A case study of the usage of solar powered, microgrid clusters in the generation of electricity in Nigeria.

To what extent do solar powered, microgrid clusters improve energy security for those living in urban areas within the country of Nigeria?

Table of Contents:

I. Introduction:

In the past 3 decades, the issue of sustainable development has increasingly gained importance on a local and global scale.[1] Many countries around the world have either adopted, or have expressed interest in, policies that promote sustainability, which the UN defines as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." There are three main pillars associated with sustainable development, environment protection, economic improvement, and social justice.[2] Unfortunately, disparities in government effectiveness and country wealth mean that there is no one-size-fits-all method to become sustainable. For developing countries, large changes towards sustainability may not be a viable option.

Nigeria is one such example of a developing country that has limited options for improvement. Even without the issue of environmental protection, the country is lagging on other basic aspects of sustainability. For example, many of its citizens live in poverty and with dire living conditions.[3] Thus, making changes towards more eco-friendly development did not seem possible until recent years.

As improvements in renewable energy technology have been made, many ways to both improve the quality of life and protect the environment in developing countries have come to light. One area where this is evident is the energy sector. In Nigeria, many people have no access

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[1] Marie-Claire Cordonier Segger and Ashfaq Khalfan. "Origins of the Sustainable Development Concept *." In *Sustainable Development Law: Principles, Practices, and Prospects*, by Cordonier Segger, Marie-Claire, and Ashfaq Khalfan.. Oxford: Oxford University Press, 2004. Oxford Scholarship Online, 2012. doi: 10.1093/acprof:oso/9780199276707.003.0002.

[2] "Sustainable Development | 75th Economic and Social Council," United Nations (United Nations), accessed December 9, 2021, https://www.un.org/ecosoc/en/sustainable-development.

[3] Obinna Ositadimma Oleribe and Simon David Taylor-Robinson, "Before Sustainable Development Goals (SDG): Why Nigeria Failed to Achieve the Millennium Development Goals (Mdgs)," *Pan African Medical Journal* 24 (2016), https://doi.org/10.11604/pamj.2016.24.156.8447.

to electricity, particularly in rural areas.[4] To solve this problem, organizations such as the US-based non-profit Rocky Mountain Institute, have begun to set up solar powered microgrids in these areas.[5] At the same time, the people of Nigeria who live in urban areas have been largely ignored by these organizations. Many of these residents also either have no, or unreliable, access to power.[6] Thus, in this essay, I will be answering the research question: To what extent do solar powered, microgrid clusters improve energy security for those living in urban areas within the country of Nigeria? To this end, I will examine two separate case studies on the usage of solar powered, microgrid clusters in the generation of electricity in Nigeria. These case studies will each represent one of my two chosen disciplines – economics and environmental science.

Overall, the discipline of economics will be used to assess the cost and macroeconomic changes needed to implement solar powered microgrids in urban areas. Assessing the cost of microgrids is important as the main aspect of energy security is the price of energy. Determining the macroeconomic changes necessary is important as Nigeria is a developing country, meaning that the resource and wealth allocation of its government is crucial to determining its future. If appropriate policies cannot be implemented to make the use of solar powered microgrids within urban areas cost-effective enough for the average Nigerian, alternatives will have to be considered.

The discipline of environmental science will be used to compare solar powered microgrids with other forms of generating energy. Current methods to achieve power, such as burning fossil fuels, are unsustainable. Thus, energy security cannot be provided through such

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[4] Laura Mellado, "Bringing Reliable Electricity to Rural Communities in Nigeria - EU External Investment Plan European Commission," EU External Investment Plan (European Commission), accessed December 9, 2021, https://ec.europa.eu/eu-external-investment-plan/stories/bringing-reliable-electricity-rural-communities-nigeria_en.

[5] "Connecting Rural Nigeria," African Energy Elites, January 28, 2021, https://www.african-energy-elites.com/rural-electrification/connecting-rural-nigeria/.

[6] Samuel Ayokunle Olówósejéjé, "What Nigeria's Poor Power Supply Really Costs and How a Hybrid System Could Work for Business," The Conversation, October 18, 2021, https://theconversation.com/what-nigerias-poor-power-supply-really-costs-and-how-a-hybrid-system-could-work-for-business-144609.

methods as one day, the world's supply of accessible fossil fuels will run out.[7] On the other hand, by looking at the effectiveness of solar powered microgrids, it can be assessed whether or not solar power is the best way to maintain continuous power, compared to other renewable energy sources.

An interdisciplinary approach is necessary for this essay because the issue of sustainable development itself pertains to both the economic and environmental science perspectives. While environmental protection is a very important goal, it is key to remember that many developing countries do not have the economies necessary to sustain such development and improve the lives of their citizens. In such cases, there is always a trade-off, where the quality of life is generally valued higher. The key here is to find the optimal balance between these two factors.

[7] Hannah Ritchie, "How Long before We Run out of Fossil Fuels?," Our World in Data, August 8, 2017, https://ourworldindata.org/how-long-before-we-run-out-of-fossil-fuels.

II. Energy Security in Nigeria:

Energy security is defined as "the continuous availability of energy in varied forms, in sufficient quantities, and at reasonable prices."[8] Energy security is dependent on many factors, including, but not limited to, energy infrastructure, energy sources, and energy policies.

As a country, Nigeria's main energy security problem comes from the lack of available electricity. Only 56.5% of Nigeria's population has access to electricity, as compared to a global percentage of 89.6%,[9] and a 2020 World Bank Report ranked Nigeria 171st out of 190 countries in terms of electricity availability.[10] There are three main reasons for such shortages. The first is a lack of government investment in electricity infrastructure. The second is a decrease in private investment caused by a negative perception of the electricity tariff system. The third is an issue with the fuel supply. Many gas suppliers don't want to supply power plants with gas as the government's buying price is much lower than what can be found on the market. Even when gas suppliers are willing to work with power plants, many of the pipelines are tapped into and vandalized, disrupting the supply of gas.[11]

Even for those who are connected to the electric grid, the cost of electricity is oftentimes too high for the average consumer to use power.[12] After recent hikes in electricity tariffs, the average Nigerian resident is charged anywhere between N20 to N30 ($.05 to $.07) per kWh

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[8]Hisham Khatib, et al. "World Energy Assessment: United Nations Development Programme, United Nations Department of Economics and Social AFFAIRS, World Energy Council, World Energy Assessment and the Challenge of SUSTAINABILITY (2000)." *Compendium of Sustainable Energy Laws*, 2005, p. 111.

[9] Peter Hansen. "A Significant Portion of Nigeria's Population Is Still without Access to Electricity." Climate Scorecard, 1 Feb. 2021, www.climatescorecard.org/2021/02/a-significant-portion-of-nigerias-population-is-still-without-access-to-electricity/.

[10] "Doing Business 2020," World Bank, *World Bank Publications*, The World Bank, July 2020.

[11]Natasha Mellersh. "A Scramble for Power – the Nigerian Energy Crisis Explained: ALB ARTICLE." ALB Legal and Business Issues from Africa, Global Legal Group, 13 July 2015, iclg.com/alb/5679-a-scramble-for-power-the-nigerian-energy-crisis-explained.

[12] "Challenges and Interventions Needs in the Nigerian Electricity Supply Industry (NESI)." *CENTRE FOR THE STUDY OF THE ECONOMIES OF AFRICA*, cseaafrica.org/challenges-and-interventions-needs-in-the-nigerian-electricity-supply-industry-nesi/.

(kilowatt hour) depending on where they live.[13] While this may seem relatively cheap compared to US electricity costs, it is important to note that Nigeria's GDP per capita is around $2000, compared to $63,500 for the US.[14]

Due to such limitations, many Nigerians have turned to generators and other self-generated power. Ugochukwu K. Elinwa et al. reports that "84% of all urban households depend on a gasoline or diesel-powered generator for electricity."[15] Problematically, the exhaust from such generators can cause many problems. For example, many diesel-powered generators produce nitrogen oxide, which is a major cause of ozone depletion. In addition, many of the contaminants in the exhaust are known as cancer-causing substances.[16]

[13] Kingsley Jeremiah Abuja. "Nigerians to Pay More for Electricity from April." *The Guardian Nigeria News - Nigeria and World News*, 4 Jan. 2020, https://guardian.ng/news/nigerians-to-pay-more-for-electricity-from-april/.

[14] "GDP per Capita (Current Us$)." GDP per Capita (Current US$), World Bank.

[15] Ugochukwu K. Elinwa, et al. "Cleaner Energy in NIGERIA Residential Housing." *Results in Engineering*, vol. 9, Mar. 2021, p. 1. doi:10.1016/j.rineng.2020.100103.

[16] Niyi Awofeso. "Generator Diesel EXHAUST: A Major Hazard to Health and the Environment in Nigeria." *American Journal of Respiratory and Critical Care Medicine*, vol. 183, no. 10, 2011, pp. 1437–1437, doi:10.1164/ajrccm.183.10.1437.

III. Solar Powered Microgrids:

A microgrid is "a group of interconnected loads and distributed energy resources that can connect and disconnect from the [main] grid."[17] While microgrids can be powered by a variety of sources, including distributed generators and batteries,[18] solar powered microgrids have gained popularity as a climate-friendly way to produce energy.

In recent years, many developing countries have started using solar powered microgrids as a way to provide electricity to those not connected to the national grid. The main reason for this expansion is a decrease in the cost needed for renewable power generation. The International Renewable Energy Agency found that "costs for electricity from utility-scale solar photovoltaics (PV) fell 85% between 2010 and 2020."[19]

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[17] Dan T. Ton and Merrill A. Smith. "The U.S. Department of Energy's Microgrid Initiative." *The Electricity Journal*, vol. 25, no. 8, 2012, pp. 84–94, doi:10.1016/j.tej.2012.09.013.

[18] "Microgrids – What Are They and How Do They Work?" *NSci Technologies*, 7 Nov. 2019, nsci.ca/2019/11/08/microgrids-what-are-they-and-how-do-they-work/.

[19] "Renewable Power Generation Costs in 2020." IRENA, *International Renewable Energy Agency*, 2020.

IV. Economics:

Whether or not solar powered microgrids will be successful in improving energy security for Nigerians is largely dependent on whether changes in Nigerian governmental policy will lead to cheaper solar equipment. The study**:** *Integrating a Solar PV System with a Household Based Backup Generator for Hybrid Swarm Electrification: A Case Study of Nigeria*, found that while a solar powered electricity generation system would reduce the LCoE (Levelized Cost of Electricity) by around 34%, the largest barrier to building a solar powered microgrid would be the ICS (Initial Cost of System). This is mainly because the equipment needed to generate solar power typically has a high upfront cost,[20] which many Nigerians cannot afford without help from outside sources. As the Nigerian government maintains control over energy distribution,[21] the availability of outside help will largely be affected by macroeconomic policy.

The Keynesian economic model is particularly applicable here. The Keynesian economic theory argues that the government can "directly influence the demand for goods and services by altering tax policies and public expenditures."[22] This theory is important as it connects macroeconomic policy changes with microeconomic responses that ensue. This is exactly what happens within the energy sector as changes in Nigerian governmental control lead to changes within private organizations such as businesses, non-profits, and the private companies that run the power distribution system[23]. Under this theory, it becomes key that the government expresses

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[20] Rolex Muceka, et al. "Integrating a Solar Pv System with a Household Based Backup Generator for Hybrid Swarm Electrification: A Case Study of Nigeria." *Springer Proceedings in Energy*, 2018, pp. 43–58, doi:10.1007/978-3-319-93438-9_4.

[21] Yemi Oke, "Conflicting Laws Keep Nigeria's Electricity Supply Unreliable," The Conversation, October 27, 2019, https://theconversation.com/conflicting-laws-keep-nigerias-electricity-supply-unreliable-81393.

[22] The Editors of Encyclopaedia Britannica, "Keynesian economics". *Encyclopedia Britannica*, 18 Apr. 2017, https://www.britannica.com/topic/Keynesian-economics. Accessed 20 October 2021.

[23] Ayodeji Adegboyega, "Inside Nigeria's Electricity Companies and Their Perpetual Loss-Making," Premium Times Nigeria, August 24, 2021, https://www.premiumtimesng.com/news/headlines/480730-inside-nigerias-electricity-companies-and-their-perpetual-loss-making.html#:~:text=In%202013%2C%20the%20government%20unbundled,arm%20run%20by%20the%20government.

interest and creates policies that promote the innovation and usage of renewable energy. In particular, government investment is important as it is can promote energy security and affordability, create jobs, and address environmental and other externalities.[24]

One such policy would be government encouragement towards innovations of solar energy technology. Improvements in technology mean that the ACS (Annualized Cost of the System) – which is calculated by finding the sum of the ACC (Annualized Capital Cost), AOM (Annualized Operation and Maintenance Cost), ARC (Annualized Replacement Cost), and AFC (Annualized Fuel Consumption Cost) – will decrease. One reason for this change is because innovations that improve aspects such as the durability of PV cells will decrease the AOM and ARC,[25] allowing solar powered microgrids to become cheaper for the average Nigerian. Empirically, this has been shown to be true as the Berkeley Lab in 2020 found that innovations in technology have led to an increase in the lifetime of utility-scale solar from 21.5 years in 2007 to 32.5 years. Additionally, the costs of operation and maintenance have dropped from $35 per kWDC (kilowatts DC) per year in 2007 to $17 per kWDC per year.[26]

Additionally, the Nigerian government needs to shift energy subsidies away from fossil fuels and towards renewable energy sources such as solar energy in order to incentivize use. In the past 16 years, Nigeria has spent over $30 billion on fossil fuel subsidies.[27] Even if only a portion of the money spent on fossil fuel subsidies was directed towards renewable energy,

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[24] "Beyond the Debate: The Role of Government in Renewable Energy Finance." *Science in the News*, 12 Aug. 2013, https://sitn.hms.harvard.edu/flash/2012/energy-finance/.

[25] Rolex Muceka, et al. "Integrating a Solar Pv System with a Household Based Backup Generator for Hybrid Swarm Electrification: A Case Study of Nigeria." *Springer Proceedings in Energy*, 2018, pp. 43–58, doi:10.1007/978-3-319-93438-9_4.

[26] William Driscoll. "Pv Plants Lasting Longer, with Lower Operational Costs." *Pv Magazine International*, 3 June 2020, www.pv-magazine.com/2020/06/03/pv-plants-lasting-longer-with-lower-operational-costs/.

[27] Stephen Onyeiwu, "Fuel Subsidies in Nigeria: They're Bad for the Economy, but the Lifeblood of Politicians," The Conversation, November 4, 2021, https://theconversation.com/fuel-subsidies-in-nigeria-theyre-bad-for-the-economy-but-the-lifeblood-of-politicians-170966.

significant improvements would still occur. Historically, subsidies have increased solar adoption globally by 49% from 2010 to 2015. In addition, the increased technological innovation induced by these subsidies has also led to increased adoption as well as various social benefits.[28] If similar results occur within Nigeria, many more Nigerians living in urban areas would have access to energy.

Lastly, foreign direct investment (FDI) can also be extremely helpful in increasing accessibility of solar powered microgrids. While costs of PV cells have decreased over time,[29] the equipment is still expensive. Current investment in solar power within Nigeria is limited[30] and the large amount of money needed to start a solar microgrid is difficult to acquire. FDI could be a possible way to gain this money, but Nigeria has been notoriously known for its difficulty to do business. Thus, "foreign direct investment would be minimal." Another problem is that renewable energy businesses also have "restricted access to capital" as there are no "specialized funds for renewable energy investment."[31] This means that the chance that Nigerian companies will be able to develop their own solar technology is rather small, meaning that any technology will have to be imported from other countries. Problematically, duties on the importation of solar products into Nigeria increase the prices of the panels, further deterring the creation of solar powered microgrids.[32] Changes towards these governmental policies will need to be made if solar powered microgrids are to ever become successful.

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[28] Todd D. Gerarden, "Demanding Innovation: The Impact of Consumer Subsidies on Solar Panel Production Costs." Cambridge, MA: Harvard Environmental Economics Program, 2018. https://scholar.harvard.edu/files/gerarden/files/gerarden_jmp.pdf

[29] David L. Chandler, "Explaining the Plummeting Cost of Solar Power," MIT News | Massachusetts Institute of Technology, November 20, 2018, https://news.mit.edu/2018/explaining-dropping-solar-cost-1120.

[30] Ogheneruona Endurance Diemuodeke et al., "Solar PV Electrification in Nigeria: Current Status and Affordability Analysis," *Journal of Power and Energy Engineering* 09, no. 05 (2021): pp. 1-25, https://doi.org/10.4236/jpee.2021.95001.

[31] Gbadebo Collins Adeyanju, et al. "Exploring the POTENTIALS, Barriers and Option for Support in the NIGERIA Renewable Energy Industry." *Discover Sustainability*, vol. 1, no. 1, 2020, doi:10.1007/s43621-020-00008-5.

[32] Chijioke Mama. "What's the Current State of Solar Equipment Import Trade in Africa?" *Solar Magazine*, 24 Feb. 2021, solarmagazine.com/state-of-solar-equipment-import-trade-in-africa/.

Overall, it can be concluded that governmental interference is crucial towards increased adoption of solar powered microgrids, by allowing for cheaper solar power equipment. This overall will improve energy security for Nigerians, as solar power as a whole is cheaper than fossil fuels when considered over an extended period of time. As long as the upfront cost of buying solar technology is decreased through policy changes, more Nigerians will be able to access the equipment and thus, receive power. Thankfully, as the economic benefits of solar power become increasingly apparent, the Nigerian government has already started moving in the right direction,[33] inspiring hope that achieving energy security for Nigerians in urban areas is not a far-off goal.

[33] Tope Alake, "Nigeria Bets on Solar to Power Its Covid Recovery," Bloomberg.com (Bloomberg, April 8, 2021), https://www.bloomberg.com/news/articles/2021-04-08/nigeria-bets-on-solar-to-power-its-covid-recovery.

V. Environmental Science:

Environmental science is defined as an "interdisciplinary academic field that draws on ecology, geology, meteorology, biology, chemistry, engineering, and physics to study environmental problems and human impacts on the environment."[34] Since a component of energy security is continual availability of energy, it is important to identify the most stable and sustainable form of energy. All fossil fuels do not fit this requirement as at some point, they will run out, meaning that they are unable to provide continuous electricity. Thus, the only form of energy that truly provides energy security in the long term is renewable energy.

Between the main sources of renewable energy, it is important to distinguish which is the best fit for urban areas in Nigeria. Environmental science can be used to compare between the different sources, taking into consideration geographical location, weather, and climate. Some sources of renewable energy may not be suitable for use as a power source for urban microgrids as they may be too costly or too inconsistent to be used as a power source.

Solar power is typically the most publicized form of renewable energy. Yet, it also has its drawbacks. As previously covered, the upfront cost of PV cells can be very expensive. Additionally, solar panels cannot generate electricity when there is no sun. This and other problems mean that it is very possible that solar powered microgrids may not be the optimal choice for urban areas in Nigeria. That is why a comparative analysis between renewable energy sources using environmental science is important.

The study: *Optimal Microgrid Power Supply System for Nigerian Detached Communities: Environmental Impact and Energy Cost Criteria*, found that solar powered

[34]Bill Kte'pi. "Environmental science". *Encyclopedia Britannica*, 27 Dec. 2018, https://www.britannica.com/science/environmental-science.

microgrids with battery storage were "the most environmentally friendly and cost effective" in urban areas where there is still grid supply. In comparison, microgrids powered by wind energy were more suitable for rural areas where there was more space and less "grid availability." In either case, both strategies were rated higher than the current combination of diesel generators and connection to the national grid. What is interesting to note is that this study found that combining solar power with diesel generators and battery storage was less environmentally harmful than combining wind power with diesel generators and battery storage.[35]

As Nigeria's main renewable energy sources are solar, hydropower, and wind,[36] the above study does not fully cover all the potentials for renewable energy generation. At the same time, the conclusion of the study cannot be fully ignored. The main reason for this is the limited area in which hydropower is available. In a microgrid, the source of energy should be near the area that is being powered by it. Thus, a hydropower microgrid would only be possible in a few select areas, meaning that it is not that important for the purposes of this investigation.

Another important aspect to consider is the reason why solar power is a more effective microgrid energy source compared to wind power. The most likely factor that could have led to this result is the amount of space needed for wind turbines to be effectively placed. Due to their large size, wind turbines generally need to be placed in areas with large expanses of empty land. Urban areas do not fit this criterion. Thus, for an urban microgrid to be powered by wind, more equipment would be needed to provide houses with electricity. Additionally, "the cost of travel and maintenance on the turbines increases [with distance]",[37] creating an additional expense that

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[35] J. Akinbomi, et al. "Optimal Microgrid Power Supply System for Nigerian Detached Communities: Environmental Impact and Energy Cost Criteria." *Nigerian Journal of Technology*, vol. 40, no. 3, May 2021, pp. 491–500, doi:10.4314/njt.v40i3.15.

[36] Okafor, et al. "Challenges to Development of Renewable Energy for Electric Power Sector in Nigeria." *International Journal of Academic Research*, 2010, pp. 211–216, https://doi.org/10.1186/2192-0567-2-15.

[37] Dallas Lloyd. "Wind Energy: Advantages and Disadvantages." *Wind Energy: Advantages and Disadvantages*, 11 Dec. 2014, large.stanford.edu/courses/2014/ph240/lloyd2/.

could be avoided with the use of solar energy. In comparison, solar panels can be installed within cities, with many developed countries choosing to place panels on the rooftops of buildings.

An important issue to note is the inconsistency of both solar panels and wind energy. Out of the main sources of renewable energy, only hydropower can constantly provide power regardless of the weather. Thus, during the rainy season, the energy generated by solar panels may not be enough to ensure energy security for Nigerians. There are a few possible solutions to this. The first, is by storing energy in the batteries of the microgrid prior to the rainy season. If enough energy is generated and stored, it may still be possible to have electricity during the season without turning to diesel generators. Another solution is connecting the microgrid to the central national grid. Although the cost of electricity may increase, the time that users will pay this money will be comparatively short as opposed to the yearlong usage of the microgrid. Either way, energy security will still be improved through the usage of the microgrid as for a greater part of the year, energy will both be more consistent and more affordable for the average citizen.

VI. Global Application:

The two case studies on solar powered microgrids show that they can be a very possible option to improve energy security in urban areas of Nigeria. This is very promising, as this result shows that economic and societal development need not come at the expense of the environment. In particular, it shows that renewable energy sources can now compete with fossil fuels and even replace fossil fuel usage. This refutes the mainstream opinion that developing countries cannot worry about climate change as they would be doing so at the expense of their people. It is clear by looking at the potential of solar powered microgrids, that renewable energy sources will not stunt economic and social improvement within developing countries and may even be beneficial to this cause.

At the same time, the economic case study shows that government support of renewable energy resources is still needed. Many governments in developing countries today still have policies in place that benefit fossil fuels and other non-renewable sources of energy. These policies are severely outdated, and if not changed, may actually harm the people of the country by depriving them of energy security. In addition, these policies will exacerbate the effects of global warming and climate change, both of which have very severe and wide-ranging impacts. For example, OXAM International finds that tens, if not hundreds of millions of people would be thrown into poverty should the world reach the two-degree threshold, as hunger, displacement and natural disasters grow.[38]

The future of renewable energy is very bright. As renewables, for the first time, become cheaper than fossil fuels, investment into this technology has also become much more appealing.

[38] "Rising Temperatures Will Push Millions of People into Poverty Unless Governments Take Swift Action," Oxfam International, October 24, 2018, https://www.oxfam.org/en/press-releases/rising-temperatures-will-push-millions-people-poverty-unless-governments-take-swift.

As long as governments start to acknowledge the need to start limiting the usage of fossil fuels, the transition to renewable energy will not take long. This transition is necessary as fossil fuel supplies are finite, and fossil fuels themselves are extremely harmful.

VII. Conclusion:

Solar powered microgrid clusters have been generally viewed as an effective way to improve energy security in rural areas. Yet, the potentials of this new technology have not been widely analyzed with regards to more densely populated areas. Through the two case studies analyzed, it can be concluded that such clusters are still a very possible option for urban areas, as they can increase the affordability and accessibility of energy while also providing sustainability that other alternatives can rarely provide.

When considering the economic implications of such microgrid clusters, the Keynesian macroeconomic theory is particularly important as it focuses on the role of the government within the economy. This is particularly critical in ensuring that solar powered microgrid clusters become accessible and beneficial to the general public. Unfortunately, Nigeria's current government policies are not helpful to the promotion of such technology. A few key policy changes will need to be made. These include implementing policies that improve innovation, implementing subsidies for renewable energy, and solar power in particular, and working to encourage FDI. Thus, the stance of Nigeria's government from now on will become particularly crucial in determining the exact benefits of solar powered microgrids to urban energy security.

When considering the environmental impacts of microgrid clusters, it can undoubtedly be concluded that they are much more sustainable than the petroleum generators used in the status quo. This sustainability directly impacts energy security, as fossil fuels are limited resources, while the sun and other forms of renewable energy are much more reliable in the long term. In addition, solar power is uniquely important, as the case study explicitly finds that, other forms of renewable energy are not as effective at generating power. At the same time, there are some drawbacks of solar power, such as the fact that it is not available on overcast days. Luckily,

microgrids have batteries within their grid, meaning that power can be stored. Additionally, the microgrid can be attached to the national grid in times of great need. This overall means that solar power is still much better than fossil fuels in providing a reliable energy source.

After combining both the economic and environmental considerations, the answer to the question: To what extent do solar powered, microgrid clusters improve energy security for those living in urban areas within the country of Nigeria, becomes clearer. By using environmental science, it can be determined that solar power is the best form of power to improve energy security. By using economics, it can be concluded that solar powered, microgrid clusters can be implemented within Nigeria as long as government policy is sufficient and effective. Overall, this creates a very promising view of the future of energy security for Nigerians living in urban areas.

VIII. Bibliography:

Abuja, Kingsley Jeremiah. “Nigerians to Pay More for Electricity from April.” *The Guardian Nigeria News - Nigeria and World News*, 4 Jan. 2020, https://guardian.ng/news/nigerians-to-pay-more-for-electricity-from-april/.

Adegboyega, Ayodeji. “Inside Nigeria's Electricity Companies and Their Perpetual Loss-Making.” Premium Times Nigeria, August 24, 2021. https://www.premiumtimesng.com/news/headlines/480730-inside-nigerias-electricity-companies-and-their-perpetual-loss-making.html#:~:text=In%202013%2C%20the%20government%20unbundled,arm%20run%20by%20the%20government.

Adeyanju, Gbadebo Collins, et al. “Exploring the POTENTIALS, Barriers and Option for Support in the NIGERIA Renewable Energy Industry.” *Discover Sustainability*, vol. 1, no. 1, 2020, doi:10.1007/s43621-020-00008-5.

Akinbomi, J., et al. “Optimal Microgrid Power Supply System for Nigerian Detached Communities: Environmental Impact and Energy Cost Criteria.” *Nigerian Journal of Technology*, vol. 40, no. 3, May 2021, pp. 491–500., doi:10.4314/njt.v40i3.15.

Alake, Tope. “Nigeria Bets on Solar to Power Its Covid Recovery.” Bloomberg.com. Bloomberg, April 8, 2021. https://www.bloomberg.com/news/articles/2021-04-08/nigeria-bets-on-solar-to-power-its-covid-recovery.

Awofeso, Niyi. “Generator Diesel EXHAUST: A Major Hazard to Health and the Environment in Nigeria.” *American Journal of Respiratory and Critical Care Medicine*, vol. 183, no. 10, 2011, pp. 1437–1437, doi:10.1164/ajrccm.183.10.1437.

"Beyond the Debate: The Role of Government in Renewable Energy Finance." *Science in the News*, 12 Aug. 2013, https://sitn.hms.harvard.edu/flash/2012/energy-finance/.

Britannica, The Editors of Encyclopaedia. "Keynesian economics". *Encyclopedia Britannica*, 18 Apr. 2017, https://www.britannica.com/topic/Keynesian-economics. Accessed 20 October 2021.

"Challenges and Interventions Needs in the Nigerian Electricity Supply Industry (NESI)." *CENTRE FOR THE STUDY OF THE ECONOMIES OF AFRICA*, cseaafrica.org/challenges-and-interventions-needs-in-the-nigerian-electricity-supply-industry-nesi/.

Chandler, David L. "Explaining the Plummeting Cost of Solar Power." MIT News | Massachusetts Institute of Technology, November 20, 2018. https://news.mit.edu/2018/explaining-dropping-solar-cost-1120.

"Connecting Rural Nigeria." African Energy Elites, January 28, 2021. https://www.african-energy-elites.com/rural-electrification/connecting-rural-nigeria/.

Diemuodeke, Ogheneruona Endurance, Yacob Mulugetta, Henry Ifeanyi Njoku, Tobinson Alasin Briggs, and Mohammed Moore Ojapah. "Solar PV Electrification in Nigeria: Current Status and Affordability Analysis." *Journal of Power and Energy Engineering* 09, no. 05 (2021): 1–25. https://doi.org/10.4236/jpee.2021.95001.

Driscoll, William. “Pv Plants Lasting Longer, with Lower Operational Costs.” *Pv Magazine International*, 3 June 2020, www.pv-magazine.com/2020/06/03/pv-plants-lasting-longer-with-lower-operational-costs/.

Elinwa, Ugochukwu K., et al. “Cleaner Energy in NIGERIA Residential Housing.” *Results in Engineering*, vol. 9, Mar. 2021, p. 1. doi:10.1016/j.rineng.2020.100103.

Gerarden, Todd D. “Demanding Innovation: The Impact of Consumer Subsidies on Solar Panel Production Costs.” Cambridge, MA: Harvard Environmental Economics Program, 2018. https://scholar.harvard.edu/files/gerarden/files/gerarden_jmp.pdf

Hansen, Peter. “A Significant Portion of Nigeria's Population Is Still without Access to Electricity.” *Climate Scorecard*, 1 Feb. 2021, www.climatescorecard.org/2021/02/a-significant-portion-of-nigerias-population-is-still-without-access-to-electricity/.

Hayes, Adam. “Economics.” *Investopedia*, Investopedia, 13 Sept. 2021, www.investopedia.com/terms/e/economics.asp.

IRENA, “Renewable Power Generation Costs in 2020.” *International Renewable Energy Agency*, 2020.

Khatib, Hisham, et al. “World Energy Assessment: United Nations Development Programme, United Nations Department of Economics and Social AFFAIRS, World Energy Council, World Energy Assessment and the Challenge of SUSTAINABILITY (2000).” *Compendium of Sustainable Energy Laws*, 2005, p. 111. doi:10.1017/cbo9780511664885.002.

Kte'pi, Bill. "Environmental science". *Encyclopedia Britannica*, 27 Dec. 2018, https://www.britannica.com/science/environmental-science.

Lloyd, Dallas. “Wind Energy: Advantages and Disadvantages.” *Wind Energy: Advantages and Disadvantages*, 11 Dec. 2014, large.stanford.edu/courses/2014/ph240/lloyd2/.

Mama, Chijioke. “What's the Current State of Solar Equipment Import Trade in Africa?” *Solar Magazine*, 24 Feb. 2021, solarmagazine.com/state-of-solar-equipment-import-trade-in-africa/.

Mellado, Laura. “Bringing Reliable Electricity to Rural Communities in Nigeria - EU External Investment Plan European Commission.” EU External Investment Plan. European Commission. Accessed December 9, 2021. https://ec.europa.eu/eu-external-investment-plan/stories/bringing-reliable-electricity-rural-communities-nigeria_en.

Mellersh, Natasha. “A Scramble for Power – the Nigerian Energy Crisis Explained: ALB ARTICLE.” *ALB Legal and Business Issues from Africa*, Global Legal Group, 13 July 2015, iclg.com/alb/5679-a-scramble-for-power-the-nigerian-energy-crisis-explained.

“Microgrids – What Are They and How Do They Work?” *NSci Technologies*, 7 Nov. 2019, nsci.ca/2019/11/08/microgrids-what-are-they-and-how-do-they-work/.

Muceka, Rolex, et al. “Integrating a Solar Pv System with a Household Based Backup Generator for Hybrid Swarm Electrification: A Case Study of Nigeria.” *Springer Proceedings in Energy*, 2018, pp. 43–58, doi:10.1007/978-3-319-93438-9_4.

Okafor, et al. “Challenges to Development of Renewable Energy for Electric Power Sector in Nigeria.” *International Journal of Academic Research*, 2010, pp. 211–216, https://doi.org/10.1186/2192-0567-2-15.

Oke, Yemi. “Conflicting Laws Keep Nigeria's Electricity Supply Unreliable.” The Conversation, October 27, 2019. https://theconversation.com/conflicting-laws-keep-nigerias-electricity-supply-unreliable-81393.

Oleribe, Obinna Ositadimma, and Simon David Taylor-Robinson. “Before Sustainable Development Goals (SDG): Why Nigeria Failed to Achieve the Millennium Development Goals (Mdgs).” *Pan African Medical Journal* 24 (2016). https://doi.org/10.11604/pamj.2016.24.156.8447.

Olówósejéjé, Samuel Ayokunle. “What Nigeria's Poor Power Supply Really Costs and How a Hybrid System Could Work for Business.” The Conversation, October 18, 2021. https://theconversation.com/what-nigerias-poor-power-supply-really-costs-and-how-a-hybrid-system-could-work-for-business-144609.

Onyeiwu, Stephen. “Fuel Subsidies in Nigeria: They're Bad for the Economy, but the Lifeblood of Politicians.” The Conversation, November 4, 2021. https://theconversation.com/fuel-subsidies-in-nigeria-theyre-bad-for-the-economy-but-the-lifeblood-of-politicians-170966.

“Rising Temperatures Will Push Millions of People into Poverty Unless Governments Take Swift Action.” Oxfam International, October 24, 2018. https://www.oxfam.org/en/press-releases/rising-temperatures-will-push-millions-people-poverty-unless-governments-take-swift.

Ritchie, Hannah. “How Long before We Run out of Fossil Fuels?” Our World in Data, August 8, 2017. https://ourworldindata.org/how-long-before-we-run-out-of-fossil-fuels.

Segger, Marie-Claire Cordonier, and Ashfaq Khalfan. "Origins of the Sustainable Development Concept *." In *Sustainable Development Law: Principles, Practices, and Prospects*, by

Cordonier Segger, Marie-Claire, and Ashfaq Khalfan.. Oxford: Oxford University Press, 2004. Oxford Scholarship Online, 2012. doi: 10.1093/acprof:oso/9780199276707.003.0002.

"Sustainability." United Nations. United Nations. https://www.un.org/en/academic-impact/sustainability#:~:text=In%201987%2C%20the%20United%20Nations,development%20needs%2C%20but%20with%20the.

"Sustainable Development | 75th Economic and Social Council." United Nations. United Nations. Accessed December 9, 2021. https://www.un.org/ecosoc/en/sustainable-development.

Ton, Dan T., and Merrill A. Smith. "The U.S. Department of Energy's Microgrid Initiative." *The Electricity Journal*, vol. 25, no. 8, 2012, pp. 84–94, doi:10.1016/j.tej.2012.09.013.

World Bank. "Doing Business 2020," *World Bank Publications*, The World Bank, July 2020. Number 32436.

World Bank. "GDP per Capita (Current Us$)." *GDP per Capita (Current US$)*, World Bank, data.worldbank.org/indicator/NY.GDP.PCAP.CD.