INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
Soonmin H. et al., Vol.9, No.1,March 2019

Investigation of Solar Energy: The Case Study in Malaysia, Indonesia, Colombia and Nigeria

Ho Soonmin*‡, Abraham Lomi**, Edmund C Okoroigwe***, Leonardo Rodriguez Urrego****

*Centre for Green Chemistry and Applied Chemistry, INTI International University, Putra Nilai,71800, Negeri Sembilan, Malaysia.

**Department of Electrical Engineering, National Institute of Technology, Malang, INDONESIA

***Department of Mechanical Engineering, University of Nigeria Nsukka, Enugu State Nigeria.

****Faculty of engineering, Universidad EAN Bogotá, Colombia.

‡ Corresponding Author; Tel: +606-7982000, E-mail: soonmin.ho@newinti.edu.my

Received: 08.11.2018 Accepted:19.12.2019

Abstract- In the present scenario of world (a growing world population & developing countries), the increasing consumption of electricity controls the progress of different forms of energy (renewable or nonrenewable energy) use around the world. Fossil fuels are non-renewable sources, and accounted for 81 % of total energy demand in 2017. However, there are some disadvantages associated with their use such as environmental pollution, emissions of greenhouse gasses, and they are depleting at a faster rate. Therefore, researchers have to work hard in order to find an alternative (such as solar energy) way for fossil fuel to generate energy. A large number of investigations on the solar energy have been carried out by many researchers in order to improve the living conditions, to help reduce air pollution and to go green. The purpose of work is to explore the current status, challenges, recent efforts and future prospects of solar energy in different countries including Malaysia, Indonesia (Asia region), Nigeria (Africa region) and Colombia (South America).

Keywords Solar energy, solar radiation, renewable energy, energy, fossil fuel.

1. Introduction

Sun delivers interminable electromagnetic power (solar energy). Earth receives a fraction of what actually is formed in the Sun as it emits 38 x 10^7 EW energy and earth relieves 0.17 EW which is felicitous for life existence. In fact, the sustenance of life on earth is primarily dependent upon the appropriate temperature delivered by the Sun [1]. In terms of solar radiation, Sun possesses 60 MW/m^2 power whereas earth receives 1325 MW/m^2 to 1418 MW/m^2 power with a typical value of 1367 MW/m^2, also called solar constant [2]. It is reported that Australia receives the highest amount of solar radiation of 4–6 KWh/m^2 among all continents [3]. Electricity demand is envisaged to face a sharp rise of 1.5-3.0 times by 2050 [4] hence, making it inevitable to look for an everlasting resource of energy that must be environment-friendly at the same time. Solar energy offers the best possible solution in this regard [5]. Although we are utilizing the fraction of it, it is capable of fulfilling the world's energy demand to a large extent. As the growing monster of energy poverty is a serious threat predominantly in underdeveloped and developing countries [6]. The use of conventional biomass fuel is not only disturbing social and environmental factors but also causes premature deaths [7]. National renewable energy laboratory claims that the global energy demand can be fulfilled by efficiently utilizing the solar radiation received within 1 hour by earth [8]. However, high cost of associated equipment that harnesses solar energy, make it seem unfavorable, also other available renewable alternatives such as hydro [9-11], wind [12-14], biomass [15-17], geothermal [18, 19], and marine are much more cost-effective [20]. But solar energy possesses the greatest potential among all renewable resources and known as "mother renewable energy resource" due to free of cost non-stop universal availability, pollution free delivery and unlikely to be affected by any natural disaster [21]. Therefore, this prime reason provokes the impetus to huge investment in it globally. As a result, the drastic growth of 33 % is observed in the solar energy sector as compared with other energy sectors [22]. In fact, 7.5 GW of total solar energy was globally available in 2007, that rapidly increased to 402 GW mark in 2017 [23]. Furthermore, solar-based energy conversion efficiency of 26 % is observed in 2017 [24], whereas scientists are still trying to achieve more [25].

Solar energy exists in abundance all over the globe. In this work, the uses of solar energy in different countries such as Indonesia, Malaysia, Colombia and Nigeria were discussed. Current status, future prospects, funds, laws and issues will be highlighted.

2. Literature Survey

2.1. Solar energy in Indonesia

Indonesia is a tropical country in the equator, so the potential for solar energy is high enough with the average shine of 6-7 hours per day with an ideal duration of irradiation that can be utilized to generate electrical energy through solar panels for 5-6 hours per day. It is a country rich of natural resources with a primary energy source that can be managed and used to meet national energy needs, especially the needs of electrical energy to remote communities. But reliance on energy derived from fossil thinned provided opportunities to develop environmentally friendly energy sources (sources of energy derived from new and renewable energy sources). Based on ESDM data (2016), Indonesian geothermal reserves amounted to 17,546 MW and its potential of about 29.543 MW. Installed capacity of geothermal power plant (until 2018) is 1,438 MW. Electricity potency from large scale hydro power amounted at 75.091 GW, while the potential of mini/micro hydro was about 19,385 MW. The potential of wind energy is 60,647 MW, while the potential of electricity from bioenergy is about 32,653 MW.

Hydropower energy resource is grouped into large scale (can be developed for power plants above 10 MW per location) and small-scale/ micro (potential electricity generation less than 10 MW). The potential for large-scale hydropower and small-scale/micro was estimated about 75 GW and 450 MW, respectively. The potential is fairly spread in various parts of Indonesia. The use of hydropower resource is still relatively low at 4.2 GW of large-scale and small-scale of about 84 MW. Utilization of hydropower resources should be developed primarily with small-scale power spread schemes to meet local electricity needs [26].

Indonesia has a potential power from biomass of 49,810 MW is undeveloped and only 0.89 % have been commercially developed. Based on Presidential decree, it has target to install about 810 MW in 2025, an increase of 74 percent, a very small potential contribution. Table 1 shows the potential and installed capacity of renewable energy resources.

The goverment has committed to develop and build new power plant from the renewable energy sources of and the target energy mix with 23 percent of renewable energy in 2025 since the electricity demand rising with increasing population. Based on Figure 1, the potential of solar power is quite high in Indonesia (as a tropical country) with an intensity of 4.8 kWh/m^2/day and current installed capacity of solar power plant is 224.5 MW (in the end of 2017), 6,500 MW (in 2025), and 45,000 (in 2050 or 21.65 percent of the total potential energy). Indonesia offers significant solar power resources, but the country has yet to develop a strong market. The use of solar energy in Indonesia is still very low due to the cost of equipment (solar panels) is still expensive. With the growing market demand for solar panels in the world, estimated future prices of solar panels will tend to fall. Therefore, solar energy utilization in Indonesia should be developed including the possible use of the integrated scheme with grid.

The largest power plants are located in Bali (2 MW), Kupang (5 MW) and Gorontalo (2 MW). There was over 700 MW in memoranda of understanding as well as commitments by PLN (State Electricity Company-is an Indonesian government owned corporation) to develop utility-scale solar PV systems in Indonesia by the middle of 2016. The government has been committed to construct the power plant [27] from renewable energy sources to increase installed capacity of renewable energy mix up to 23 % in 2025. The estimated potential for different regions is partially a result of these differences in resource across the country, but is mainly an outcome of differences in the availability of land and rooftops. Solar photovoltaic (PV) is expected to be used [28, 29] on a significant scale by 2030 in three ways: in utility-scale plants, on residential and commercial rooftops, and in off-grid settings for electrification in remote areas or to displace costly diesel-powered generation.

The off-grid potential for solar PV has been estimated about at 2.1 GW (Maluku), about 0.95 GW (Papua), about 0.42 GW (Sulawesi & Nusa Tenggara) by Ministry of Energy and Mineral Resources (MEMR). In the General Planning of National Energy (RUEN) 2015-2050, it is assumed that this potential will have been fully exploited of about 14.4 GW in 2030 and 45 GW in 2050 through active efforts by the government and PLN to provide electricity to 1.1 million households currently not electrified. With an overall target of 6.4 GW of solar PV installed by 2025. The market continues to grow until 2030 to reach 9.3 GW of installed capacity (2.1 GW related to the off-grid solar segment, and 7.2 GW is allocated to grid-tied solar PV [30]). As the theoretical potential for solar PV exceeds 500 GW, this implies that less than 1 % of this will be captured by 2030, despite abundant potential across the different regions of Indonesia. This might limit the potential for renewables and in particular solar PV (without any storage), because of the mismatch between the peak in demand and the time of day when solar PV produces at its peak. However, the anticipated quickly increasing demand for cooling in buildings (from 29 % of electricity consumption in 2014 to 35 % in 2030) is likely to flatten electricity demand, increasing the opportunity for solar PV to match electricity demand in buildings [31].

Table 1. The potential and installed capacity of renewable energy sources [27]

No.	Type of Energy	Potential (MW)	Installed Capacity (MW)	Utilization (%)
1	Geothermal	29,544	1,438.5	4.9
2	Hydro	75,091	4,826.7	6.4
3	Mini & Microhydro	19,385	197.4	1.0
4	Bioenergy	32,654	1,671	5.1
5	Solar Energy	207,898	78.5	0.04
6	Wind Energy	60,647	3.1	0.01
7	Ocean Energy	17,989	0.3	0.002
Total		443,208	8,215.5	1.9

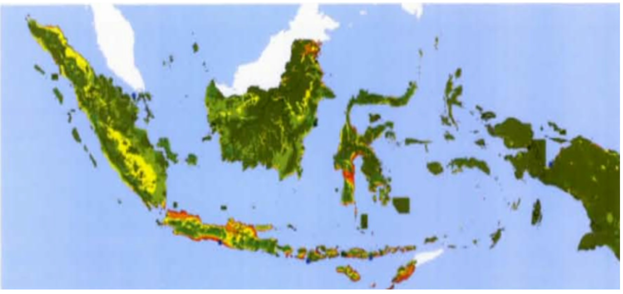

Fig. 1. The area of solar energy potential in Indonesia.

Solar Energy in Nigeria

Even though Nigeria is an oil and gas producing nation, renewable energy is contributing to her national energy mix especially in the use of hydropower for electricity generation while other renewables such as solar PV and biomass are being explored. Owing to her large land area of about 923,768 km^2 and her relative position to the Equator, adequate amount of solar energy can be generated to make substantial impact on the national energy statistics although it is currently utilized by small groups for electricity and heating purposes.

According to our recent study [32], the northern states of Nigeria have direct normal irradiance (DNI) ranging from 6 to 7.5 kWh/m^2/day which is higher than the recommended threshold value required for concentrating solar power technologies. However, from the coastal region to the northern region, about 3.4 to 7 kWh/m^2/day is intercepted on the average [33]. Similarly, quantified the amount of solar radiation incident upon the surface of Nigeria to vary between 12.6 MJ/m^2/day in the coastal zones and 25.2 MJ/m^2/day in the northernmost areas [34].

As a result of this high solar resource potential, solar energy exploitation forms part of the national energy policy (NEP) of Nigeria. Specifically, the solar energy policy in the NEP states that *"The nation shall aggressively pursue the integration of solar energy into the nation's energy mix, which should be based on the established potentials and available technologies nationwide.*" The standing policy has been a major motivation for scholars, government agencies and investors to embark on research, pilot projects and investment respectively in order to realize the set goals of the working document. Hence, it is imperative to review the roles played by the aforementioned groups in the harnessing of the abundant natural resource.

Studies on the development and utilization of solar energy in Nigeria, dating back to 1980s when the establishment of Centres for Energy Research at University of Nigeria, Nsukka (in southeast) and Usmanu Danfodiyo University, Sokoto (northwest). Following that, more centres have been established in many other universities across the country with specific mandates on energy research to cover the entire country. The fundamental studies have covered the estimation of solar radiation over major cities and the entire country. Detailed analysis of those studies will be too much to compile in this study. Researchers have successfully [35] developed a pyranometer, (using local materials due to the high cost of the imported devices) to estimate the solar radiation. It was observed that the device was able to measure up to 359W/m^2 on a bright day. With a multiplying factor of 2.08 to the systems reading, the actual value solar radiation value would be obtained. Aidan and co-workers modelled the relationship between the unavailable solar radiation and the meteorological parameters such as relative sunshine duration, cloud cover and relative humidity over seven states in the northern Nigeria [36]. This is in the bid to understand better the available solar radiation for solar devices design in the area. The findings of the study conclude that unavailable radiation is a good dependent variable for parameterization of the solar radiation. Similarly, Hussaini and co-workers studied the correlation between the solar radiation and meteorological parameters in Maiduguri, Nigeria by using a 33-year data evaluated with standard solar radiation estimation equations [37]. It was observed that the Angstrom coefficient obtained in the study suggests that there should be caution in using predicted values obtained from other computations. In other words, solar radiation values obtained from mere predictive methods might not be the best values compared to actual measurements. Meanwhile, Sanusi and Aliyu developed a new model that correlates global solar radiation with maximum temperature in order to effectively predict the solar radiation of the city [38]. The statistical results show that the temperature dependent model was able to predict correctly the solar radiation of the city of Sokoto Nigeria.

Recently, Okoye and co-workers evaluated the solar resource potential on an inclined plane of some selected cities based on single and double tracking mechanisms [39]. The nine cities were selected on population basis although the very southern (coastal) states were not included. The results obtained showed that the annual solar resource potential for the locations ranged from 1621 to 2279 kWh/m^2 when on a fixed inclined surface without trackers while a yield of 1664 to 2983 kWh/m^2 using solar trackers is obtainable. In addition, global solar radiation across the entire country have been undertaken. Especially, the study of Fagbenle for solar radiation across Nigeria [40], using meteorological data from Nigeria Meteorological Agency shows positive relationship between city latitude and solar radiation increase regardless the zone [41]. This confirms the studies showing increase in daily solar radiation from the coastal region to the northern region of the country. The study also shows the least total solar radiation intensity is witnessed in the month of August. Even though there are so many studies on assessment of solar radiation potential of the country, Ozoegwu found the need to standardize the several models already developed by indigenous researchers on solar radiation estimation which come with varying accuracy [42]. Hence the study carried out a comprehensive review of avalanche of solar radiation models, re-calibration and comparative testing of some of the models using data for Enugu metropolis sourced from the Nigerian Meteorological Agency. The study observed that Nigerian solar assessment study is affected by very narrow application of artificial intelligence and time-series approaches and suggests that future assessment of the Nigerian solar energy should depend on not only stochastic regression but also artificial intelligence techniques for better results. This decision is helpful in policy making, equipment sizing and installation, solar energy planning as well as in energy education.

In addition to solar radiation studies, research has included the growth and characterization of various thin film materials on glass substrates with a view to developing the manufacturing of thin film solar cells, panels and modules in Nigeria. For instance, Ottih and Ekpunobi used chemical bath method to deposit cadmium nickel sulphide on glass and studied the effect of varying deposition time on optical and its electrical properties [43]. Ezenwa and Okereke studied the optical characteristics of cadmium sulphide, copper sulphide and cadmium sulphide/copper sulphide thin films produced by chemical bath deposition methods [44]. Offia and co-workers deposited and characterized copper selenide thin film whose spectral analysis after heat treatment shows that the heat treatment process increased its crystalline properties [45]. The thin film possesses the quality for use as thin film PV cell material. The results of these and many others of such methods show that the thin films possess good optical and electrical properties that can be adopted for production of solar cells and photovoltaic panels which imply that there is hope for manufacture/production of solar cells in Nigeria.

The experimental findings of various researches carried out over the years have resulted to some pilot and demonstration projects across the country. Solar energy is usually utilized in the form of solar thermal devices for generating thermal energy transferred to the desired system. They comprise solar cookers, solar driers, solar stills (for desalination of water), solar water heaters, solar water pumping, solar incubators and chicken brooders (Trombe wall systems). Dasin and co-workers investigated locally designed solar food dryer with heat storage system and observed great performance over traditional sun drying within the same environment and solar radiation intensity [46]. Okoroigwe, Eke & Ugwu [47] and Okoroigwe Ndu & Okoroigwe [48] designed, constructed and tested hybrid solar-biomass dryer capable of 24-hour operation for grain and agro materials processing. They proposed a method of improving the efficiency of dryer. The obtained efficiency values are higher than those of the initial construction. The results showed that efficiency based on solar, biomass and solar-biomass heating in drying of fresh okra, fresh groundnut and fresh cassava chips increased from 5.19–16.04 %, 0.23–3.34 % and 1.636–8.96 %, respectively. Similarly, Itodo and co-workers [49] have focused their works on the active solar dryer. Finally, they claim that produced dryer exhibited drying efficiency of 29 %, which is remarkably higher than the initial construction.

At National Centre for Energy Research, University of Nigeria, Nsukka solar chicken brooding systems of varying capacities have been developed, built and operated with appreciable efficiency close to 97 % and reduced mortality of about 1-3 %. Solar powered chicken brooders of capacity of 50, 100, 200, 2000 chicks and above have been developed by Okonkwo at University of Nigeria and are being operated today [50]. Prototypes of 100 chick capacity were disseminated to Poultry farmers in Nigeria under the UNESCO's University Industry Science Partnership programme in 2000 while a solar trombe wall chicken brooder of 2000 birds capacity is operating at Igbeli Poultry Farms Ltd, Eziani Nsukka, which is built by the National Centre for Energy Research, University of Nigeria.

A more common solar energy application in Nigeria, is in electricity generation although not yet contributing to the national grid system. Photovoltaic systems have been installed at micro levels for domestic and research purposes. Across the country there are several pilot PV power plants for household electrify, community light projects (off grid), street light system (ranging from 0.1 to 10 kW). At the dawn of the century, many individuals and corporate bodies were not aware of the benefits of solar PV while those who understood were discouraged due to the high cost of the accessories. Nowadays, through years of awareness creation and information dissemination, the technology is penetrating all facets of the society. Owing to the unreliable electricity supply from thermal plant operated grid system in Nigeria, many people are installing PV systems in their homes while government is supplementing street light projects with solar powered systems. There is strong advocacy for solar energy application in agricultural mechanization such as water pumping systems for irrigation in the arid northern states. Large commercial farms integrate solar energy in their farm operations.

Nigeria remains a big market for solar energy technologies on the basis of her teaming population and persistent thermal electricity failures. Even though poverty is inherent among the low income class (which constitutes greater portion of the population), the middle and upper income earners can afford to install solar energy such as the PV systems. Of all the renewable energy options, solar devices (especially solar powered photovoltaic panel) appear to have proven commercializable technology which makes it more preferable. As more awareness is being created and issues surrounding conventional power generation from fossil fuels persist the future of solar energy application in daily livelihood of Nigerians is very bright. Government through enabling solar energy policies encourages installation of carbon neutral electricity generation technologies. The government should as a matter of urgency incentivize solar energy technologies by removal of taxes on importation of solar technologies while it encourages investors on this by enhanced feed in tariff. As long as the nation's economy depends on oil and gas, her electricity and thermal energy will continue to depend on fossil fuel and this will continue to be a major challenge to full utilization of solar energy for electricity generation even though there are plans to generate part of her future electricity through massive solar installation.

2.2. Solar energy in Colombia

In South America, solar energy moves drastically (although the main energy vector of the entire region is hydro) and country such as Chile is "betting on" solar energy. For the year 2017 Chile had an installed capacity of approximately 2,183 MW, which is 20 % of the installed capacity in renewable energy. Other countries such as Uruguay, Bolivia and Brazil have 239, 13 and 1097 MW, equivalent to 6, 2 and 1 % of the installed capacity in renewable energy, respectively. The case of Colombia is different because of the entry of the new Law 1715 renewable energy has begun to awaken from the lethargy of generation with another type of renewable energy other than hydro [51] since. However, it is important to put in context the conditions and characteristics of the country before explain of the Law and of the Colombian progress in the subject of renewable energies and especially photovoltaic.

Colombia is in the northwestern region of South America on the equatorial axis, currently has 49,833,209 residents in 32 decentralized departments and its capital is Bogotá D.C. At the energy level, it is divided into two zones: i) Interconnected Zones, which have access to electric power service through the National Interconnected System (SIN). ii) Non-interconnected Zones (ZNI), identified according to Article 1 of the Law 855 of 2003, as municipalities, localities and hamlets not connected to the SIN [52]. The Non-Interconnected Zones are areas that supply the energy through diesel generation plants mostly, solar panels and small hydroelectric plants, thus evidencing a lag of the national electricity infrastructure and a single alternative to renewable energies.

Colombia, because it is located on the equatorial axis, has privileged climatic characteristics such as temperatures are constant throughout the year. For this reason, the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) developed a schematic reference document detailing the solar radiation in the soil in different regions of the country. The potential of solar energy in Colombia is 4.5 kWh/m^2/ day and the surface with an optimal solar resource is the Peninsula of La Guajira, with 6kWh/m^2/ day of radiation, surpassing the world average of 3.9 kWh/m^2/day. At there is an interactive map of radiation indices in Colombia [53]. These magnificent and environmental conditions and the phenomena "El Niño" and "La Niña" associated with large changes in precipitation throughout the national territory prompted the development of Law 1715 [54].

Colombia has the third largest installed hydropower capacity in south America, at about 11725 MW (makes up 69.64 %) in 2017. Meanwhile, a total of 9.8 MW of photovoltaic (or 0.06 %) was installed as shown in Figure 2 [55]. Solar energy has started to penetrate in the populations with basic deficiencies in the service and that are not connected to improve their quality of life. It is due to their location in areas of difficult access, low capital development, deficits in infrastructure. The Law was signed and its regulation has been completed in 2018, most major projects (greater than 300 kW) were completed before 2017 as isolated installations with batteries [56]. This shows that the zones with settlements, are characterized by vulnerability conditions are one of the best options for this type of technology, especially for the price of generation. Characteristics such as difficult access, problems of public order and transport logistics mean that the price from diesel is between 0.4 to 0.53 US $/kWh. It is a very attractive price for potential foreign investors [57, 58].

The implementation of photovoltaic systems in Colombia has allowed 2 % of the population of the areas that do not have access to electricity to meet their lighting, cooling and leisure needs, allowing them to expand their capacities and improve their quality of life. The systems installed have focused mainly on the rural sector. One of the most important projects isolated to the electric grid and with batteries storage was carried out in the Department of La Guajira, where one of the most important indigenous communities of the country is located (Wayúu community [59, 60]). Even with this panorama of positive development from the social and productive contexts in isolated regions, different barriers were presented for the evolution of alternative generation technologies. Therefore, it is necessary to formulate programs to develop renewable energy sources that seek to diversify the national energy market and laws that expand the energy matrix and allow the implementation of self-consumption, distributed and hybrid systems [61]. Thus, the new Law was born, regulated by seven governmental entities in Colombia that would give way to new challenges in electricity generation from alternative and renewable energy sources. This allowed the transition to pre-feasibility and feasibility analysis for new projects in urban areas for self-generation from photovoltaic or other clean generation technologies such as wind power [62].

Colombia, due to its aforementioned location, has constant solar radiation in certain areas of the territory, obtaining some of the highest rates worldwide registered along with those of Africa. Currently, in the Colombian national territory the installation of photovoltaic infrastructure corresponds to the 9.8 MW officially registered and some 5.28 MW informal represented in small projects (about 20,000 solar panels). These projects are distributed by 46 % in the ZNI and 54 % in the SIN. However, recently the largest project currently connected to the electric grid with an installed capacity of 9.8 MW and generating about 16.5 GWh per year was inaugurated in September 2017 (Colombian power company Celsia in Jumbo, Department of Valle del Cauca).

Regarding the projects installed in the SIN (Figure 3), only 15 out of 32 departments at the national level have participated with photovoltaic energy projects. The departments such as Atlántico, Cundinamarca, Valle del Cauca and Antioquia are the departments with the largest projects in photovoltaic systems for power generation. Cundinamarca (Bogotá D.C.) participates with a total of 865 kWp of installed capacity, with a total of 9050 solar panels installed in different types of infrastructure from recreational companies, to educational industry.

In rural territory and specifically in ZNI, the projects are currently more profitable. However, from a logistical and sustainable point of view, they have had many problems since, as previously mentioned, they are found in indigenous communities or in places with very difficult access. In the last decade, 23 departments have had a total photovoltaic development of 2.25 MWp in ZNI. Figure 4, shows that 18 % of the projects executed correspond to solar fields greater than 100kWp, and 77 % to projects smaller than 50 kWp. ZNI projects with installed capacities greater than 100kWp are located in the departments of Cundinamarca, Amazonas, Guajira, Amazonas and Arauca.

Because the new Law is so important in the future of facilities in Colombia, it is important to know about the entities that regulate it and the benefits of it. In terms of regulation, Colombia currently has few leading entities that influence the use of renewable energies in an efficient manner such as (i) Ministry of Mines and Energy (MME), (ii) The Mining and Energy Planning Unit (UPME), (iii) Energy and Gas Regulation Commission (CREG), (iv) Institution for Planning and Promotion of Energy Solutions for Non-Interconnected Zones (IPSE), (v) Inter-Sectoral Commission for the Rational and Efficient use of energy and non-conventional energy sources (CIURE). Likewise, there are two specialized funds for the support of renewable energy projects in Colombia that are: Financial Support Fund for Energization the Non-Interconnected Zones (FAZNI), and National Royalties Fund (FNR). This Law is formalized to regulate the integration of renewable energies in the national energy system, especially for non-interconnected areas (ZNI). Likewise, to promote the use of non-conventional sources of energy (FNCE) and non-conventional sources of renewable energy (FNCER) in the country through reductions in the income statement (Article 11), tax incentives on technology and residential, commercial and large-scale projects (Article 12), tariff incentives (Article 13) or through accelerated depreciation in machinery, equipment and civil works (Article 14).

The above has allowed the entry of new companies mostly foreign and multinationals that have begun to invest in photovoltaic solar technology projects to generate and sell to the electricity grid. In addition, some self-generation projects for smaller companies as well. This is demonstrated by the large number of projects submitted to the UPME to be approved by Law 1715 and can obtain all the benefits mentioned above. As of May 2018, 2619.5 MW was registered in Phase I and 1398 MW in Phase II for 353 registered photovoltaic projects. Phase I, II and III are classified as pre-feasibility, feasibility projects and projects with definitive designs & schedule, respectively [63]. Among the 353 projects presented, there are 72 projects are solar farms (above 90 MW of installed capacity). The foregoing demonstrates that the great energy future in Colombia based on renewable energies and specifically solar energy. All these projects will be completely done by the year 2025.

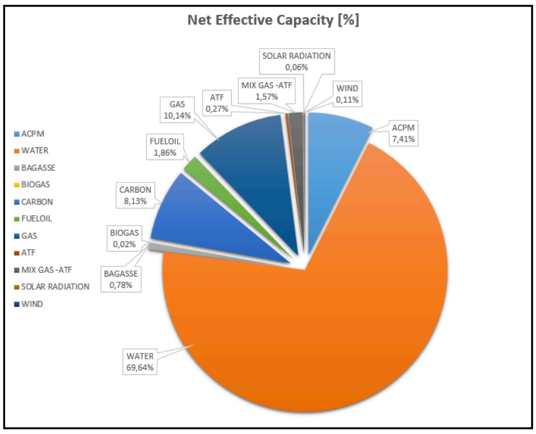

Fig.2. Installed capacity by technology/resource % [44]

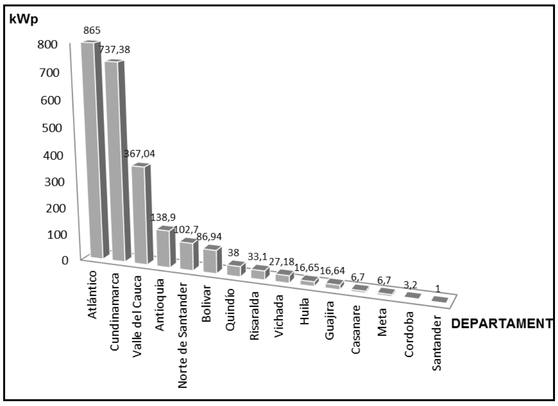

Fig.3. Installed capacity-kWp (SIN) [56]

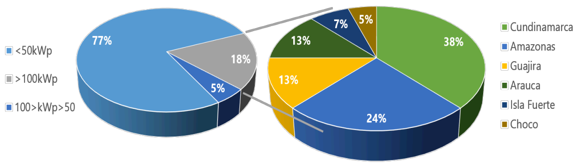

Fig 4. ZNI installed capacity

2.3. Solar energy in Malaysia

Malaysia has a promising potential to establish solar power plant due to is located at equatorial zone [64], received great average daily solar radiation (4500 kWh/m^2) and abundant sunshine for about 10 hours per day. Table 2 shows that the highest solar radiation of 1900 kWh/m^2 in Kota Kinabalu, then, followed by Bayan Lepas (1809 kWh/m^2) and Georgetown (1785 kWh/m^2) in different cities in Malaysia [65]. However, solar energy seems so unpopular because of high cost of installation and solar electricity tariff rate. Therefore, the government has introduced different incentives [66], policies [67], funds [68], investments [69] and strategies (as highlighted under 9th and 10th Malaysia Plan) to encourage the growth of the solar energy. Table 3 shows the solar energy capacity in Malaysia from 2008 to 2017 [70]. The solar energy capacity was increased from nine to 362 megawatss in 2017. Malaysian has shown positive behavior towards the government efforts on promoting solar technology [71, 72, 73]. There are many government agencies [74, 75, 76] such as Petronas, Tenaga Nasional Bhd, sustainable energy development authority Malaysia (SEDA) and Malaysia Energy Centre (PTM) play a very important role in setting the importance in the nation's energy development. In future, Tenaga Nasional Bhd will build the biggest solar plant on 98 ha site in Malaysia.

Table 2. Annual solar radiations in different cities in Malaysia [65]

Region /cities	Annual average value (kWh/m^2)
Kuching	1470
Bangi	1487
Kuala Lumpur	1571
Petaling Jaya	1571
Seremban	1572
Kuantan	1601
Johor Bahru	1625
Senai	1629
Kota Bahru	1705
Ipoh	1739
Taiping	1768
Georgetown	1785
Bayan Lepas	1809
Kota Kinabalu	1900

Table 3. Solar energy capacity in Malaysia from 2008 to 2017

Year	Megawatts
2008	9
2009	11
2010	13
2011	14
2012	32
2013	138
2014	203
2015	263
2016	340
2017	362

3. Conclusion

Indonesia, Malaysia and Colombia all lie along the equator, so the potential for solar energy is high enough with the average shine of 6-7 hours per day. Therefore, government has committed to build solar power plant for a variety of applications. We must understand that cannot continue relying on fossil fuels in future since the demand of eletricity becomes increased as well as the economic and population growth. In Nigeria, photovoltaic systems have been installed at micro levels for domestic and research purposes including for household electrify, community light projects & street light system.

Acknowledgements

This research work was supported by INTI International University (HO SM).

References

[1] Y.A. Cengel, and M.A. Boles, Thermodynamics: An engineering approach, 8th ed., McGraw-Hill Education: New York, 2014.

[2] F.S. Johnson, "The solar constant", Journal of Meteorology, vol. 11, pp. 431-439, 1954.

[3] ARE (2016) Australian Renewable Energy. Integrated solar radiation data sources over Australia Final report: project results and lessons learnt.

[4] D. Ibrahim, and Z. Calin, Sustainable energy systems and applications, 1st ed, Springer: Berlin, 2012.

[5] A. Shahsavari, and M. Akbari, "Potential of solar energy in developing countries for reducing energy related emissions," Renewable and Sustainable Energy Reviews, vol. 90, pp. 2750-291, 2018.

[6] IEA (2016) The international energy agency. Energy and Air Pollution. 2016.

[7] WHO (2016). Ambient (outdoor) air quality and health. http://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health.

[8] NREL (2017) Solar energy basic. https://www.nrel.gov/workingwithus/re-solar.html.

[9] M.B. Sebastian, and B. Michael, "Trading of pumped storage hydropower plants on energy only and ancillary services markets", 2015 International Conference on Renewable Energy Research and Applications (ICRERA), pp. 649-653, 2015.

[10] K. Tunc, "Hydropower plants tailwater energy production and optimization", 2015 International Conference on Renewable Energy Research and Applications (ICRERA), pp. 181-183, 2015.

[11] D. Murat, I. Kosalay, G. Dogan, and S. Cem, "Validation of hydroelectric power plant model for speed governor development studies", 2015 International Conference on Renewable Energy Research and Applications (ICRERA), pp. 278-282, 2015.

[12] M.R. Ali, and M.M. Jasim, "Performance of wind turbines at three sites in Iraq", International Journal of Renewable Energy Research, vol. 8, pp. 1327-1338, 2018.

[13] C. Zheng, Z. Xiao, Y. Peng, C. Li, and Z. Du, "Rezoning global offshore wind energy resources", Renewable Energy, vol. 129, pp. 1-11, 2018.

[14] C. Jung, and D. Schindler, "On the inter annual variability of wind energy generation-a case study from Germany", Applied Energy, vol. 230, pp. 845-854, 2018.

[15] G. Mao, N. Huang, L. Chen, and H. Wang, "Research on biomass energy and environment from the past to the future: a bibliometric analysis", Science of The Total Environment, vol. 635, pp. 1081-1090, 2018.

[16] H. Liu, and G. Lv, "Biomass energy flow between species and species survival in fragmented landscapes", Ecological Complexity, vol. 37, pp. 1-10, 2018.

[17] C. Vadenbo, D. Tonini, V. Burg, T.F. Astrup, O. Thees, and S. Hellweg, "Environmental optimization of biomass use for energy under alternative future energy scenarios for Switzerland", Biomass and Bioenergy, vol. 119, pp. 462-472, 2018.

[18] S. Taichiro, S. Yu, and K. Hiroaki, "Exchangeable batteries for micro EVs and renewable energy", 2017 IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA), pp. 701-705, 2017.

[19] A. Harrouz, A. Meriem, I. Colak, and K. Korhan, "Smart grid and renewable energy in Algeria", 2017 IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA), pp. 1166-1171, 2017.

[20] I. Dincer, and M.F. Ezzat, Solar Energy Production, In I. Dincer (1st Ed) comprehensive energy systems, Oxford: Elsevier, 2018, pp. 208-251.

[21] C.G. Ozoegwu, "The solar energy assessment methods for Nigeria. The current status, the future directions and a neutral time series method," Renewable and Sustainable Energy Reviews, vol. 92, pp. 146-159, 2018.

[22] Bloomberg. (2017). Solar is the fastest growing energy, says top fossil fuel major. https://www.bloomberg.com/news/articles/2016-06-08/solar-is-the-fastest-growing-energy-says-top-fossil-fuel-major.

[23] REN 21 (2018) Renewables 2018 global status report. http://www.ren21.net/gsr-2018/pages/summary/summary/.

[24] Y. Kunta, K. Hayato, Y. Wataru, T. Irie, K. Konishi, K. Nakano, and Y. Kenji, "Silicon heterojunction solar cell with interdigitated back contacts for a photoconversion efficiency over 26 %", Nature Energy, 2, 17032, 2017.

[25] MIT (2017) The biggest clean energy advances in 2016. MIT Technology Review. https://www.technologyreview.com/s/603275/the-biggest-clean-energy-advances-in-2016/.

[26] L. Abraham, The Role of Renewable Energy: Sumba Iconic Island, an Implementation of 100 Percent Renewable Energy by 2020, Lecture notes in Electrical Engineering, Springer, Vol. 365, 2015.

[27] S.F. Kennedy, “Indonesia’s energy transition and its contradictions: emerging geographies of energy and finance”, Energy Research & Social Science, Vol. 41, p. 230-237, 2018.

[28] M.I.A. Irsyad, A. Halog, and R. Nepal, “Estimating the impacts of financing support policies towards photovoltaic market in Indonesia: a social energy economy environment model simulation”, Journal of Environmental Management, Vol. 230, p. 464-473, 2019.

[29] A.M. Fathoni, N.A. Utama, and M.A. Kristianto, “A technical and economic potential of solar energy application with feed in tariff policy in Indonesia”, Procedia Environmental Sciences, Vol. 20, p. 89-96, 2014.

[30] A.J. Veldhuis, and A. Reinders, “Reviewing the potential and cost-effectiveness of grid-connected solar PV in Indonesia on a provincial level”, Renewable and Sustainable Energy Reviews, vol. 27, pp. 315–324, 2013.

[31] IRENA. Renewable Energy Prospect Indonesia, March, 2017.

[32] O. Ogunmodimu, and E.C. Okoroigwe, “Concentrating solar power technologies for solar thermal grid electricity in Nigeria: A review”, Renewable and Sustainable Energy Reviews, vol. 90, pp.104–119, 2018.

[33] O.S. Ohunakin, M.S. Adaramola, O.M. Oyeola, and R.O. Fagbenle, “Solar energy applications and development in Nigeria: Drivers and barriers”, Renewable Sustainable Energy Review, vol. 32, pp. 294 – 301, 2014.

[34] A. Giwa, A. Alabi, A. Yusuf, and T. Olukan, “A comprehensive review on biomass and solar energy for sustainable energy generation in Nigeria”, Renewable and Sustainable Energy Reviews, vol. 69, pp. 620–641, 2017.

[35] C.I. Ezekwe, and C.O. Ezeilo, “Measured solar radiation in a Nigerian environment compared with predicted data”, Solar Energy, vol. 26, pp. 181-186, 1981.

[36] J. Aidan, A. Yadima, and J.C. Ododo, “Modelling of unavailable solar radiation using some climatological parameters”, Nigerian Journal Solar Energy, vol. 15, pp. 118 – 126, 2005.

[37] A.M. Hussaini, M. Maina, E. Onyewuenyi, and J.C. Ododo, “Correlation of solar radiation with some meteorological parameter for Maiduguri, Borno State, Nigeria”, Nigerian Journal Solar Energy, vol. 15, p. 199 – 212, 2005.

[38] Y.A. Sanusi, and M. Aliyu, “Estimation of mean monthly global solar radiation in Sokoto and its environs using maximum temperature data”, Nigerian Journal of Solar Energy, vol. 15, pp. 193 – 198, 2005.

[39] C.O. Okoye, A. Bahrami, and U. Atikol, “Evaluating the solar resource potential on different tracking surfaces in Nigeria”, Renewable and Sustainable Energy Reviews, vol. 81, pp. 1569–1581, 2018.

[40] R.L. Fagbenle, “Estimation of total solar radiation in Nigeria using meteorological data”, Nigerian Journal of Renewable Energy, vol. 1, pp. 1–10, 1990.

[41] A.S. Aliyu, J.O. Dada, and I.K. Adam, “Current status and future prospects of renewable energy in Nigeria”, Renewable and Sustainable Energy Reviews, vol. 48, pp. 336–346, 2015.

[42] C.G. Ozoegwu, “The solar energy assessment methods for Nigeria: The current status, the future directions and a neural time series method”, Renewable and Sustainable Energy Reviews, vol. 92, pp. 146–159, 2018.

[43] I.E. Ottih, and A.J. Ekpunobi, “Chemical bath deposited CdNiS anti-reflection films”, Nigerian Journal of Solar Energy, vol. 23, pp. 115–119, 2012.

[44] I.A. Ezenwa, and N.A. Okereke, “Optical properties of Cadmium sulphide (CDS), Copper sulphide and CdS/CuS Thin Films and their application in photovoltaic technology”, Nigerian Journal of Solar Energy, vol. 22, pp. 61–65, 2011.

[45] S.U. Offia, S.C. Ezugwu, F.I. Ezema, and O.U. Oparaku, “Spectral Analysis of Chemical Bath Deposited Copper Selenide Thin Films”, Nigerian Journal of Solar Energy, vol. 22, pp. 97–104, 2011.

[46] D.Y. Dasin, N.Y. Godi, and O.C. Kingsley, “Experimental investigations of the performance of passive solar food dryer tested in Yola – Nigeria”, International Journal of Energy Engineering, vol. 5, pp. 9–15, 2015. doi: 10.5923/j.ijee.20150501.03.

[47] E.C. Okoroigwe, M. Eke, and H.U. Ugwu, “Design and evaluation of combined solar and biomass dryer for small and medium enterprises for developing countries”, International Journal of Physical Sciences, vol. 8, pp. 1341 – 1349, 2013.

[48] E.C. Okoroigwe, E. Ndu, and F.C. Okoroigwe, “Comparative evaluation of the performance of an improved solar-biomass hybrid dryer”, Journal of Energy in Southern Africa, vol. 26, pp. 38 – 51, 2015.

[49] I.N. Itodo, A.M. Adewole, and S.K. Edamaku, “Development of an active solar crop dryer - Design analysis and performance evaluation”, Journal of Food Science and Technology –Mysore, vol. 41, pp. 37–42, 2004.

[50] W.I. Okonkwo, “Renewable Energy application an alternative towards sustainable poultry production. Proceedings of the International Conference of the Faculty of Engineering, University of Nigeria, Nsukka. UBA Hall of Fame, University of Nigeria, Nsukka, 25 – 28 April, 2018. Pp. L36 – L45.

[51] G. Tomas, and R. David, “Assessing the obstacles to the participation of renewable energy sources in the electricity market of Colombia,” Renewable and Sustainable Energy Reviews, Vol. 90, pp. 131-141, 2018.

[52] M. Ana, and V. Kafarov, “Barriers to social acceptance of renewable energy systems in Colombia,” Current Opinion in Chemical Engineering, Vol. 10, pp. 103-110, 2015.

[53] H. Andres, S. Andres, and R. Carlos, “Optimal power dispatch of small scale Standalone microgrid

located in Colombian Territory", Energies, Vol. 11, DOI: https://doi.org/10.3390/en11071877.

[54] M. Jimenez, J.F. Carlos, D. Isaac, "Diffusion of renewable energy technologies: the need for policy in Colombia", Energy, vol. 111, pp. 818-829, 2016.

[55] Ministry of Mines and Energy (2017). Energy market in Colombia 2017. Variables of electric generation, Bogota. http://www.siel.gov.co/portals/0/generacion/2017/Informe_de_variables_Dic_2017.pdf.

[56] D. Rodriguez-Urrego, and L. Rodriguez-Urrego, "Photovoltaic energy in Colombia: current status, inventory, policies and future prospects", Renewable and Sustainable Energy Reviews, vol. 92, pp. 160-170, 2018.

[57] A.H. Mamaghani, S. Avella, B. Najafi, and R. Fabio, "Techno-economic feasibility of photovoltaic, wind, diesel and hybrid electrification systems for off-grid rural electrification in Colombia", Renewable Energy, vol. 97, pp. 293-305, 2016.

[58] A. Vides-Prado, E.C. Ojeda, C. Vides-Prado, I.H. Orozco, and B.S. Agustin, "Techno-economic feasibility analysis of photovoltaic systems in remote areas for indigenous communities in the Colombian Guajira", Renewable and Sustainable Energy Reviews, vol. 82, pp. 4245-4255, 2018.

[59] L. Rodriguez-Urrego, J.V. Llanos, D. Rodriguez-Urrego, and A.M. Garcia, "Design, implementation and operation of a solar hybrid system in a remote area in the Colombian Guajira desert", WIT Transactions on Ecology and the Environment, vol. 195, pp. 427-438, 2015.

[60] A.M. Aguirre-Mendoza, C. Diaz-Mendoza, and J. Pasqualino, "Renewable energy potential analysis in non-interconnected islands. Case study: Isla Grande, Corales del Rosario Archipelago, Colombia. Ecological Engineering". https://doi.org/10.1016/j.ecoleng.2017.08.020.

[61] J.A. Hernandez, D. Velasco, and C.L. Trujillo, "Analysis of the effect of the implementation of photovoltaic systems like option of distributed generation in Colombia", Renewable and Sustainable Energy Reviews, vol. 15, pp. 2290-2298, 2011.

[62] F. Leon-Vargas, M.A. Garcia-Jaramillo, and E. Krejci, "Pre-feasibility of wind and solar systems for residential self-sufficiency in four urban locations of Colombia: implication of new incentives included in Law 1715", Renewable Energy, DOI:10.1016/j.renene.2018.06.087.

[63] UPME and Ministerio de Minas Energia, (2015) "Plan energetico Nacional Colombia: Ideario energetico" 2050 SRC.

[64] M. Saad, A. Safari, W. Mustaffa, M. Younis, S. Rahman, and O. Rosli, "Solar energy in Malaysia: Current state and prospects", Renewable and Sustainable Energy Reviews, vol. 16, pp. 386-396, 2012.

[65] http://www.thegreenmechanics.com/2013/08/annual-solar-radiations-in-different.html.

[66] R. Kardooni, S. B. Yusoff, F.B. Kari, and L. Moeenizadeh, "Public opinion on renewable energy technologies and climate change in Peninsular Malaysia", Renewable Energy, vol. 116, pp. 659-668, 2018.

[67] L.H. Halabi, S. Mekhilef, and M. Hossain, "Performance evaluation of hybrid adaptive neuro fuzzy inference system models for predicting monthly global solar radiation", Applied Energy, vol. 213, pp. 247-261, 2018.

[68] B. Soumia, M.K. Nallapaneni, and T. Ali, "Data acquisition system: on the solar photovoltaic module and weather parameters monitoring", Procedia Computer Science, vol. 132, pp. 873-879, 2018.

[69] A. Ali, K. Sopian, H.A. Kazem, and M.T. Chaichan, "Nanofluidbased grid connected PV/T systems in Malaysia: a techno economical assessment", Sustainable Energy Technologies and Assessments, vol. 28, pp. 81-95, 2018.

[70] https://www.statista.com/statistics/873026/solar-energy-capacity-malaysia/

[71] N. Gomesh, I. Daut, M. Irwanto, Y.M. Irwan, and M. Fitra, "Study on Malaysian's perspective towards renewable energy mainly on solar energy," Energy Procedia, vol. 36, pp. 303-312, 2013.

[72] M.A. Alghoul, F.Y. Hammadi, N. Amin, and N. Asim, "The role of existing infrastructure of fuel stations in deploying solar charging systems, electric vehicles and solar energy: a preliminary analysis," Technological Forecasting and Social Change, vol. 137, pp. 317-326, 2018.

[73] A.N. Syafawati, I. Daut, M. Irwanto, Z. Farhana, N. Razliana, Z. Arizadayana, and S.S. Shema, "Potential of solar energy harvesting in Ulu Pauh, Perlis, Malaysia using solar radiation-analysis studies," Energy Procedia, vol. 14, pp. 1503-1508, 2012.

[74] N. Izadyar, H.C. Ong, W.T. Chong, J.C. Mojumder, and K.Y. Leong, "Investigation of potential hybrid renewable energy at various rural areas in Malaysia," Journal of Cleaner production, vol. 139, p. 61-73, 2016.

[75] R. Haiges, Y.D. Wang, A. Ghoshray, and A.P. Roskilly, "Optimization of Malaysia power generation mix to meet the electricity demand by 2015," Energy Procedia, vol. 142, pp. 2844-2851, 2017.

[76] K.C. Goh, H.H. Goh, A. Yap, M. Masrom, and S. Mohamed, "Barriers and drivers of Malaysian BIPV application: Perspective of developers," Procedia Engineering, vol. 180, p. 1585-1595, 2017.