Renewable Energy in Africa: A Discussion of the Feasibility and Socio-Economic Effects of Solar Photovoltaic(PV) System

C Long¹ and X Zhang²

1. University College Dublin, Belfield, Dublin 4, Eircode: D04 V1W8, Ireland.
2. Fudan University, 220 Handan Rd, Wu Jiao Chang, Yangpu District, Shanghai, China
E-mail: sapienssuwan@gmail.com

Abstract. The development and expansion of the modern world cannot be separated from the support of electricity. The 'pollution-free' and unlimited renewable energy plays an increasingly important role in the energy supply market. Started with the interpretation of world energy consumption from 2008 to 2017, this paper takes Africa (primarily rural Africa), which has a shallow electricity connection rate, as an example to discuss the feasibility of deploying solar photovoltaic(PV) systems through analyzing its natural resources, government policies, and other factors. It briefly described both off-grid and grid-connected solar PV systems and their possible technical issues. Moreover, the potential socio-economic effects of the deployment of solar PV systems in the region have been predicted. Solar PV systems can solve the power supply issues for the people who live in rural areas with unsound infrastructure. Further research will quantify the benefits and analyze the impact factors to optimize the utility equation.

1. Introduction
Electricity has a remarkable contribution to medical care, modern education, and labor productivity[1]. With the continuous development of the social economy and innovation of science and technology, people are relying on electricity heavier. According to the BP Statistical Review of the World Energy Report, from 2008 to 2018, the world total primary energy consumption reached to13864.9 million tones oil equivalent, while energy consumption in Africa only counted 3.3% of the total energy consumption worldwide. Compared to the proportion of Africa's population, the penetration rate of electricity in
Africa is still shallow. There are over 573 million people in Sub-Saharan Africa who lack access to power, which makes the region has over 20 countries with the lowest electrification rate in the world[2]. Improving electricity coverage across the continent is one of the most critical challenges.

| Table 1. 2008 to 2017 Africa Energy Consumption (Mtoe) |
|-----------------------------------------------|
| Year  | 2008  | 2009  | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Coal  | 113.89| 110.27| 109.39| 106.41| 105.13| 104.07| 112.02| 107.12| 108.24| 109.58|
| Oil   | 145.55| 150.21| 151.92| 151.43| 164.15| 168.12| 164.59| 175.96| 184.42| 191.29|
| Gas   | 84.64 | 82.33 | 88.01 | 95.16 | 100.15| 99.9  | 108.46| 108.26| 115.47| 122.6 |
| Nuclear | 3.39  | 3.34  | 3.15  | 3.52  | 3.12  | 3.68  | 3.59  | 3.19  | 3.92  | 3.7   |
| Hydro | 8.11  | 8.38  | 9.47  | 9.53  | 9.77  | 10.57 | 10.36 | 9.99  | 10.54 |       |
| Other renewables | 1.2   | 1.4   | 1.57  | 1.7   | 1.85  | 2.32  | 4.32  | 4.97  | 5.17  | 6.18  |
| Biofuels/Waste | 311.92| 319.69| 327.38| 340.54| 349.57| 357.83| 367.9 | 377.01| 390.16| 367.46|

*a Mtoe means Million Tonnes of Oil Equivalent

| Table 2. 2008 to 2017 World Energy Consumption (Mtoe) |
|-----------------------------------------------|
| Year  | 2008  | 2009  | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Coal  | 3313.7| 3289.99| 3595.49| 3789.32| 3741.13| 3927.77| 3918.49| 3836.09| 3730.89| 3789.93|
| Oil   | 4068.41| 3989.63| 4146.4| 4132.18| 4209.75| 4285.3| 4334.28| 4390.2| 4449.49|       |
| Gas   | 2591.77| 2538.8| 2740.11| 2790.09| 2837.89| 2901.63| 2900.58| 2943.72| 3034.95| 3106.8 |
| Nuclear | 712.17| 703.31| 718.96| 673.71| 641.83| 646.48| 661.35| 670.73| 679.65| 687.48|
| Hydro | 275.27| 279.78| 295.98| 301.56| 315.57| 325.93| 334.94| 334.4| 349.22| 351.03|
| Other renewables | 91.15| 103.21| 112.92| 127.82| 143.21| 163.56| 183.17| 202.39| 227.4| 258.75|
| Biofuels/Waste | 1220.93| 1230.18| 1295.06| 1313.89| 1340.19| 1377.02| 1412.91| 1323.47| 1349.29| 1329.06|

2. Energy Consumption Overview
The world energy consumption still heavily relies on non-renewable resources in the past ten years. In 2008, there are over 80% of world energy consumption was generated by coal, oil, and gas, counted as 9973.88 million tones oil equivalent, which is nearly the same proportion compared to the data in 2017. Hydro energy consumption increased from 275.27 Mtoe to 351.03 Mtoe between 2008 to 2017, the same trend as geothermal, solar...
and other renewable energies, from a total of 90.22 Mtoe in 2008 increased to 256.83 Mtoe in 2017. The detailed figures are shown in Table 1.

As shown in Table 2, the total energy consumption of Africa is 812 Mtoe oil equivalent. Coal, oil, and natural gas contributed to 52.15% energy consumption. Compare to the world average (9.5% in 2017) there is 45.23% of energy are from biofuels and wastes, which is only slightly less than the non-renewable energies. The fuelwood marked up the majority part of biofuel usage. The energy consumption structure has not changed in the past from 2008 to 2017. Because of the presence of vast forests, agriculture industry, a large rural population and a low GDP per capita, there is large use of solid biofuel for cooking[3]. The low efficiency of the extensive use of wood and charcoal resulted in Africa has higher energy intensity than the world average[4].

Heavily relying on non-renewable energy is not a sustainable solution. Earth resources, especially non-renewable resources, have limited supply capability and are not inexhaustible. Economic development is increasingly constrained by energy development and utilization. Renewable energy can greatly alleviate the vast demand for electricity in the future. It also ensures the sustainable development of the economy. The diversified, enormous reserved renewable energy resources in Africa give unlimited solar potential which could generate up to 10 TW electricity, as well as the abundant hydro, wind, and geothermal energy [5].

Most African countries were covered by bright sunlight over 300 days, and the radiance level is much higher than the world average, where the solar industry has huge potentials[6]. Compared to other renewable energies, solar PV has many compatible characteristics. It will not be exhausted, compare to nuclear and hydro-power, and it will not threaten the survival of human beings and damage the environment.

There are two kinds of solar PV system, grid-connected and off-grid, which can be used in the rural area where the infrastructure is underdeveloped. They can provide environmentally sustainable electricity to locals. But there are also some technical problems of solar PV systems that need to be solved.

### 3. Grid-connected and off-grid solar PV system

The off-grid photovoltaic system is equipped with solar panels, batteries, converter, charge controllers and other accessories. The sample schematics are shown in Figure 1. It is an ideal system for people living in rural areas and isolated from the distribution network. The converter can convert the DC power generated by solar power into AC power. While the excess electrical energy generated is stored in rechargeable batteries, and power to the load when the solar power is unavailable. [7].
Figure 1. Example of solar PV system: (a) off-grid and (b) grid connected.

The controller in the grid-connected PV system not only load energy from the gird but also can provide excess power back to the grid. By lighten the impact of load distribution system harmonics and reactive power, load compensation may also be performed [7]. For expensive and inefficient African power systems, grid-connected photovoltaic systems can greatly alleviate this pressure.

The small residential solar PV system is easy to install. Using aluminium rails to secure the solar panels on the existing roof or remove the roof tiles and replace them by solar panels are all proven solutions for the installation. [8]. It will deduct the electricity expenditures by paying at a cost similar or lower price than the using existing grid system. Since 1976, PV module price has dropped 99.6% from $79.3/W to $0.3/W, demonstrating a learning rate of 28.5%[9] while the charges of the modules in the PV system marked up to 70% of the total cost [10].

As stated before, the primary energy resources in Africa are mainly firewood. Burning firewood, as well as the process of produce electricity in power plants, will result in severe pollution. Hence, lowering pollution emissions is one of the most important reasons for installing and operating solar PV system. [11]. Besides, reducing carbon dioxide emissions, selling energy savings to global markets and/or saving next-generation resources should also be factored into the economic benefits of solar PV systems [12].

The benefits of both off-grid and grid-connected solar PV system are remarkable, but there are still technical problems which cannot be ignored that hinder its development. Power plants need to withstand voltage fluctuations at all various levels because of the intermittent nature of photovoltaic power generation[13]. The irradiation will result in the output of solar energy has a voltage fluctuation, which makes the grid connection unstable[14]. The harmonic current generated by the nonlinear load is injected into the power grid, causing the voltage waveform of the utility grid to be distorted. It seriously polluted the environment of the power grid and threatened the safe and economic operation of various electrical equipment in the power grid[15].

Meanwhile, the proliferation of large-scale photovoltaic power plants will lead to the
reverse trend of some feeders and substations. The feeder line started to adjacent the output power to the transmission system. Therefore, it has a negative impact on the line voltage regulator[14].

Power loss is also a technical issue that cannot be ignored. The distribution feeder will have reactive power fluctuations because of the high PV penetration[14]. Injection of the reactive power will increase the power losses, and make the exchange rate of active power lower[16].

Some non-technical issues also need to be taken into consideration. The lack of skilled personnel will greatly reduce the effectiveness of the system. Poor wire transmission availability in remote areas will bring more challenges to grid-connected solar PV System[17]. All of these factors will affect the deployment of grid-connected and off-grid solar PV system.

4. Solar energy system deployment results

There are over 40% of the total population using grid connected and off-grid solar PV system in Mozambique have access to electricity[18]. The electricity generated by both solar PV and hydro-power supported hundreds of school, medical centres and other public buildings.

Based on the research conducted by Okoye, et al., 31.8 Mwh of power generated per year can create total net present value (NPTV) to $ 774,951 (without carbon trading). The solar PV system is economically viable in Nigeria, and its marginal return on the investment is considerable [19].

According to Egypt's Solar Atlas, Egypt has 9 to 11 hours of sunshine a day cross the whole country. The steady radiation of sunlight brings Egypt a solar energy amount of 2,000 to 3,000 kWh/m2/day[20]. Hydroelectric power and renewable (including wind and solar photovoltaics), accounted for 7.5% [21]. Egypt has installed solar PV systems in which the capacities reach up to 300 MKwh. The rooftop PV system generated over 30 MKwh in 2018. The proportions of Egypt’s different solar PV system capacities are shown in Figure 2. The projects under construction are projected that they can produce more than 2000 MKwh electricity [22].

The deployment of renewable energy technologies is gaining momentum. The total installed renewable energy systems have more than 3.7 GW capacities, where 76% are from hydro-power and 24% from solar and wind energy). An additional 10 GW wind and solar projects were committed by the government in 2022, of which renewable energy will account for 20% of the power structure [23].

52% electricity access rate overall and 43% in Sub-Saharan Africa make Africa has the lowest lighting level worldwide. There are more than 600 million people still live in the shadows [24]. The explosive growth of modern technology and solar system development give Africa an unprecedented opportunity to help their locals improve quality of life and increase their incomes. There are many perspectives to analyze the socio-economic benefits of deploying solar PV systems in rural areas.
Currently, energy affordability is still a significant concern because of the high electricity prices and under-developed infrastructure. Their income cannot support the locals in Africa to afford electricity usage [24]. A cost-effective solar solution can both provide affordable electricity and support other activities which can generate more incomes. In Gabber, Senegal, the household who used solar was willing to pay $0.5/kw to plant high-value crops.

Besides helping local SMEs, the economic growth generated by the Solar PV system has the potential to create a booming power industry, which can improve the quality of life among millions of people[25]. The estimated 372,000 jobs can be provided through deploying the off-grid solar system in both South Asia and parts of Sub-Saharan, where there would be 20% female employees take the jobs[26]. Incomes and electricity consumption are positively correlated. Higher incomes and energy consumption will ensure the industry financially survival. Thus, combining job creation with electrification is a brilliant way to attract investment [27]. Reliable energy could help schools in rural areas to get in touch with modern technology through the internet. It will also improve local medical care by powering health centers and refrigerate medicines [28].

5. Government policy

The African governments put sustainable development at the forefront of their development plan in order to achieve the Sustainable Development Goals (SDGs) targets. Over 84% African Nationally Determined Contributions (NDCs) have qualified its targets of renewable energy sector[29]. A new renewable energy deal proceeded by African development will enable 130 million households to get access to clean cooking in 2025. The South African government has streamlined the environmental impact assessment process for Variable Renewable Energy (VRE) projects, which is considered the most appropriate development plan, in renewable energy development zones. Ethiopia government gives income tax exemption for the companies that are engaged in the generation of electricity. The companies will also benefit from the customs duty
exemptions for capital goods and equipment. The tax incentives offered by the Nigeria government enable renewable energy manufacturers to promote their energy-efficient equipment and their accessories widespread. The rural electrification strategy and implementation plan (RESIP) of Nigeria also aim to expand electricity access rate cost-effectively by using both grid and off-grid approaches from renewable resources in rural areas. Tanzania government give VAT, customs and excise duties exemption to photovoltaics (PV) and solar energy system components.

As shown in the Figure 3, the usage of Hydro energy is growing steadily in the past ten years. The energy consumption of other renewable energies (includes geotherm, solar) in Africa has increased nearly six times between 2008 (1.2 Twh) to 2017 (6.9 Twh).

![Figure 3. 2008 to 2017 Africa Other Renewable & Hydro Energy Consumption.](image)

Along with with the price reduction of the solar PV system components and the government policies, as well as the local economic growth, renewable energy consumption will keep the development trends and take more shares of the total energy consumption.

**6. Conclusion**

Electricity is an indispensable part of modern society, which is directly related to people's quality of life, lifestyle, medical care, education, etc. It is urgent to solve the problem of low electricity access rates in Africa. Solar photovoltaic systems, both grid-connected and off-grid system, are a great way to help people in rural Africa to get electricity supply. The unlimited solar energy in Africa can generate a considerable amount of electricity, as well as produce high corresponding income. However, the underdeveloped infrastructure makes the deployment of grid-connected solar PV system more complicated. The low education level and lack of technicians will reduce the utility of both systems. Nevertheless, with the support of the government, and the continuous improvement of infrastructure, the overall solar market in Africa has excellent prospects. The series of positive butterfly effects brought by power supply will help Africa increase its GDP as well as other national production indices. Governments, international organizations, investment institutions, etc. should consider expanding the deployment of solar projects in Africa.
7. References

[1] B. Bridge, D. Adhikari, M. Fontenla. Electricity, income, and quality of life. In: *Soc. Sci. J.*, 53 (1), 2016: 33-39.

[2] IEA, IRENA, UNSD, WB, WHO. Tracking SDG 7: The Energy Progress Report 2019. Research report. Washington DC, 2019.

[3] International Energy Agency. World Energy balances. Research report. Paris, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019.

[4] International Energy Agency. World Energy Outlook 2014. Research report. IEA, Paris, 2014.

[5] United Nations Environment Programme. *Atlas of Africa Energy Resources*. Kenya: Progress Press Ltd; 2017.

[6] Africa Progress Panel. Research report. Power, People, Planet - Seizing Africa's Energy and Climate Opportunities. Geneva: Africa Progress Panel, 2015.

[7] Karthikeyan V, Rajasekar S, Das V, Karuppapan P, Singh A. K. Grid-Connected and Off-Grid Solar Photovoltaic System. In: *Green Energy and Technology*, 2017:125–157.

[8] Frequently Asked Questions on Solar Photovoltaics.(n.d.) [Online]. Available: https://www.seai.ie/publications/FAQs_on_Solar_PV.pdf

[9] Swarbreck J, Chase J, Radioa P, Bromley H, Wang X, Hayim L. 2018 Long-Term PV Market Outlook. Research report. BloombergNEF Research, New York, USA, 2018.

[10] International Journal of Photoenergy Volume.(2015). [Online]. Available: http://dx.doi.org/10.1155/2015/256101

[11] Georgopoulou E, Lalas D, Papagiannakis L. A multi-criteria decision aid approach for energy planning problems: the case of renewable energy option. *European Journal of Operation Research* 1997; 103: 38e54.

[12] Ramadhan, Mohammad, Naseeb, Adel. The cost benefit analysis of implementing photovoltaic solar system in the state of Kuwait. In: *Renewable Energy 36*, 2011:1272-1276.

[13] B. Belcher, B.J. Petry, T. Davis, K. HatipogluThe effects of major solar integration on a 21-Bus system: technology review and PSAT simulations Conf. Presented at: 2017. - IEEE SOUTHEASTCON.

[14] F. Katiraei, J. R. Aguero. Solar PV Integration Challenges. *IEEE Power and Energy Magazine*, 2011; 9(3):62-71.

[15] Mo Yueping, Weng Shuangan. *Power supply and distribution engineering*. 2nd ed. China: China Machine Press; 2015.

[16] Molina, Marcelo, Santos, Euzeli, Pacas, Mario. Improved power conditioning system for grid integration of photovoltaic solar energy conversion systems. In: *Transmission and Distribution Conference and Exposition: Latin America*, 2010: 163 - 170.

[17] S. Anees. Grid integration of renewable energy sources: Challenges, issues and possible solutions. In: *IEEE 5th India International Conference on Power Electronics (ICPE), Delhi*, 2012: 1-6.

[18] AllAfrica (2014), Mozambique: US $530 million Invested in Rural Electrification. [Online]. Available: http://allafrica.com/stories/201404240243.html

[19] Okoye, Chiemeke & Oranekwu-Okoye, Blessing. Economic feasibility of solar PV system for rural electrification in Sub-Sahara Africa. Presented at: 2017 Renewable and Sustainable Energy Reviews.
[20] Egypt - Renewable Energy. (September 2019). [Online]. Available: https://www.export.gov/article?id=Egypt-Renewable-Energy

[21] IEA (2017), IEA Energy Balances for 2015. [Online]. Available: www.iea.org/Sankey/#?c=Egypt&s=Balance

[22] NREA, NPPA, Atomic Energy Authority, Nuclear Materials Authority, Ministry of Electricity & Renewable Energy. (2018). Annual Report 2018. [Online]. Available: http://nrea.gov.eg/Content/reports/Englishv2%20AnnualReport.pdf

[23] IRENA, Global Energy Transformation: A roadmap to 2050. Research report. International Renewable Energy Agency, Abu Dhabi, 2018.

[24] United Nations. World Energy Trilemma Index 2019 Full Report, United Nations E/2019/68 Economic and Social Council Special edition: progress towards the Sustainable Development Goals. Presented at:2019 World Energy Council.

[25] Castellano A, A. Kendall, and M. Nikomarov. Brighter Africa: The Growth. Potential of the Sub-Saharan Electricity Sector. McKinsey & Company, 2015.

[26] International Renewable Energy Agency. Renewable Energy and Jobs – Annual Review 2019. Research report. International Renewable Energy Agency, Abu Dhabi, 2019.

[27] G Prasad, S Dieden. (2007). Does Access To Electricity Enable The Uptake Of Small And Medium Enterprises In South Africa. [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.492.8722&rep=rep1&type=pdf

[28] F. Birol. Energy economics: A place for energy poverty in the agenda. The Energy Journal, 2007, 28 (3) 1-6

[29] International Renewable Energy Agency. Renewable Energy and Jobs – Annual Review 2018. International Renewable Energy Agency, Abu Dhabi, 2018.