Evaluating Nigeria's Solar and Hydropower Future Development Potential

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Executive Summary

The Nigerian government has commissioned this group to evaluate the renewable energy development in the country, focusing on solar photovoltaics (PV) and small hydropower.

Nigeria is projected to be the fourth largest country in the world within a few decades. Currently, the country relies on gas power plants for approximately 80% of its electricity. Nigeria has committed to reducing its carbon intensity by expanding the use of renewable energy.

Solar PV fills a niche of supplying off-grid electricity at smaller scales which is important for increasing rural electrification rates. Rural populations predominantly live in the northern regions where there is high solar irradiation but less grid infrastructure. Small hydropower can be targeted for on-grid use to decrease Nigeria's reliance on gas power plants. Small hydro plants can range from capacities of single digit kilowatts to 30 megawatts.

Solar PV and hydropower can address the problems of increasing generation capacity for growing population and per capita energy demand, diversifying energy generation sources, and increasing electrification in rural areas. Three important criteria for generating sources are considered: physical, political-economic, and social-cultural potential. Additionally, project financing is discussed. The deployment of both technologies at smaller unit sizes reduces capital requirements, thus broadening the range of financing options.

Analysis of solar and small hydropower through the three criteria show that they are strong candidates but need government support to reach the country's stated renewable energy goals. The government should take the following actions to support solar PV and small hydro development: collect high resolution water flow data, develop proactive water management policies, introduce a rural electrification community survey, create a database of formal land agreements in rural areas, and continue efforts to reduce corruption in the electricity industry to attract foreign investment.

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1. Introduction and Background

1.1 Nigerian Background and Significance of Electrification

Africa is one of the world's most resource rich continents. Filled with oil, natural gas, abundant sunlight, wind, water, and coal, Africa has all the resources to be an energy hub; however, the continent only has a currently installed capacity of 147 GW – equitable to the capacity that China installs in one to two years. Nearly 600 million members of Africa's diverse population have no access to electricity. Algeria, Egypt, Ethiopia, Nigeria, and South Africa account for 60% of African primary energy use; the remaining 40% is shared amongst Africa's other 49 countries. In addition, countries with access to electricity are rife with daily blackouts and unreliability. To compensate for these power failures, countries can spend up to 1-5% of their total GDP on diesel consumption as a reparative measure. As the International Agency for Renewable Energy states, "reliable and affordable power supply is an essential prerequisite for economic growth. Electricity from renewable sources can play a key role in improving electricity supply in Africa."[1]

Nigeria, located on the West Africa Coast, is a particularly important country for electricity development. With a population of 201 million people, Nigeria ranks as the 7th most populous country in the world, as well as Africa's most populous country, and is projected to jump to 3rd place by 2050[2]. Comprised of around 250 different ethnic groups with a median age of approximately 18.3 years, Nigeria's population can be summarized in three words: diverse, young, and plentiful. As seen in Figure 1, the population is concentrated primarily in the south where Nigeria's two main cities lie: the capital Abuja, and Lagos. The north, in comparison, is almost entirely rural and is less densely populated.

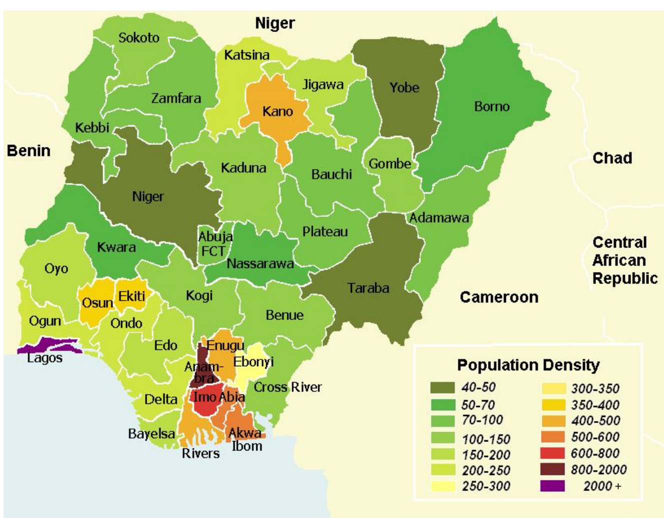

Figure 1. Population Density of Nigeria[3]

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[1] International Renewable Energy Agency (IRENA). "Prospects for the African Power Sector." Abu Dhabi, 2012.

[2] Provost, Claire. "Nigeria Expected to Have Larger Population than US by 2050." *The Guardian*, Guardian News and Media, 13 June 2013.

[3] Adeleke A. "Renewables in Nigeria." Centre for Petroleum, Energy Economics and Law, University of Ibadan, 2017.

Throughout Nigeria, there is a clear need for investment in electrification. Nationally, only 59.3% of the population – and only 41.1% of rural communities – have electricity access[4]. Correspondingly, roughly 60% of Nigeria's states are less than 50% electrified; those who are have access to electricity with a reliability rate of 6 hours per day. This translates to an energy need of 31,240 MW (as of 2015), an installed capacity of 12,000 MW, an available capacity of 7,000 MW, and an on-grid available capacity of only 5,000 MW.[5] In order to compensate for this access to electricity, private generators are playing an increasingly important role. These generators, however, are diesel powered, meaning they are expensive and thus primarily an option for the wealthy With all of the pitfalls of the current energy system, it is no surprise that support for renewable energy sources is increasing. As a paper from the Journal of Energy in Southern Africa put it, "switching over to the utilization of renewable energy resources in Nigeria is long overdue because of the increased recognition of the contribution renewable energy makes to rural development, lower health costs (linked to reduced-air pollution), energy independence, and climate change mitigation."[6]

1.2 Nigeria's Energy Structure

Nigeria's energy system was previously overseen solely by the government. The Federal Government of Nigeria (FGN) oversaw the overall energy market through policy formulation, regulation, operation, and investment in the Nigerian power sector. Under the FGN, the Federal Ministry of Power (FMP) oversees the energy sector while the National Electric Power Authority (NEPA) is a state-owned organization responsible for the power generation, transmission, and distribution of power. The FMP has launched several subsidiary institutions, most notably the Nigerian Electricity Regulatory Commission (NERC) and Rural Electrification Agency of Nigeria (REA).[7] Established in 2005, NERC seeks to ensure fair and competitive electricity trading through market regulation. The REA's aim is towards universal access to electricity, by connecting all local governments and selected neighboring towns to the national grid. While corruption is a common occurrence in Nigeria, the monopolization of the energy sector impeded its growth, particularly in renewable energy. To diversify and mitigate the corruption and monopolization of the energy market the Nigerian Electricity Supply Industry (NESI) was established to privatize the energy market. Outside of the federal government, there are also key industry market players, including Generating Companies (GENCOs), Distribution Companies (DISCOs), Transmission Company of Nigeria (TCN), National Integrated Power Plant (NIPP) Generation Companies, and Independent Power Producers (IPPs).

Nigeria is Africa's largest oil producer, but exports almost all produced oil and reimports it as refined petroleum products. Oil accounts for only approximately 16% of Nigeria's GDP, but does account for approximately 75% of all government revenue and 90% of export earnings. Nigeria's growth trajectory is thus impacted heavily by the fluctuating prices of oil and crude oil

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[4] "Access to Electricity, Rural (% of Rural Population)." *Data*, The World Bank.
[5] Adeleke A. "Renewables in Nigeria."
[6] Aukuru, U., Okoro, O. "Renewable energy investment in Nigeria: A review of the Renewable Energy Master Plan."
[7] GIZ, The Nigerian Energy Sector: An Overview with a Special Emphasis on Renewable Energy, Energy Efficiency and Rural Electrification (June 2015)

production.[8] Although there is a large dependence on oil, Nigeria's government has sought to implement renewable energy throughout the country.

1.3 Renewable Energy Policy

Nigeria has historically been lacking policies supporting renewable energy generation, but there have been major strides in the past five years. The Renewable Energy Master Plan (REMP), which was drafted in 2005 and reviewed in 2012, created a road map for increasing the role of renewable energy in Nigeria. Specifically, the plan targeted increased electrification rates of 42% in 2005, 60% in 2015, while simultaneously increasing renewable energy contributions from 13% of total energy generation in 2015 to 23% in 2024 and 36% in 2030. However, REMP was not approved nor signed into law by the Federal Executive Council (FEC). The earliest approved document was Renewable Energy Policy Guidelines released in 2006, which describes the Federal Government's vision, policies and objectives for promoting renewable energy in the power sector.[9]

More recently, several notable policies were implemented to promote renewable energy. This includes the National Renewable Energy and Energy Efficiency Policy (NREEEP), which was proposed by the FMP and approved by the FEC in May 2015. NREEEP seeks to outline the global thrust of policies for the promotion of renewable energy and energy efficiency. The Nigeria Feed-in Tariff for Renewable Energy Sourced Electricity was implemented in November 2015, and requires DISCOs to source at least 50% of their total procurement from renewables.[10] These policies provide an opportune environment for renewables development.

2. Renewable Technology Selection

Hydropower and solar energy show great potential for increasing Nigerian electricity capacity. Nigeria currently has around 1.9 GW of installed generating capacity, predominantly from three large hydropower (LHP) plants: Kainji Power Station, Jebba Power Station, and Shiroro Power Station.[11] Combined with extensive development of small hydropower (SHP), hydropower is expected to produce over 12 GW electricity in 2030, accounting for around 55% of total projected renewable electricity generation.[12] However, a primary concern regarding hydropower viability is the high generation variability between Nigeria's wet and dry seasons, which can differ by as much as 90%.[13]

Solar photovoltaic has tremendous physical potential in Nigeria, especially in the northern regions. If only one percent of the land is covered with photovoltaic cells, the estimated generation would be 207,000 GWh/yr; this figure represents over two times the country's current

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[8] GIZ (June 2015)
[9] Federal Ministry of Power and Steel, Federal Republic of Nigeria, Renewable Electricity Policy Guidelines (December 2006)
[10] IEA, Nigeria Feed-in Tariff for Renewable Energy Sourced Electricity, https://www.iea.org/policiesandmeasures/renewableenergy/?country=Nigeria
[11] Federal Ministry of Power, National Renewable Energy and Energy Efficiency Policy (April 2015)
[12] Ibid.
[13] GIZ (June 2015)

electricity demand.[14] Solar is projected to be the second largest contributor to renewable electricity, accounting for around 29% of total generation in 2030.

Biomass and wind are less promising for electricity generation. According to the IEA, biomass is Nigeria's largest source of energy production, at around 44% or 114 Mtoe in 2016, but the electricity production from biomass was negligible in 2012.[15] Even though biomass is projected to increase to around 3 GW capacity by 2030, challenges in implementation make this a less-promising electricity source. Wind also has potential in Nigeria – particularly the northern region, which has the country's highest wind speeds. However, social challenges - such as the kidnapping of a French national in charge of the Katsina 10 MW plant - have resulted in no operational wind farms in Nigeria.

Table 1. Nigerian Renewal Energy and Energy Efficiency Policy (NREEEP) Summary of renewable electricity targets[16]

Resource	2012 [MW]	Short Term, 2015 [MW]	Medium Term, 2020 [MW]	Long Term, 2030 [MW]
Hydro (LHP)	1,938.00	2,121.00	4,549.00	4,626.96
Hydro (SHP)	60.18	140.00	1,607.22	8,173.81
Solar	15.00	117.00	1,343.17	6,830.97
Biomass	-	55.00	631.41	3,211.14
Wind	10.00	50.00	57.40	291.92
All renewables	**2,023.18**	**2,483.00**	**8,188.20**	**23,134.80**

3. Analysis methodology

Our analysis of the electrification potential of small hydropower and solar PV in Nigeria, first introduces each technology with a brief overview of their positive and negative aspects. Next, we analyze the physical potential of the considered resource (water flow and solar irradiation, respectively). We then examine the resources' political-economical potential, such as policies help or hinder the economic viability of potential hydropower or solar plants. Subsequently, we analyze the resources' social-cultural potential, including disruptions to locals caused by energy installations or public pushback about potential siting options. Finally, we analyze the financing feasibility of hydropower and solar projects, and discuss their potential complementary uses.

[14] Ibid.

[15] IEA, Nigeria Sankey Diagram (2016) https://www.iea.org/Sankey/#?c=Nigeria&s=Balance

[16] Federal Ministry of Power, National Renewable Energy and Energy Efficiency Policy (April 2015)

4. Small Hydropower Analysis

4.1 Strengths and Weaknesses

In general, hydropower's strengths include its relatively smaller area requirement compared to renewable energy sources like wind and solar. In addition, hydropower can be designed to utilize a range of water flow magnitudes, from hundreds to millions of watts and beyond. However, weaknesses of hydropower plants include generation dependency on variable rainfall and river flows, and construction costs that scale non-linearly due to a lack of hydro structural modularity.

Although large hydropower sites currently provide the bulk of Nigeria's hydropower, the government is focusing on developing the country's small hydropower capacity. Small hydro plants can not utilize economies of scale like larger hydro projects and thus have a higher cost per unit of electricity. However, they can be sited at a larger range of sites across the country and have smaller and less damaging footprints on their surrounding environments. They are also easier to finance because they are less prone to cost overruns due to less infrastructure requirements and easier project management.[17]

The Nigerian Ministry of Power classifies small hydro as any project with a generation capacity below 30 MW; projects below 1 MW are classified as mini hydro.[18] Small hydropower plants can follow dam or run-of-the-river designs.

A dam provides dispatchable electricity generation given adequate water reservoirs. Additionally, water can be pumped against its normal flow to store energy and smooth out intermittent generation from renewables. The downside of dams are their significant environmental impacts, such as sedimentation and erosion, that affect people and wildlife that depend on the riparian ecosystem. Even though smaller dams affect the local ecosystem less, they have similar impact on the riparian environment as larger dams because dams change the natural flow of sediments, minerals, and organisms.[19] Also, water stored behind the dam can either enable or compete with other uses of water such as irrigation and natural environmental consumption.

Run-of-the-river plants generate electricity without a dam by transferring the kinetic energy of the river to a turbine. In this way, the environmental impact is greatly reduced; however, they are not dispatchable because there is no way to store a river's flow.

4.2 Existing Hydropower in Nigeria

As of 2019, Nigeria has approximately 2.0 GW of total installed hydropower, with 52 MW provided by ten small plants, 40 MW provided by one medium plant, and 1930 MW provided by three large plants. Nigeria is rapidly expanding its hydropower capacity: 4.3 GW of

[17] Atif Ansar et al., Should we build more large dams? The actual costs of hydropower megaproject development. Energy Policy. (June 2014)
[18] GIZ (June 2015)
[19] Kelly Kibler, Desiree Tullos, Cumulative biophysical impact of small and large hydropower development in Nu River, China. Water Resources Research. (April 2013)

additional capacity are currently under construction or undergoing permitting through seven small, two medium, and four large plants. In addition, plans for 13 small plants, 12 medium plants, and 14 large plants have been announced, contributing 5.6 GW of future planned capacity.[20]

The government set goals in their unratified 2005 Renewable Energy Master Plan to expand their small hydro capacity to 600 MW in 2015 and 1,000 MW by 2025. As of 2019, there exists only 52 MW of installed small hydro capacity, so they are not on track to meet their goals. In fact, disregarding any timelines, the total capacity of all active, permitted, under construction, and announced small hydro plants totals only 241 MW as of 2019. In their 2015 National Energy Efficiency Policy, the government also set a goal of ensuring that a minimum of 10% of total electricity generation is maintained from large and small hydropower plants at all times, but did not specify a timeline for this goal.[21]

4.3 Physical Potential

4.3.1 Geographical Limitations

Nigeria is a relatively water-rich country. About two-thirds of Nigeria lies in the watershed of the Niger River, Africa's third longest river. Accordingly, many major tributaries of the Niger flow through Nigeria – notably, Benue in the Northeast, the Kaduna in the North Central, the Sokoto in the Northwest, and the Anambra in the Southeast. These rivers offer a promising source of hydropower; for instance, it is estimated that the Kaduna, Benue, and Cross rivers have a total capacity of about 4,650 MW[22]. Generally, due to hilly terrain and geography favorable to building dams and reservoirs, estimates of Nigeria's technically exploitable hydropower range from 14,750 MW to 20,000 MW.[23] However, river flows can be highly variable – with high discharge in the rainy season from March to July and September to mid October and low discharge in the dry season from November to February[24] – restricting the feasibility of installing large hydropower throughout the country.[25]

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[20] https://power-globaldata-com.libproxy.mit.edu/PowerCountries/PowerPlantsGrid?CountryIds=477~181&Hdn Geographys=C181;Nigeria&IsHybridPlants=0&SelectedColumns=1-26-4-5-6-11-10-12-295

[21] Federal Ministry of Power, National Renewable Energy and Energy Efficiency Policy (2015)

[22] Zarma, Ismaila. (2017). Hydro Power Resources in Nigeria.

[23] Energy Commission of Nigeria (ECN). Renewable Energy Master Plan (REMP). Abuja; 2005.

[24] Climate-Data.org, Lagos climate, https://en.climate-data.org/africa/nigeria/lagos/lagos-552/#climate-graph

[25] Kela, Roseline et al., Potentials of Small Hydro Power in Nigeria: The Current Status and Investment Opportunities, International Journal of Scientific & Engineering Research, Volume 3, Issue 5 (2012)

Figure 2. Map of Nigeria's major rivers[26]

4.3.2 Seasonal Limitations

The variability of rainfall across Nigeria makes deploying dammed hydro and run-of-the-river more feasible in southern regions, which also host the country's urban and grid-connected populations. In the south, precipitation can last for over 8 months of the year, whereas in the extreme north, annual rainfall can last less than 3 months.

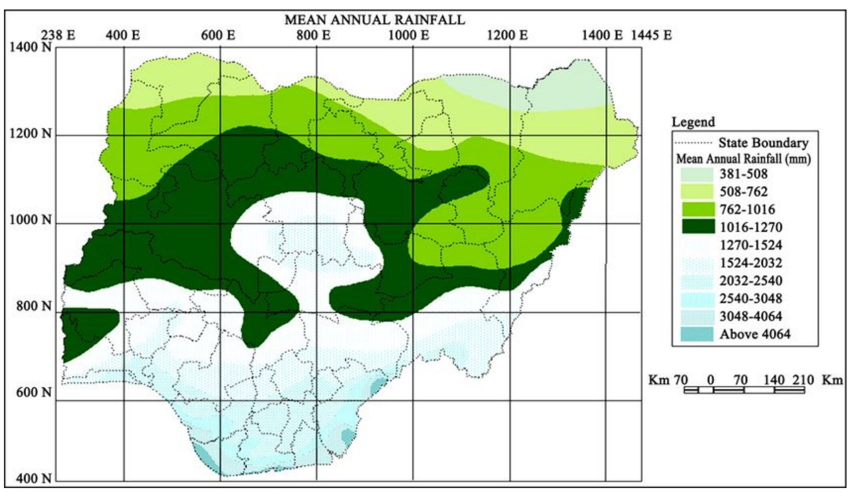

Figure 3. Mean annual rainfall across Nigeria[27]

Thus, the most attractive areas for building small hydropower sites are largely in Nigeria's southern, southeastern, and Plateau regions, which experience higher and longer duration rainfall. This results in a higher capacity factor for a hypothetical project which

[26] Maps of World, Nigeria Physical Map (June 2015), https://www.mapsofworld.com/physical-map/nigeria.html

[27] Ishaku, Hassan & Majid, M. (2010). X-Raying Rainfall Pattern and Variability in Northeastern Nigeria: Impacts on Access to Water Supply. Journal of Water Resource and Protection. 02. 952-959. 10.4236/jwarp.2010.211113.

improves financing, to be discussed later. In addition, the local topography of the region also provide larger average drops and hydraulic heads.[28] Such regions can potentially support run-of-the-river small hydro plants. In contrast, hydro plants in the northern and Jos Plateau regions of Nigeria may require reservoirs for flow regulation. Since most of Nigeria's urban, grid-connected populations are located in the country's southern regions, it is prudent to use small hydropower developed in these regions to improve the capacity and thus reliability of urban, grid-connected electricity supply.

4.4 Surveys of Hydropower Potential

As of 2015, the Nigerian government estimates the potential of technically exploitable small and medium hydropower at over 3,500 MW.[29] A survey of estimated potential at various locations was conducted by the Power Holding Company of Nigeria, previously known as NEPA, and is summarized in Table 2.

Table 2. NEPA estimate of undeveloped, exploitable hydropower sites potentials in Nigeria[30]

Location	River	Install potent capacity (MV
Donka	Niger	225
Zungeru II	Kaduna	450
Zungeru I	Kaduna	500
Zurubu	Kaduna	20
Gwaram	Jamaare	30
Izom	Gurara	10
Gudi	Mada	40
Kafanchan	Kongum	5
Kurra II	Sanga	25
Kurra I	Sanga	15
Richa II	Daffo	25
Richa I	Mosari	35
Mistakuku	Kurra	20
Korubo	Gongola	35
Kiri	Gongola	40
Yola	Benue	360
Karamti	Kam	115
Beli	Taraba	240
Garin Dali	Taraba	135
Sarkin Danko	Suntai	45
Gembu	Dongu	130
Kasimbila	Katsina Ala	30
Katsina Ala	Katsina Ala	260
Makurdi	Benue	1060
Lokoja	Niger	1950
Onitsha	Niger	1050
Ifon	Osse	30
Ikom	Cross	730
Afokpo	Cross	180
Atan	Cross	180
Gurara	Gurara	300
Mambilla	Danga	3960
Total		12220

Although a 2004 estimate by the Inter-Ministerial Committee on Available Energy Resources put Nigeria's small and medium hydropower potential reaching 3,500 MW, there have been few surveys of the country's small hydropower potential since a 1980 survey of 12

[28] Manohar, Krishpersad & Adeyanju, Anthony A.. (2009). Hydro power energy resources in Nigeria. Journal of Engineering and Applied Sciences. 4. 68-73.
[29] Federal Ministry of Power, National Renewable Energy and Energy Efficiency Policy (2015)
[30] Manohar, Krishpersad (2009)

Nigerian federation states. That survey, summarized in Table S, found 734 MW of small hydropower among 277 potential sites but did not cover many of the most promising geographic regions in the south, where precipitation is high and river flows are more constant.[31]

Table 3. Nigeria's small hydropower potentials as surveyed in 1980.[32]

State (Pre 1980)	River basin	Total sites	Total capacity (MW)
Sokoto	Sokoto-Rima	22	30.6
Katsina	Sokoto-Rima	11	8.0
Niger	Niger	30	117.6
Kaduna	Niger	19	59.2
Kwara	Niger	12	38.8
Kano	Hadeija-Jamaare	28	46.2
Borno	Chad	28	20.8
Bauchi	Upper Benue	20	42.6
Gongola	Upper Benue	38	162.7
Plateau	Lower Benue	32	110.4
Benue	Lower Benue	19	69.2
Rivers	Cross River	18	258.1
Total		277	734.2

Source: Renewable Energy Master Plan (REMP) (2005).

General estimates of Nigeria's small hydropower capacity indicate that the nation's REMP targets and using small hydropower to both augment and stabilize urban electricity supply are physically feasible. However, more detailed surveys of Nigeria's small hydropower potential are needed in order for the country to site and build facilities to meet REMP's goals for small hydropower.

4.5 Political and Economic Potential

4.5.1 Capital Accessibility

Cost is one of the primary considerations of any energy project. The installed cost for small hydro ranges from 2000 - 4000 USD (2010) per kW compared to 1000 - 2000 for large hydro projects.[33] Although small hydropower's unit cost of electricity is higher, there is a larger pool of funding sources for multiple 4 million USD, 1 MW-scale small hydro plants than a multi-billion dollar, large hydro plant. For scale, a one megawatt plant can support up to 20,000 people given approximate per capita electricity consumption at 180 kWh annually[34] and assuming a reasonable 40% capacity factor.[35]

Building a number of smaller projects provides more opportunities for domestic workers to learn technical skills in comparison to a single large project. A single large projects will have a higher reliance on foreign skilled labor because there is little return for educating unskilled

[31] Ibid.
[32] Ohunakin, Olayinka et al., Small Hydropower (SHP) Development in Nigeria: An Assessment, Renewable and Sustainable Energy Reviews 15 (2011) 2006 - 2013, http://eprints.covenantuniversity.edu.ng/7362/1/1-s2.0-S1364032111000049-main.pdf
[33] International Renewable Energy Agency (IRENA), Renewable Energy Technologies: Cost Analysis Series. (June 2012) https://www.irena.org/documentdownloads/publications/re_technologies_cost_analysis-hydropower.pdf
[34] GIZ (June 2015)
[35] IRENA (June 2012)

workers. The cost of small hydro projects should go down due to learning-by-doing as a domestic, skilled workforce develops.[36]

In addition, by financing smaller, more affordable projects, a larger percentage of funding can be sourced from domestic and regional investors like the African Development Bank. Exchange rate risks can be reduced by basing loans in local currencies. Additionally, small hydro projects can be bundled into packages that reduce risk and create sizable opportunities for larger investors. Finally, even if financing comes from international investors, building a portfolio of projects over time requires repeated interactions among the same actors – which, as game theory suggests, encourages cooperative behavior.

4.5.2 Regulation

Physical hydropower potential and financing are important factors in the development of hydropower plants, but political entities (grouped in Table 4 by level of governance and market domain) also significantly influence in the development of hydropower projects.

Table 4. Political entities involved in hydroelectricity

	Water	**Electricity**
International	Niger Basin Authority, Lake Chad Basin Commission	n/a
Federal	Federal Ministry of Water Resources, Federal Ministry of Environment	Federal Ministry of Power, Nigeria Electricity Regulatory Commission, Transmission Company of Nigeria, Nigerian Bulk Electricity Trading
Sub-federal	State Water Agencies, Local Government Authorities	n/a

The Nigerian Electricity Regulatory Commission (NERC) governs procurement and licensing for hydropower plants. It requires competitive procurement and licenses for on-grid projects larger than 10 MW;[37] significantly, small hydropower projects may be sized below 10 MW, allowing for faster installation for on-grid use. Larger projects used off-grid are exempt regardless of capacity. The responsibilities of the Federal Ministry of Power, Transmission Company of Nigeria, and Nigerian Bulk Electricity Trading are the same as described above in section 1.2.

As hydropower introduces competing demand with other uses of water such as drinking, cooking, sanitation, fishing, and transportation, management of water flow is as vital as

[36] Hannes Pfeiffenberger, Franz Wirl, The costs of hydro power: Evidence on learning-by-doing, economies of scale and resource constraints in Austria. Int'l Journal of Energy Research. (1990)

[37] GIZ (June 2015), Page 99

managing the flow of electrons. Additionally, water flows must be coordinated between plants to sensibly distribute hydroelectric generation across the nation.

At the federal level, hydroelectric project developers and managers interface with the Federal Ministry of Water Resources (FWMR) and Federal Ministry of Environment (FMENV). The FMENV approves the Environmental and Social Impact Assessment that developers must submit to NBET in order to initiate the process of obtaining a Power Purchase Agreement. The FWMR, in addition to its primary role of supplying water, regulates civil work and issues water licences to hydro projects.[38] The FWMR has established the Water Regulation Commission to address the sometimes competing uses of water for electricity and agriculture. The FWMR also coordinates state water agencies who in turn provide guidance to local government authorities on supplying water.[39] Although local government can better provide local solutions, differences in local policies may increase the difficulty of quickly developing projects in multiple regions.

In addition to intra-national water resource management, Nigeria must also negotiate how upstream countries use water, as dams in upstream countries could retain water which would reduce generation in Nigeria. On the other hand, sudden releases could overstress Nigeria's hydro infrastructure leading to structural failure and catastrophic flooding.

Nigeria has a historical track record of international water management. In 1964, it established the Lake Chad Basin Commission with Cameroon, Niger, and Chad to manage the basin's shared water resources.[40] Similarly, The Niger Basin Authority was established in 1980 by Niger, Benin, Chad, Guinea, Côte d'Ivoire, Mali, Nigeria, Cameroon and Burkina Faso to promote cooperation between the member states on the use of the Niger River for energy, irrigation, fishing, and transport among other uses.[41] As Nigeria and the other countries build more hydropower, it would be wise to strengthen the Niger Basin Authority to preempt disputes with agreed upon water sharing policies, and so it could act as an arbiter if situations arise.

Nigeria may need to sponsor a similar organization for the Benue River that flows in from Cameroon. In 2012, 49 Nigerians died from water released by Cameroon's Lagdo dam that then flowed along the Benue River.[42] Following this, Nigeria sent their Minister of Water Resources to reach a Memorandum of Understanding to avoid future incidents.[43] A better solution would be an institutionalized process specifically between Cameroon and Nigeria to manage water resources along the Benue river to further reduce risk to human life and to hydroelectric projects.

[38] GIZ (June 2015)

[39] Macheve, Berta, Alexander Danilenko, Roohi Abdullah, Abel Bove, and L. Joe Moffitt, State Water Agencies in Nigeria A Performance Assessment. (2015) https://openknowledge.worldbank.org/bitstream/handle/10986/22581/9781464806575.pdf

[40] The Commission. Lake Chad Basin Commission. (Accessed May 2019) http://www.cblt.org/en/lake-chad-basin-commission

[41] Niger Basin. International Waters Governance. (Accessed May 2019) http://www.internationalwatersgovernance.com/niger-basin.html

[42] Mike Ebonugwo, Jude Njoku, Favour Nnabugwu, Peter Duru and Funmi Olasupo, Flood: As Nigeria awaits release of water from Lagdo Dam. Vanguard. (Accessed May 2019)

[43] Ibid.

4.6 Social and Cultural Potential

How water resources are regulated directly impacts ways of life in long-settled communities, and changes in water stores and flows may exacerbate ethno-religious and herder-farmer conflicts. Another consideration is educating the public about small hydro to offset negative perceptions created by the side effects of large hydro dams.

Fadama, a local term meaning fertile lands, are regenerated by annual flooding of rivers which carry silt and water in which new crops can be planted. Locational distribution of dams and temporal distribution of water discharges affect water levels and silt transport along rivers. To a lesser extent, run-of-the-river hydropower plants also impact silt transport. When farming becomes less viable on these lands, the community structures built around them disappear and may create competitive societies in place of cooperative ones.[44]

Changes in water flows and physical installations affect navigation along rivers, which is a traditional method of transportation.[45] Mandating a lock system at each hydro dam or requiring run-of-the-river designs that enable passage around hydropower plants would increase project costs but also create public buy-in by preserving a valued method of transportation. However, the impacts of installing small hydro dams need not be negative. Although there will be reduced flow at certain times of the year, water released during the dry season can improve and extend the navigability of rivers.[46]

Long standing ethno-religious and herder-farmer conflicts are partly based on water availability; farmers need water for crops and herders need it for their livestock. Ethno-religious divisions tend to coincide with the divide between farmers and herders for most of the country, excluding the northern regions.[47] Factions may oppose the construction of hydroelectric projects regardless of the physical size if they perceive hydro projects as a potential barrier to accessing water. This may be through official channels like the public comment period in environmental impact assessments (EIA),[48] or through unofficial channels by protesting. The situation may worsen if one group believes they lost water because another group used a dam to store water and generate electricity at their own discretion. If run-of-the-river plants are used, the changes in water flow would be negligible, reducing potential conflict. Given the unfamiliarity with run-of-the-river plants, the differences to dammed-hydro should be explained, to garner community buy-in.

There are no single all-encompassing solution to manage competing interests. A good start is engaging stakeholders well before an EIA to achieve a positive outcome for all groups even if that is not the optimum for individuals. Another action would be to strengthen the Ministry of Power by giving it the tools to forecast and regulate, to some extent, the flows of

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[44] S.M. Toro, Post-construction effects of the Cameroonian Ladgo dam on the River Benue. Water and Environment Journal. (1997)
[45] Ibid.
[46] Ibid.
[47] Emmanuel Akinwotu, Nigeria's Farmers and Herders Fight a Deadly Battle for Scarce Resources. NY Times. (June 2018)
[48] Nerry Echefu and E. Akpofure, Environmental impact assessment in Nigeria: regulatory background and procedural framework. UN Environment Programme. (December 2001) https://www.iaia.org/pdf/case-studies/EIANigeria.pdf

water changed by installed hydroelectric plants. This would help address some concerns around equitable water and energy access.

4.7 Financing Opportunities

Financial barriers posed by the absence of stable, low-cost financing for hydropower projects are as serious as physical and technical challenges. We examine the feasibility of international and domestic investment in hydropower projects, and conduct a hypothetical NPV analysis indicating that hydropower plants may be financially appealing to investors, but that such plants' values vary dramatically based on factors such as location, capacity, and electricity prices.

4.7.1 International Investment

International bodies have invested in Nigerian hydropower. The World Bank allocated more than US $200 million to develop renewable energy projects in Nigeria.[49] In addition, the African Development Bank invested USD $100 million in hydropower plant maintenance, repairs, and investment, rehabilitating the Kainji and Jebba projects and increasing the proportion of hydropower on Nigeria's grid from 15% in 2015 to 26% in 2017.[50] The United Nations Industrial Development Organization (UNIDO) also set up a regional center focused on small hydropower development in Nigeria[51], and the Energy Commission of Nigeria signed a Memorandum of Understanding with UNIDO's International Center for Small Hydropower in China (IC-SHP) to collaborate in developing Nigeria's small and mini hydropower potential.[52]

Other nations have also provided both technical and financial investment in Nigerian hydropower. Under the Nigerian government's 2005 program to privatize electricity supply, the Transmission System Provider of Nigeria (TSP) was handed over to Manitoba Hydro International of Canada under a 3-5 year management agreement. China is a particularly prominent investor. A Chinese consortium is constructing a 3,000 MW "Nigerian Three Gorges Project" in Mambilla, which will encompass 3 dams and cost US $6 billion.[53] The Mambilla project indicates that hydropower will continue to play a significant role in Nigerian electricity generation; securing international investments for similar large-scale hydropower projects may be a feasible way to build up Nigeria's hydropower infrastructure, though attention has to be paid not to succumb to the dangers of "debt trap" diplomacy.[54]For this reason, we believe that small hydropower plants, which require less commitment from potential investors, may be worth pursuing. Following the UNIDO memorandum, China offered Nigeria support for establishing two demonstration small hydropower projects and two refurbishment projects.[55]

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[49] Ohunakin, Olayinka (2011)
[50] International Hydropower Association, Nigeria (June 2018), https://www.hydropower.org/country-profiles/nigeria
[51] United Nations Industrial Development Organization, UNIDO Projects for the Promotion of Small Hydro Power for Productive Use (January 2010), https://www.unido.org/sites/default/files/2010-02/e-book_small-hydro_0.PDF
[52] International Hydropower Association (June 2018)
[53] GCR Staff, Xi Jinping lends support to Nigeria's long delayed $6bn Mambilla dam (September 2018), http://www.globalconstructionreview.com/news/xi-jinping-lends-support-nigerias-long-delayed-6bn/
[54] The World, Built by China (NYTimes)
[55] Ibid.

4.7.2 NPV Analysis

It is hard to identify general costs for hydropower projects given that the cost for a given project is highly dependent on its location and design choices. However, to determine whether a hydropower plant could even be considered financially feasible, we conducted an NPV analysis (shown in the appendix) for a hypothetical 15 MW plant. We chose 15 MW as a middle-of-the-road value since small hydropower potentials can range from 0 to 30 MW. The electricity price of $0.12/kWh is a middle-of-the-road estimate drawn from a 2015 GIZ report on the Nigerian energy sector[56] and a 10% discount rate, 2% inflation rate, 45% capacity factor, and estimated CAPEX of $3000/kW and OPEX of $120/kW were based on similar evaluations performed by the International Renewable Energy Agency.[57]

Varying the electricity price inputted into the NPV analysis indicates that this hypothetical hydropower plant would be profitable at a levelized cost of electricity of at least 12 US cents/kWh with a NPV of $887,209 and an IRR of 3%. Since electricity prices may fall below 12 cent/kWh, it seems that building hydropower may or may not be a profitable endeavor depending on the plant's environment; however, we emphasize that a hydro plant's CAPEX and OPEX depend heavily on its geographic location and capacity, and that the costs of electricity vary.

5. Off-Grid Solar PV Analysis

5.1 Strength and Weaknesses

Solar photovoltaic electricity demonstrates strong potential for increasing electrification rates and reducing greenhouse gas emissions in rural Nigeria. The increase in electrification has positive impacts towards national development and poverty alleviation. Because the levelized cost of electricity (LCOE) for solar PV is already lower than that for off-grid diesel and gasoline generators, this technology serves as a favorable alternative to provide off-grid electricity.[58] Nigeria has high amounts of solar irradiation, with a total potential of 6,372,613 PJ per year.

However, there are high capital costs associated with solar farm development, which will require multilateral support from the Federal Government of Nigeria, private market actors, and international institutions. In addition, rural Nigeria does not have a strong local governments. This makes policy implementation more difficult. Despite this obstacle, the feasibility of solar development in the North looks promising.

5.2 Physical Potential

Nigeria possesses immense physical solar potential, with the country receiving on average 6,372,000 PJ (1,770 thousand TWh) of solar energy per year. If only one percent of this land area was covered with state-of-the-art polycrystalline photovoltaic cells, this could generate

[56] GIZ (June 2015)
[57] IRENA (June 2012)
[58] Roche, Maria Yetano. "Comparison of Costs of Electricity Generation in Nigeria." Heinrich Böll Stiftung, June 2017.

207,000 GWh per year.[59] This represents almost two times as much electricity as Nigeria's total generation capacity in 2018.[60]

Although these figures are promising, it is important to consider the differences in solar irradiation levels and population density across the country. As shown in Figure 4, the solar potential is greatest in the northern regions - at around 2200 kWh per m^2; the south of Nigeria has less potential for solar energy - at around 1600 kWh per m^2 - as it is often cloudy and has longer rainy seasons. This distribution, however, is in direct contrast with the population density. Besides Kano, which is the second most populous state in Nigeria at 3.6 million, the majority of Nigeria's population is concentrated along the southern coast; Lagos and Ibadan are the first and third most populous states in Nigeria at 9 million and 3.5 million people, respectively. Therefore, on-grid solar plants with need to optimize for transmission costs and electricity yield associated with their geographic placement. Off-grid solar eliminates the challenge of transmission, and is already substantially cheaper than electricity from off-grid gasoline or diesel. The LCOE for gasoline and diesel generated electricity is between US$0.23 and $0.42/kWh, while that of PV and hybrid systems are in the range of US$0.30/kWh and $0.22/kWh, respectively.[61] Due to the demonstrated economic advantage, the World Bank has publicly endorsed PV for off-grid applications in Nigeria.

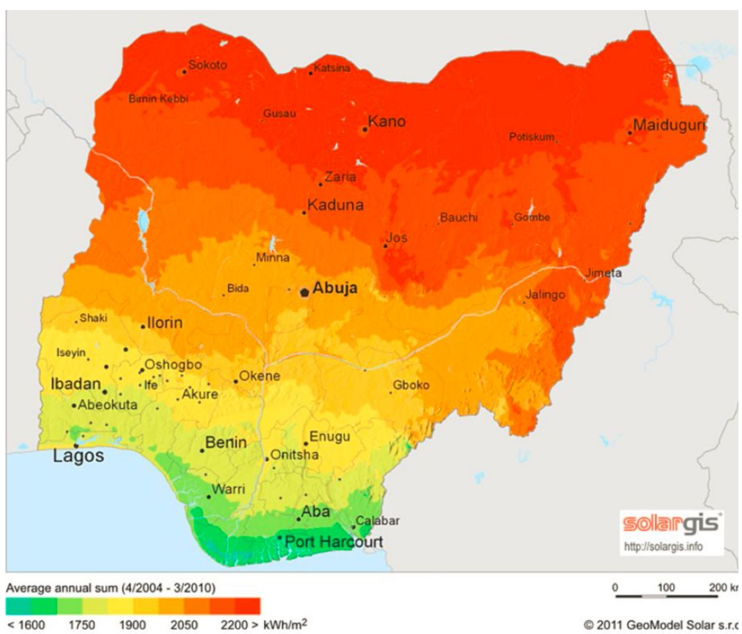

Figure 4. Solar irradiation levels, global horizontal irradiance[62]

[59] GIZ (June 2015)
[60] Power Africa, Nigeria Country Fact Sheet (November 2018) https://www.usaid.gov/powerafrica/nigeria
[61] GIZ (June 2015)
[62] Solargis, http://solargis.info (2011)

5.3 Political and Economic Potential

In response to the Federal Government of Nigeria's target to reduce carbon emissions by 45% in 2030, several policies have been implemented to promote solar energy. In November 2015, the FGN approved the Nigeria Feed-in Tariff for Renewable Energy Sourced Electricity, targeting 2 GW of renewables electricity generation by 2020, and holding DISCOs responsible for sourcing at least 50% from renewables. Furthering this effort, the FGN - through the Nigerian Bulk Electricity Trader (NBET) - signed 14 utility scale solar photovoltaic Power Purchase Agreements (PPA), with the intent to add 1.125 MW of power to the grid. None of these projects, however, have yet been able to reach financial close.[63]

Existing solar projects demonstrate the benefits of increased electrification, and help garner additional support for future projects. For example, six pilot solar mini-grids operating since early 2018 in five Nigerian states have given 15,000 people access to reliable electricity. The mini-grids were partly funded with 1.7 million euros (about $1.9 million) from the European Union and the German government in collaboration with Nigeria's state governments.[64]

PV systems have been shown to be cost effective when compared with diesel or gasoline generators for use in remote locations requiring national grid extension over a distance of 1.8 kilometers.[65] With the present effort being made to reduce cost through savings in production cost of modules and components, PV systems will become increasingly cost-competitive in the future.

5.4 Social and cultural potential

Socially and culturally there is a lot of potential for solar in Nigeria, but there are also many social and cultural constraints to be aware of. An especially important restriction for the growth of solar in Northern, rural areas is the threat of Boko Haram. An islamic terrorist organization, Boko Haram is internationally infamous for kidnapping hundreds of young Nigerian girls, along with many other atrocities. As seen in Figure 6, they are located in the area with the most photovoltaic potential (see Figure 5 above) and the driest climate. A major concern with the organization is the kidnapping of solar company employees. Since late 2018, there has been an uptick in kidnapping by Boko Haram, which will drastically slow down the rate of installation in Northern regions.[66] These panels are so important, though, because of the attacks. The Energy Commission of Nigeria, with support from the UN Development Programme, introduced solar panels for rebuilding following Boko Haram attacks. This allowed for a faster recovery and also an improvement on the quality of life: solar panels brought clean water from solar powered water pumps and allowed patients to access vaccines that required refrigeration.[67] Solar increases quality of life in very tangible aspects for rural communities.

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[63] Green Climate Fund, Funding Proposal 104: Nigeria Solar IPP Support Program (March 2019)
[64] Yee, Amy, Solar Mini-Grids Give Nigeria a Power Boost(2018) https://www.nytimes.com/2018/12/02/climate/solar-mini-grids-give-nigeria-a-power-boost.html
[65] Energy Commission of Nigeria, Renewable Energy Master Plan, REMP (November 2005)
[66] Tahir, Tahir Ibrahim. "Kidnapping: The New Wave Boko Haram." *Leadership Newspaper*, 5 May 2019.
[67] AfricaNews. "Nigerian Community Benefit from Solar Energy to Rebuild Homes after Boko Haram Attacks." *Africanews*, Africanews, 12 Jan. 2017.

Land is another important consideration within the social/cultural landscape. With the growing population, the fights over rural land has escalated. With the lack of government infrastructure in the North of Nigeria, laws that have addressed the land conflicts go largely unenforced. Another layer is the diversity of ethnic groups and split between Christians and Muslims.[68] There is an emphasis on equal distribution of solar resources and land takings, and if it is unequal, many blame the favoring of one ethnic or religious group, causing further tension and violence. This can directly impact the installation of off-grid solar that would connect to multiple villages as well as the effectiveness. With the squeezing of land, many villages are growing at rapid rates, requiring more MW of energy than the solar panels that would traditionally be installed for that region. To address these challenges, the government must take up two initiatives. Firstly, a rural specific community survey every 2-5 years (in between the country's census) by the Rural Electrification Agency of Nigeria would allow for more accurate population counts for solar installation planning, along with other data useful for rural electrification. Secondly, the government, through the FMP's Department of Renewable and Rural Power Access must work directly with land owners and herders to form land agreements when necessary. These formal agreements can then be cataloged into a database, making them more effective than local government law.

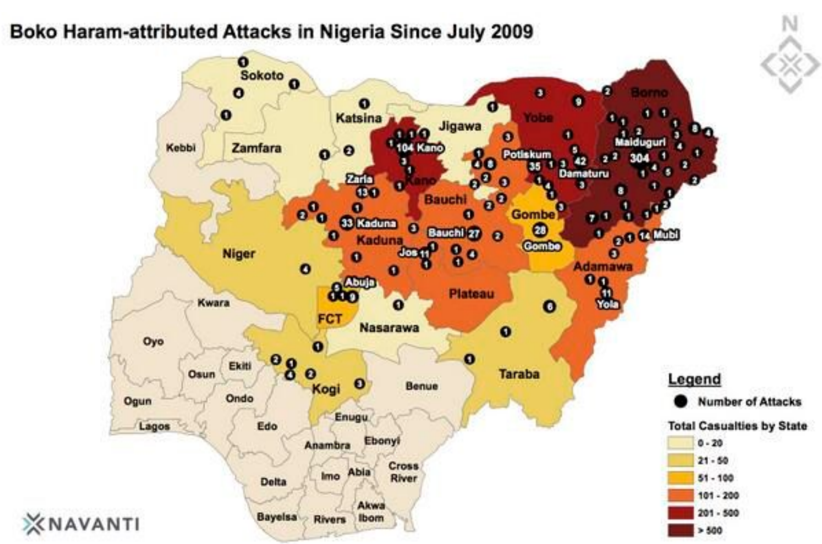

Figure 6. Map of Boko Haram Attacks (2009)[69]

The health benefits of solar cells are a clear potential amongst rural communities, one that companies are sure to emphasize. Fluorescent light bulbs and clean energy rid populations of hazardous pollutants, such as black matter, from kerosene and diesel generators. The replacement of diesel generators are particularly impactful because the access to local energy directly impacts the daily lives of community members. With individuals having to travel for

[68] Searcey, Dionne. "Nigerian Herders Face Threat From Farmers Competing for Land." *The New York Times*, 22 Sep. 2018.
[69] Beauchamp, Zack. "The Crisis in Nigeria, in 11 Maps and Charts." *Vox*, Vox, 13 May 2014.

miles in order to obtain diesel for electricity, solar cells directly connected to homes and businesses eradicates the need to travel and saves money.[70] This plays to a larger theme of the social and cultural impact of solar on people's lives, especially in rural communities. Through the access to clean, reliable electricity, communities are able to grow economically and the quality of life improves. Cell phones can be charged in order to connect globally; businesses are run consistently without the threat of power outages; students can gain access to information on the internet in order to enhance their education. People are able to gain what has become a basic human right.

5.5 Project financing

5.5.1 NPV Analysis

The NPV analysis for off-grid solar has been studied by several energy agencies over the past decade. According to a summary report by the Nigerian Economic Summit Group and Heinrich Böll Stiftung Nigeria, off-grid solar PV systems are cost competitive on a lifetime basis with diesel generators and gasoline at about $0.20/kWh.[71] The high upfront costs of solar, however, are a deterrent for investors, compared to the low upfront costs of diesel and gasoline. In order to calculate the NPV, we chose the Lazard data from the Nigerian Economic Summit Group and Heinrich Böll Stiftung Nigeria report. These numbers looked exclusively at small scale off-grid solar, so we presume that the numbers would be more favorable for larger systems that could connect to more homes. Additionally, their simplified Levelized Cost of Electricity (sLCOE) of $0.18/kWh and Fixed O&M cost of $18/kW/yr was much lower than the other sources in the report. We then calculated an NPV of $ 406,689 and IRR of 2.1% for a 1MW plant. With these numbers, it is understandable why off-grid solar PV is seen as an unfavorable, high risk but low return investment. Because of this, affordable financing becomes necessary for the construction of these systems in rural Nigeria.

5.5.2 International Investment

Nigeria's energy structure is deregulated, specifically generation and distribution are privatized while the government oversees/maintains the transmission of the electricity on the grid. The privatization has allowed for different financing options when building solar, particularly the interweaving between the public and private sector.

Within public investment, the major players are global development banks and government aid. The agencies specifically look at expanding electrification in rural areas, especially when financing solar projects. Because these rural communities are so far from transmission lines, the majority of these projects have had a focus on off-grid solar. In conjunction with the Nigerian Rural Electrification Agency, the World Bank has been financing the Nigeria Electrification project. The project aims to be the largest off-grid electrification project across 250 communities in states Niger, Ogun, Sokoto and Cross River. The project consists of four major financing components: Solar Hybrid Mini Grids for Rural Economic

[70] Yee, Amy. "Solar Mini-Grids Give Nigeria a Power Boost." *The New York Times*, 2 Dec. 2018.
[71] Roche, Maria Yetano. "Comparison of Costs of Electricity Generation in Nigeria." Heinrich Böll Stiftung, June 2017.

Development (Cost $330.00 M), Stand-alone Solar Systems for Homes and underserved (MSMEs) micro, small, and medium enterprises, (Cost $305.00 M), Energizing Education (Cost $105.00 M), Technical assistance (Cost $25.00 M). The Nigerian government has a loan from the World Bank of $5 million, the World Bank has invested $350 million, and the remaining $400 million is investment from other non-bank sources. The solar mini-grid component—the first of the project—looks to a market-based private companies to construct, maintain, and operate this mini-grid in rural communities.

6 Recommendations

The need to expand electricity access in Nigeria presents an opportunity for expanding renewables use in the country's energy system. Both hydro and solar power have ample physical capacity for meeting their assigned renewable energy targets, which will increase electrification rates and improve reliability of supply. In particular, a complementary expansion of hydro and solar power can be an effective approach for increasing both urban and rural electrification, with hydropower primarily supplying on-grid power in urban centers and solar PV for off-grid electricity in rural Nigeria.

Technical barriers to increasing small hydropower-generated electricity on the grid can be overcome through more detailed and current data collection on small hydropower resources, which are both under-surveyed and under-utilized. Politically, water management policies between states and countries that share water resources such as the Niger River need to be negotiated to ensure no conflict; similarly, smart resettlement policies should be considered to minimize social conflict if a hydropower plant location requires displacing its current residents.

Solar's decreasing costs and accessibility to rural communities make it an optimal option for off-grid electrification. Although there are concerns, this seems to be a clear solution for electrifying rural Nigeria in the coming years. This is echoed by the increased investment in solar projects within Nigeria, particularly in conjunction with partners such as the World Bank, the European Union, and USAID. In the coming years, it will be a sector that will continue to grow, but more must be done by the government in the meantime. As mentioned previously, the implementation of a rural, electrification community survey will allow for data to be utilized for solar PV planning. Additionally, the government must step in to regulate the location of these solar panels through land agreements, which should be digitized and recorded. This would allow for solar companies interesting in building to know where solar PV could be built, an important parameter especially for the development on mini-grids.

Generally, it seems that global banks and development aid can be tapped for public financial aid. It may also be worthwhile to investigate and create regulation supporting newer forms of private renewable energy project finance, such as mobile payments, or policies that build confidence for private investors to invest in Nigerian renewable energy infrastructure. Nigeria also needs to overcome a reputation for corruption to inspire more investor confidence; the country ranked poorly at 144th least corrupted of 175 countries in 2018 by one organization's index[72], and has a B credit rating (where AAA is the best possible rating, and a lower credit rating entails a higher risk of not paying back a loan). A lower credit rating increases the cost of transactions[73] and also significantly discourages foreign investment that is critical for financing energy projects;[74] thus, the government may want to look into confidence-building measures, such as timely loan payments for outstanding balances, to encourage private investment in renewable infrastructure.

Overall, we believe this combination conveniently balances the physical distributions of the power sources, as solar irradiation is more concentrated in the north, where populations are more rural and the grid infrastructure is less developed; and hydropower potential is generally stronger in the south, where urban, grid-connected populations generally live. Hydropower's relatively steady supply of energy may help balance temporal fluctuations in any on-grid solar energy supply, and solar PV will increase the electrification rates in these rural populations, improving their quality of life. As analyzed, there is an array of technical, political, social, and financial challenges in order to implement these technologies, but the increase of capacity to the grid is the first step to meeting Nigeria's energy demand.

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[72] Transparency International, Corruption Perceptions Index 2018 (Accessed May 2019), https://www.transparency.org/cpi2018
[73] S&P Global Ratings, Research Update: Nigeria 'B/B' And 'ngA/ngA-1', https://www.standardandpoors.com/en_US/web/guest/article/-/view/sourceId/20035116
[74] Osabutey, Ellis L. C. and Okoro, Chris (2015) Political risk and foreign direct investment in Africa: the case of the Nigerian telecommunications industry. Thunderbird International Business Review., 57 (6). pp. 417-429. ISSN 1096-4762

Appendix A: NPV Data

Table A1. Off-Grid Solar NPV Inputs (Lazard 2016)[75]

Parameters	**Units**	**Value**
Input	**Value**	**Units**
Inflation:		
Electricity	2.0%	per year
Maintenance	2.0%	per year
Base electricity price	$0.18	$/kWh
Installed Capacity	1000	kW
CAPEX	2400	$/kW
Plant Life	20	years
Capacity Factor	20%	
Fixed OPEX	18	$/kW
Variable OPEX	0	$/kW
Discount Rate	11%	

[75] Roche, Maria Yetano. "Comparison of Costs of Electricity Generation in Nigeria." Heinrich Böll Stiftung, June 2017.

Table A2. First 5 years of NPV analysis of 1 MW Off-Grid PV Solar

Year	0	1	2	3	4	5
Annual electricity supply [kWh]	876,000	1,752,000	1,752,000	1,752,000	1,752,000	1,752,000
Electricity Price [$/kWh]	$ 0.18	$ 0.18	$ 0.19	$ 0.19	$ 0.19	$ 0.20
Total revenue	$ 157,680	$ 321,667	$ 328,101	$ 334,663	$ 341,356	$348 183
CAPEX	$ 2,400,000	$ -	$ -	$ -	$ -	$ -
OPEX	$ 18,000	$ 18,360	$ 18,727	$ 19,102	$ 19,483	$ 19,873
Total cost	$ 2,418,,000	$ 18,3600	$ 18,727	$ 19,102	$ 19,483	$ 19,873
Cash Flow	$ (2,260,320)	$ 303,307	$ 309,307	$ 315,561	$ 321,872	$ 328,309
Discounted Cash Flow	**$ (2,260,320)**	**$ 269,942**	**$ 245,055**	**$ 222,461**	**$ 201,950**	**$ 183,330**

Results	
NPV	$ 406,689
IRR	2.1%

Table A3. Inputs for 15 MW Hydropower Plants

Input	Value	Units
Inflation:		
Electricity	2.0%	per year
Maintenance	2.0%	per year
Base electricity price	$0.10	$/kWh
Installed Capacity	1500	kW
CAPEX	3000	$/kW
Plant Life	25	years
Capacity Factor	50%	
Fixed OPEX	120	$/kW
Variable OPEX	0	$/kW
Discount Rate	10%	

Table A4. First 5 years of NPV analysis of 15 MW Hydropower Plant

Year	0	1	2	3	4	5
Annual electricity supply [kWh]	3,285,000	6,570,000	6,570,000	6,570,000	6,570,000	6,570,000
Electricity Price [$/kWh]	$ 0.10	$ 0.10	$ 0.10	$ 0.11	$ 0.11	$ 0.11
Total revenue	$ 328,500	$ 670,140	$ 683,543	$ 697,214	$ 711,158	$ 725,381
CAPEX	$ 4,500,000	$ -	$ -	$ -	$ -	$ -
OPEX	$ 180,000	$ 183,600	$ 187,272	$ 191,017	$ 194,838	$ 198,735
Total cost	$ 4,680,000	$ 183,600	$ 187,272	$ 191,017	$ 194,838	$ 198,735
Cash Flow	$ (4,351,500)	$ 486,540	$ 496,271	$ 506,196	$ 516,320	$ 526,647
Discounted Cash Flow	**$ (4,351,500)**	**$ 437,886**	**$ 401,979**	**$ 369,017**	**$ 338,758**	**$ 310,980**

Results	
NPV	$ 359,626
IRR	0.9%