct normal irradiation (DNI). These forms of irradiation could be periodical, i.e. hourly, monthly or yearly (Mokri et al., 2013). The figure 7 shows the extent of the three types of irradiation in the UAE, as measured in 2017.
There is high potential for solar power production in UAE as indicated in figure 7. The mean direct beam solar radiation (Islam et al., 2010) is more than 400 W/m² for the whole year in the UAE especially in spring season. Researchers (Albaidi et al., 2014) proposed the use of an artificial neural network ensemble framework for studying solar irradiance in UAE during the cloudy and cloud-free days. It was recommended that issues such as underestimation or overestimation of solar irradiance variables (DHI, GHI, DNI) due to cloudiness and other factors could be addressed by integrating the model with Box-Cox transformation. The model demonstrated more accurate results than previous models for predicting solar irradiation in the UAE.

Recently, the highlight of solar irradiation measurement in the UAE is the application of remote sensing. They (Gherboudj and Ghedira, 2016) implemented remote sensing and weather forecasting to assess the solar energy potential of the UAE. It was found that the UAE land is more suitable for solar PV power plants (9.7 % of the land mass) than concentrated solar power solar systems (1.0 %) which can only be located along the coastline and extreme south of the country. Another interesting research area is the use of soft computing techniques to predict GHI in the UAE (Hussain and Al-Alli, 2015). Three soft techniques were used to estimate the GHI of Abu Dhabi and it was shown that the nonlinear autoregressive with exogenous input (NARX) gave the best prediction. Meanwhile, all the three approaches failed for prediction in spring seasons. In another study (Hussain and Al-Alli, 2016), Autoregressive Integrated Moving Average (ARIMA) technique was employed for predicting GHI for Abu Dhabi. The results obtained showed that ARIMA gave a good fit for hourly GHI measurement.

Solar desalination is a research area in the UAE. UAE has relied heavily on desalination for the production of potable water due to insufficient naturally available freshwater supply. UAE produces the third largest quantity of desalinated water in the world. Solar-driven MSF and humidification dehumidification (HDH) are some of the research aspects in this field.

Recently, multi-stage flash (MSF) desalination plant was built by researchers (Al-Othman et al., 2018). They expect that could produce capacity of 1,880 m³/day. HDH is one of the hybrid desalination technologies consisting of a thermal energy source, gas or water coolant gap, humidifier, and dehumidifier or condenser. The solar HDH technology has been studied extensively (Giwa et al., 2016, Haris et al., 2016). For large-scale desalination systems, researchers (Franchini and Perdichizzi, 2014) presented a solar driven HD desalination plant model recently. The performance of the large-scale production system was found to be highly influenced by the seawater temperature.

Research interests have been directed towards the design, modeling and experimental investigations of solar heating and cooling systems due to arid conditions. A solar cooling system has been produced (Ras-Al-Khaima emirate) to provide refrigeration from a 70 kW solar field (Munawwar and Ghedira, 2014). This project involved CSEM-UAE, solar PV and solar-island prototype testing facilities. The thesis was presented in KTH School of Industrial Engineering and Management, which a solar thermal poly generation system was designed to provide energy for space cooling, fresh water production and domestic water heating (Molan, 2014). The environmental and economic prospects of the poly generation system were analyzed. Other research findings on solar energy applications in the UAE can be found in the works of different researchers (Said and Mehmood, 2017; Jayaraman et al., 2017; Orhan et al., 2017). Figure 8 shows the trend in the number of research articles on solar energy in the UAE published during the last 17 years.
Typically, PV solar cells have conversion efficiency in the range of 15 to 20%. For instance, a solar module premium monocrystalline solar cell by TSS4U has an efficiency of 18.4% (TSS4U, 2018). For commercially available solar panels, SunPower solar panels give the highest efficiency of 22.5% (Aggarwal, 2018). Meanwhile, poor efficiencies and performance of the solar panels have prompted a lot of R&D activities on achieving a high power output to input ratio from solar modules. The efficiency of PV panels was improved (Alzaabi et al., 2014) using Water Hybrid Photovoltaic Thermal system in which a solar thermal collector was affixed to the PV panels. The maximum recorded electrical efficiencies with and without cooling of the PV panels were 74.0 and 61.7%, respectively. These conversion efficiencies can be considered as the highest power efficiencies so far, as regards research done on solar energy in the UAE (Hachicha et al., 2015).

![Image](image.png)

**Fig 8:** The trend in the number of articles published on solar energy in the UAE since 2000 to date (extracted from Google scholar).

The first solar cell manufacturer in the UAE was Microsol International LL FZE, founded in 2003. It was the largest manufacturer in the Middle East (Mokri et al., 2013), produced monocrystalline and polycrystalline silicon solar cells (GreenEmirates, 2018). Another producer of solar PV cell in the UAE is SolarIn, a subsidiary of Warom Electric Middle East. With its head office based in Dubai, SolarIn is popularly known for the manufacture of monocrystalline silicon cells and modules. Other manufacturers are Hisem & Soxia and Eco FutureLab. Hisem & Soxia is a branch of a China-based solar manufacturing company (Hism, 2018) named Hisem New Energy Co., Ltd. Eco FutureLab FZE is a European R&D based company, with a facility in Dubai, to produce solar panel and systems (Eco FutureLab Fze, 2018). Their ThermalV technology makes it suitable for a solar panel to be designed for extreme hot climatic conditions, as the heat from the sun is also utilized instead of deteriorating the panel efficiency.

A new solar PV cell production company called Maysun Solar has been situated in the region’s leading free trade zone (example: Jebel Ali Free Zone). At its current rate of production, Maysun Solar manufactures about 5,000 solar cells per month (Ismail, 2018; Maysun Solar, 2018). Other solar energy solution providers are mainly in the business of solar system installation and integration, or in the supply chain management of solar panels. These include PTL SolarTM, Environmena, TSS4U Solid Solar Solutions, Enerwhere Sustainable Energy DMCC, Fairyland Solar Light LLC, SMA Solar Technology AG, ALSA and Solar Systems LLC (Mokri et al., 2013). From Table 3, it can be observed that no solar panel manufacturer within the UAE is situated at the largest Emirates, Abu Dhabi. This signifies that the market entry of solar panel manufacturers is still at infancy in the UAE.
Table 3: Solar cell manufacturers in the UAE.

<table>
<thead>
<tr>
<th>Companies</th>
<th>Location/head office in the UAE</th>
<th>Solar products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maysun Solar FZCO</td>
<td>Jebel Ali Free Zone, Jafza, Dubai</td>
<td>Monocrystalline and polycrystalline silicon cells</td>
</tr>
<tr>
<td>Microsol International LL FZE</td>
<td>Fujairah Free Zone, Fujairah</td>
<td>Monocrystalline and polycrystalline silicon cells</td>
</tr>
<tr>
<td>SolarIn</td>
<td>Single Business Tower, Dubai</td>
<td>Monocrystalline silicon cells</td>
</tr>
<tr>
<td>Hisem &amp; Soxiba</td>
<td>Dubai Silicon Oasis, Dubai</td>
<td>Monocrystalline and polycrystalline silicon cells</td>
</tr>
<tr>
<td>Eco FutureLab FZE</td>
<td>Dubai</td>
<td>Monocrystalline and polycrystalline silicon cells as well as hybrid solar system such as ThermalV</td>
</tr>
</tbody>
</table>

Currently, there are many solar energy projects have been carried out in UAE. Also, government financial support for solar energy related research. Solar energy projects including Dubai solar PV plants (Jamil et al., 2016; Mezher, 2016), Abu Dhabi solar PV plants, Abu Dhabi Masdar City, and Shams 1 CSP plant (Figure 9). Meanwhile, incentives are not currently available to individuals or industries for the use of solar power in the UAE (Das, 2014).

![Fig 9: The 100 MW Shams 1 CSP plant in UAE.](image)
Solar energy has many advantages over other renewable energy sources in UAE. There are few aspects of benefits including reclaimability of the despicable lands, relativity in technology advancement as compared to other sources, seemingly limitless potential in the country, variability in the end-use of captured solar energy, and daily average solar radiation exceeding 6 kWh/m² with high sky clearness index throughout the entire year (Munawwar and Ghedira, 2014). In the entire Gulf Cooperation Council region, solar energy is indigenously present and available for utilization. Thus, in recent time, over 90 % of installed renewable energy capacity (figure 10) is from solar energy (IRENA, 2018; Jacobson et al., 2017).

Solar energy can easily be used for off-grid electrification of rural settlement (Das, 2014) if compared to other renewable energies (Jacobson et al., 2017; Shinnar and Citro, 2007). Other renewable energy sources have some shortcomings which hindered their development, when compared to that of the solar energy in the UAE. For example, the wind resource of the UAE is less abundant, with average wind speed range of 3.5–4.5 m/s. This range is lower than the general requirement for a viable wind-based energy generation. Also, there are limited domestic sources of biomass energy although the waste-to-energy might offer a promising option. However, waste-to-energy needs the utilization of solid waste so as to meet handling requirements (Sgouridis et al., 2016). The use of seawater to irrigate biomass is still being demonstrated but this approach does not offer appreciable commercial opportunities for now. Due to the extreme aridity of the country, hydropower energy does not stand a brighter chance as a source of energy generation in the UAE. Meanwhile, the availability of mountainous coastline might support the pumping and storage of used seawater but at a very high cost of reservoir construction (Deane et al., 2010; Katsaparakakis et al., 2013). The exploitation of the geothermal energy of the UAE is not favored due to low/poor geothermal gradient potential. In addition, the alternative use of deep geological wells with saline aquifers or water from other sources to extract the heat is much more expensive than solar thermal technologies in the UAE (Sgouridis et al., 2016).

Solar energy can be used to produce hydrogen gas via electrolysis technique. It is a viable, safe and green energy source (Kazim, 2010). Besides hydrogen production, solar-powered desalination plants can be the mainstay of water generation in the UAE and other MENA countries in years to come. Likewise, the transportation sector of the UAE economy can be fully integrated with solar powered since Masdar City...
has already set a prototype by the implementation of electric vehicles fully powered by solar energy (Ali and Emziane, 2013; Mokri et al., 2013).

Solar energy should have been harnessed to a widely commercialized status within the UAE. There are several factors such as environmental hindrance, technological and financial impediments, and economic and socio-political constraints have limited the use of solar energy in the country. A common environmental challenge for both PV and CSP technologies in the UAE is the high humidity and temperature. The environmental factors lower the energy output of the cells. More importantly, dust particles are abundant in the country due to its aridity. Dust particles cover the surface of solar panels and cause an increase in the solar plant OPEX due to cleaning water cost (Jamil et al., 2016; Mokri et al., 2013). In the desert where there is a large land mass for solar systems, sand dunes exist, contrary to flat land area required to build CSP plants (Mezher et al., 2011). Therefore, more research and development activities must be carried out to improve the efficiency of the solar panel systems and CSP collectors under extreme climatic conditions.

Finned copper heat pipes have been used to improve solar panel efficiency (Hughes et al., 2011). Besides heat pipes, air, liquids, phase change materials and some thermoelectric devices have been employed in the cooling of the solar PV panels (Makki et al., 2015; Royne et al., 2015). Over the years, there have been great improvements in solar cell efficiency, development of new solar power systems and reduce production cost. However, more research activities should be carried out to make the technology highly competitive with fossil-based energy. Lack of energy storage capacity is also a barrier as highlighted by researcher. Socio-political hindrance such as lack of commercial skills, low awareness among rural settlers, and poor channel for utilization of laboratory findings are additional barriers. Since there is a high income rate, people do not really see the “need” for solar electricity production, therefore limiting the deployment of rooftop PV panels in residential buildings.

Households and smaller firms could not invest in large solar power rooftop systems due to the small population of the country. In addition, the fraction of nationals among the entire population is very low. Despite this, the development of a proper regulatory framework by the government can change the fate of solar energy (Das, 2014). Short-term plan (Al-Amir and Abu-Hijleh, 2013) includes financial incentives from the government, soft loans from local banks, tax deduction for custom on solar PV and CSP-related items. The medium- and long-term policies include deregulation of electricity production, implementation of feed-in tariffs, solar energy quota obligations, carbon tax-charge on the use of fossil fuels, and improvement in the accessibility of the grid to solar power plants. These plans can be broadly classified into two categories – regulations and financing. At the country level, there are no existing national regulatory, fiscal incentives or public financing policy yet. At the Emirates level (mainly Dubai and Abu Dhabi), there are already electric utility quota and heat obligation for solar energy with a proposition of net metering system and tendering to encourage the vast use of solar panel in the Emirates (Griffiths, 2017). There are public investments by the governments of the individual emirates - Abu Dhabi, Dubai, and Ras Al Khaimah - for solar electricity production (Tariq and Ibrahim, 2015).

Solar energy in Malaysia.

In Malaysia, we received enough sun irradiation (4000 to 5000 watt-hours per square meter per day) due to located near the equator area. Based on the Figure 11, we understand that some of the northern states (Kedah, Penang, Kelantan, Sabah) received the most amount of solar energy if compared to Johor and Sarawak. However, we faced some issues such as high costs, and lack of awareness. Nowadays, Malaysia is one of the world largest photovoltaic module producer. There are many local and international companies as indicated in Table 4. However, the current contribution from solar energy is very low (for electricity generation). One of the reasons was low efficiency. For example, solar panel made from mono-crystalline silicon, polycrystalline silicon, copper indium diselenide and amorphous silicon showed less than 10 % efficiency. Government has provided many incentives, funds and implemented several policies to promote solar energy. Government also expect that solar energy can contribute the largest shares in 2050 as shown in Table 5. Biomass, and hydropower have reached upper limit of 1340 MW and 490 MW, respectively.
Fig 11: Average daily solar radiation (watt-hours per square meter per day) (Mekhilefa et al., 2012).

Table 4: Photovoltaic manufacturing in Malaysia (Photovoltaics manufacturing in Malaysia, 2017)

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Location</th>
<th>Malaysia/foreign company</th>
</tr>
</thead>
<tbody>
<tr>
<td>First solar</td>
<td>Kulim</td>
<td>Foreign</td>
</tr>
<tr>
<td>JA Solar</td>
<td>Penang</td>
<td>Foreign</td>
</tr>
<tr>
<td>Jinko Solar</td>
<td>Penang</td>
<td>Foreign</td>
</tr>
<tr>
<td>Panasonic Energy</td>
<td>Kulim</td>
<td>Foreign</td>
</tr>
<tr>
<td>Malaysia Q-cell</td>
<td>Cyberjaya</td>
<td>Foreign</td>
</tr>
<tr>
<td>Malaysia SunEdison</td>
<td>Ipoh</td>
<td>Foreign</td>
</tr>
<tr>
<td>SunPower</td>
<td>Malacca</td>
<td>Foreign</td>
</tr>
<tr>
<td>LONGi Solar</td>
<td>Kuching</td>
<td>Foreign</td>
</tr>
<tr>
<td>TS Solartech</td>
<td>Penang</td>
<td>Malaysia</td>
</tr>
</tbody>
</table>

Table 5: Cumulative installed capacity (MW) (Waste management conference, 2011)

<table>
<thead>
<tr>
<th>Year</th>
<th>Biomass (MW)</th>
<th>Hydropower (MW)</th>
<th>Solar (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>110</td>
<td>60</td>
<td>9</td>
</tr>
<tr>
<td>2015</td>
<td>330</td>
<td>290</td>
<td>65</td>
</tr>
<tr>
<td>2020</td>
<td>800</td>
<td>490</td>
<td>190</td>
</tr>
<tr>
<td>2025</td>
<td>1190</td>
<td>490</td>
<td>455</td>
</tr>
<tr>
<td>2030</td>
<td>1340</td>
<td>490</td>
<td>1370</td>
</tr>
<tr>
<td>2035</td>
<td>1340</td>
<td>490</td>
<td>3700</td>
</tr>
<tr>
<td>2040</td>
<td>1340</td>
<td>490</td>
<td>7450</td>
</tr>
<tr>
<td>2045</td>
<td>1340</td>
<td>490</td>
<td>12450</td>
</tr>
<tr>
<td>2050</td>
<td>1340</td>
<td>490</td>
<td>18700</td>
</tr>
</tbody>
</table>

Conclusion

Recent research on solar energy in Nigeria has focused on solar resource measurement through modeling and simulation. From recent findings, the global solar irradiation in Nigeria is specific to the country’s geo-political zones. Households and smaller firms could not invest in large solar power rooftop systems due to the small population in UAE. The strategies to enhance the use of solar energy including...
deregulation of electricity production, implementation of feed-in tariffs, solar energy quota obligations, carbon tax-charge and improvement in the accessibility of the grid to solar power plants. In Malaysia, there are many international companies such as American company, Germany company were established in different states. As a result, Malaysia was one of the biggest manufacturer in the world (just behind China and European Union).

Acknowledgement

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Management.  


