Faculty of Humanities and Social Sciences

Degree in International Relations

Final Dissertation

Sustainable Development through Microgrids

What countries in Sub-Saharan Africa have the most favorable environment for this key technology against poverty and climate change?

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Index

Acronyms

African Development Bank (ADB)

Average Revenue Per User (ARPU)

African Union (AU)

Ethiopian Electric Authority (EEA)

Gross Domestic Product (GDP)

Greenhouse Gas (GHG)

German International Development Cooperation Agency (GIZ)

Human Development Index (HDI)

International Energy Agency (IEA)

Minigrid Partnership (MGP)

Official Development Assistance (ODA)

Purchasing Power Parity (PPP)

Results-Based Financing (RBF)

Rural Electrification and Renewable Energy Corporation (REREC)

Renewable energy sources (RES)

Rwanda Utilities Regulatory Authority (RURA)

Sustainable Energy for All (SEforALL)

Sub-Saharan Africa (SSA)

United Nations (UN)

United Nations Framework Convention on Climate Change (UNFCC)

World Bank (WB)

1. Introduction

Energy poverty in Africa is one of the multiple challenges that the continent is facing today. This issue involves important limitations to development, as energy is an essential prerequisite for any nation to evolve socially and economically.

Since its independence from colonial rules, Africa is home to 54 sovereign countries that are commonly grouped in two different regions: Northern and Sub-Saharan Africa. In this study, there will be a focus on the states located in Sub-Saharan Africa, which differ in many aspects from their northern neighbors. This division lies not only in the geographical partition of the Sahara Desert, but also on ethnocultural reasons, having different traditional languages, races, and religions, being the north mostly Arab and the Sub-Saharan region largely Christian. In addition, despite the richness of natural resources and increasing economic expansion, Africa is the least wealthy continent per capita, having the poorest rates in the Sub-Saharan region (WB, 2021). Corruption and political instability mark these presidential republican states, that often fall to the power of authoritarian military regimes (Tordoff, 2016).

Sub-Saharan Africa hosts the lowest electricity rates in the world (WB; FDA, 2021) and, at the same time, the highest practical solar PV power potential (WB; ESMAP; SOLARGIS, 2017). This breach shows the opportunity to focus on the electricity access through solar solutions in this region. Additionally, population growth and climate change are accelerating the need for an alternative to carbon energy.

As we will see, Microgrids[1] offer the opportunity to pursue a sustainable model of development that differs from the traditional carbon-intensive model seen in many other parts of the world. It is a decentralized electrification system that involves the creation and consumption of energy (currently focusing on solar-powered resources) within a community. In other words, a self-sufficient solar-powered neighborhood. It is especially

[1] There is a current global debate on the terminology between Microgrids and Minigrids. To avoid confusion, in this study the term of Microgrid will be used accordingly to the United States' Department of Energy.

useful in those places where it is too expensive or complicated to connect the rural and isolated areas to the Macrogrid (or major centralized energy source).

For these reasons, this study will show the multiple dimensions of the energetic problem, the current poverty status, and how factors like climate change are aggravating it. In addition, it will analyze the key factors involved in the implementation and development of Microgrids as a key technology to sustainable development. Finally, it will propose the most favorable states for the development of this technology.

2. Motivations and reasons for research

The growing global concern for environmental issues has encouraged public and private entities to work together towards sustainable solutions. This offers a great opportunity for green initiatives to flourish and expand, as much as it broadens the space for the already-developed actions to increase their activities and further develop. That is why, it is important to carefully analyze the projects that have taken place and to adapt the strategies to the new technologies.

Africa presents an incredible potential for Microgrids. Not only because of its abundant and endless renewable resources, but also because of the great amount of opportunities due to its underdeveloped energetic infrastructures. Instead of converting the current structures – like European countries would have to do, African countries can directly develop their access to electricity through sustainable means, skipping the transformational step.

This research aims to gather data relating Microgrid projects for two main reasons: First of all, to create awareness on the Microgrid technology. It is unknown for many, and it represents a powerful tool to shift towards self-sufficiency and renewable energies, two trends that have been on the rise in the past years. Although there are some limitations to this type of mechanisms, the benefits are striking. Public entities such as the European Union (EU), the United Nations Development Programme (UNDP) or the United States

Agency of International Development (USAID) have already undergone projects in Greece (EU, 2021), Yemen (UNDP, 2020), and Haiti (Projects, 2021), respectively. Also, in the private sphere, well-known companies such as Siemens or Bloom Energy are likewise aware of the numerous gains that Microgrids have (Haggerty, 2019).

The second motive is to study what countries facilitate its most efficient and favorable development in Africa. As we have seen, this region has an enormous potential that can be utilized to improve social and economic development, therefore it is important to focalize the efforts in the most efficient environment. Accordingly, there are diverse factors to take into account when thinking about project implementation and development in the African continent: policy regulations, economic capacity, population trends…

With the increasing interest from public and private actors on sustainable development, the growing advances on the Microgrid technologies and the lowering costs of solar panels, it is the time to draw upon.

The author started realizing about the importance of sustainable development in her year abroad in Australia. This country, apart from having some of the most unique wildlife and landscapes in the world, is home to the aboriginal people who habited the country before western colonization. Aboriginals have developed an admirable respect culture to the environment they live in: for thousands of years they have understood that nature is precious, its resources finite, and that unbalancing the natural processes of earth can be devastating. And most importantly, they have acted accordingly.

After her first contact with the aboriginal culture, the author started to get interested about environmental issues and to get involved with the green movement. Her preoccupation towards building a sustainable world has attracted increased attention to these topics.

She currently studies a double degree in International Relations with Global Communication, specializing in Security and Foreign Policy in the Pontifical University Comillas. In order to complete her studies, it is a requirement to carry out a research paper on each of her degrees. Furthermore, her motivations are very much related to her professional aspirations. International cooperation and sustainable development are fields in which the author would want to work in the future.

The importance of the environmental issues, especially in Africa, are obvious. There is a clear need to adapt and evolve. And apart from being important, these changes are extremely urgent. As the 2016 UN Environment Adaptation Gap Finance Report states, "the costs of (climate) adaptation are likely to be two to-three times higher than current global estimates by 2030, and potentially four-to-five times higher by 2050", and it points out that Sub-Saharan Africa will be the region with the highest costs per unit of GDP (UNDP & GEF, Climate Change Adaptation in Africa, 2018).

Therefore, the reason underlying this research paper is the desire to study the most efficient and feasible alternatives for sustainable development in developing countries, specially focusing on energy. Our recent history has evidenced the global dependence on non-renewables, but this study aims to take a step forwards a green future.

In conclusion, this research paper is the result of the interest for two topics: international development and environmentalism.

3. State of the matter

3.1. Dimensions of poverty in Africa

Africa has been struggling with poverty issues for a long period, and it still is. As of February 2021, 32 of the 46 states on the United Nations List of Least Developed Countries are African (UNCDP, 2021).

Although the concept of poverty can be defined and measured in many ways, there are some indexes that can clearly demonstrate the precarious situation in which many African citizens live, such as GDP per capita, Human Development Index (HDI) or poverty rate (ratio of the number of people whose income falls below the poverty line). In terms of GDP per capita, Sub-Saharan Africa stands with \$1.596, compared to \$7.991 in the Middle East &

North Africa, $24.744 in Europe & Central Asia or $11.530 in East Asia & Pacific (WB, GDP per capita, 2019). World's average remained at $11.441, thus Sub-Saharan Africa falls way below the average GDP per capita. Moving on to HDI, UNDP rates the world's lowest human development in Africa, specifically in Central Africa (UNDP, Human Development Reports, 2020). Lastly, poverty rates are also preoccupying, having up to an 86% of people whose income falls below the poverty line in 2018 (Macrotrends, 2021).

In this fight against poverty, the Covid-19 pandemic has severely stricken the region. According to the World Bank, GDP per capita growth forecast is expected to be more than 5-7 % points lower due to Covid-19 (WB, How much will poverty rise in Sub-Saharan Africa in 2020? , 2020). Moreover, as we can see in the following figures, poverty rates are on the rise, affecting practically every Sub-Saharan country. The levels to which these rates will further increase depends on many factors: cooperation efforts, economic resilience, adaptative capacity...

In the first graph, we can see how the poverty rate in Sub-Saharan Africa was decreasing, and predictions pointed a further decline for 2021 (39.4%). This drop ceased during the post-Covid indicators, where the poverty rates have increased up between 42.2% and 43.7% - higher than 2018's values. This graph clearly illustrates how poverty increased in SSA during the pandemic.

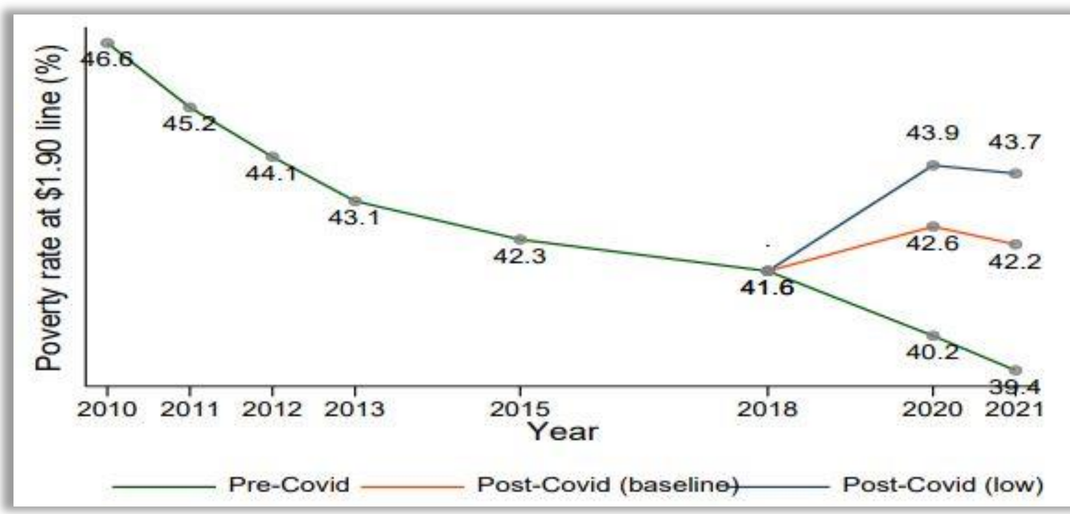

Figure 1: Poverty Rate at $1.90 line (%) for SSA forecast

Also, it is important to point out the extent in which poverty rates differently affects each country. The repercussion largely relies on different aspects, such as the exporting nature of the country, the level of tourism dependence or an unequal distribution of wealth. As it is visible in the map (Figure 2), the percentage points remark the countries where the increase in poverty rates will be higher, being Zimbabwe the most affected one.

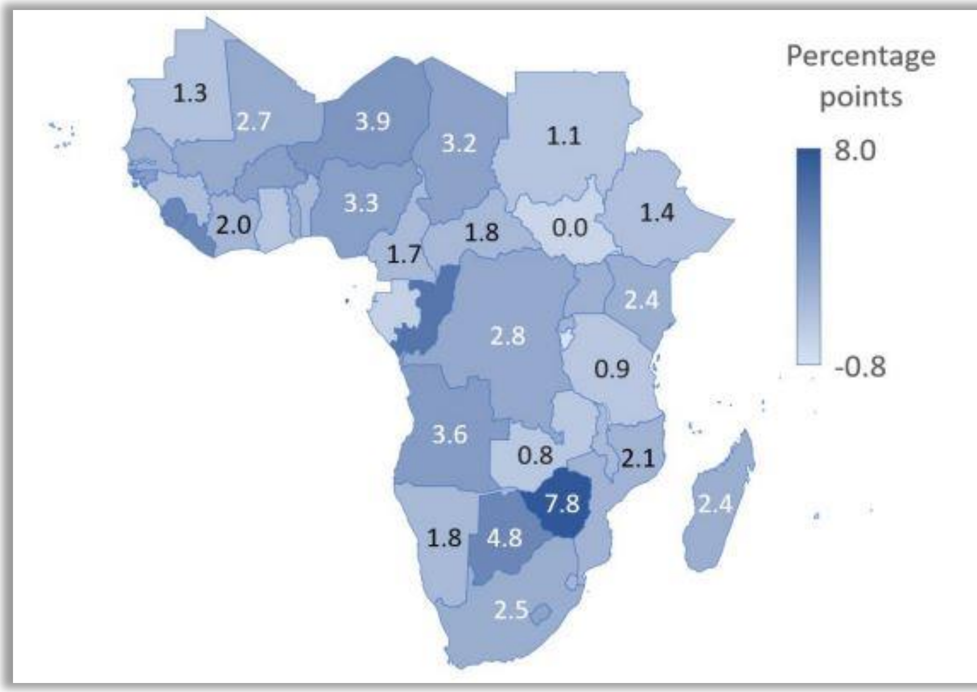

Figure 2: Forecast of SSA countries' increase in poverty rates, 2020

If poverty was not enough of a challenge for African countries, Covid-19 has aggravated the situation. This decline on the provision of basic needs reflects the necessity to enlarge the efforts dedicated to poverty alleviation in order to move back to a positive outlook in the region. And although the coronavirus crisis had (and still has) a devastating impact, it is not the only threat that African governments – and society at large, face.

3.2. A vulnerable continent to climate change

Consequences of climate change are already visible, even when the repercussions are still not as severe as experts predict it to be, especially in Africa. As stated by the IPCC (Intergovernmental Panel on Climate Change), "Africa is likely to be the continent most vulnerable to climate change" (IPCC, 2007). Likewise, on October 2020, the World Bank reaffirmed the statement claiming that Sub-Saharan Africa will be particularly threatened by climate change (WB, Poverty Overview, 2020). There are two main reasons for this: high dependence on the ecosystem for livelihoods and weak adaptative capacity.

In the first place, the dependency on the ecosystem: Despite being a mineral-rich continent, Africa's economy largely depends on its agricultural production. According to Britannica, "Agriculture is by far the single most important economic activity in Africa. It provides employment for about two-thirds of the continent's working population and for each country contributes an average of 30 - 60% of GDP and about 30% of the value of exports." (Britannica, 2021). In addition, more than 60% of the Sub-Saharan population are smallholder farmers (McKinsey, 2019).

Change in rain patterns, soil erosion and water pollution are some of the global warming consequences that greatly affect the agricultural sector. Therefore, taking into account the importance of agriculture for Africa's GDP and how alterations on small farms would affect the local food system, the negative effects of climate change on the ecosystem and, in particular, agricultural resources are clearly evident for all the spheres of the African society.

Due to this rising issue, financial support from organizations and specially from the Green Climate Fund has been key in helping agriculture mostly in East and West Africa (GCF, 2018).

The second reason mentioned is the adaptative capacity: Although African leaders emphasized on the need of adaptation to climate change during the AU summit Agenda 2063, adaptation efforts are unsteady and inconsistent (UN, Agenda 2063, 2015). A significant obstacle to improve this adaptative capacity is the difficulty to gather climate data (Dinku, 2018). As the London-based Overseas Development Institute points out, "In order for African communities and businesses to adapt more effectively to the inevitable impacts of climate change, weather and climate information services must be vastly strengthened as quickly as possible" (ODI, 2021). In like manner, political corruption or lack of economic resources impede adaptation strategies to take place.

In the 2021 Climate Adaptation Summit, world leaders such as Uhuru Kenyatta (President of Kenya), Nana Akufo-Addo (President of Ghana), Angela Merkel (President of Germany) or Justin Trudeau (President of Canada) agreed on the urgency to improve adaptation efforts towards climate change in the African region. One of the results was the creation of the African Adaptation Acceleration Program (AAAP) (ADBG, 2021). This program will be conducted by the African Development Bank and the Global Center on Adaptation, and it aims to mobilize $25 Million for the improvement of the adaptative measures (GCA, 2021).

Furthermore, poverty and climate change are deeply correlated. According to the Brundtland Report, poverty accelerates environmental pressures (Development, 1987), which could be having a direct impact on climate change, and the consequences of global warming have a more devastating effect in poorer countries due to the reliance on the natural environment and the lack of adaptative measures (Rayner & Malone, 2001).

As the African Institute for Security Studies states, "Low levels of development and generally weak state capacity, especially in sub-Saharan Africa, pose formidable obstacles to adapting to climate change. Extreme poverty, infrastructure deficits and poor state capacity remain pervasive issues and render millions of Africans highly vulnerable to climate change" (ISS, 2018).

It is important to keep in mind that unless there is significative environmental action, the aftermath in terms of poverty rates in Africa can be devastating.

3.3. Electricity challenges in Africa

Modern economic activities are highly dependent on electricity access. That is why energy is not only important for poverty alleviation, but also for national economic development.

Today, electricity in Africa faces one main challenge: accessibility. The International Energy Agency (IEA) defines energy access as "a household having reliable and affordable access to both clean cooking facilities and to electricity, which is enough to supply a basic bundle of energy services initially, and then an increasing level of electricity over time to reach the regional average." (IEA, Defining energy access: 2020 methodology, 2020). Moreover, the current global electrification rate is approximately 89%, and the expectations for 2030 grow to 94. In terms of people, the numbers stand at 840 million people without energy access (WB, State of the Mini Grid Market Globally, 2019). Focusing on the area of this study, the numbers are especially alarming: according to the 2020 African Energy Atlas, only half of the African population has access to electricity – 53% to be specific (Energy A. , 2020). This number has decreased 2% with respect to previous year, and 30 million people have no longer the capacity to afford electricity prices due to the coronavirus (IEA, The pandemic is already significantly impacting energy access trends in Africa, 2020).

The African paradox relating energy resides on the fact that the continent is rich in energy resources – specially renewables - but does not profit from its potential. Still, the Sub-Saharan region is not an exception in the world's dependency on fossil fuels. As it is noticeable in the graphs below, today, fossil fuels continue to be the primary energy source, even though the next most-used energy is a renewable one: hydropower.

These predictions estimate a steadily rise of the PV, positioning it as the primary electricity resource, as we can observe in Figure 3. In 2020 fossil coal represented the majority of the primary electricity generation measured in Kilowatt-hour. In ten years time, there are great expectations of renewable (solar and wind) power.

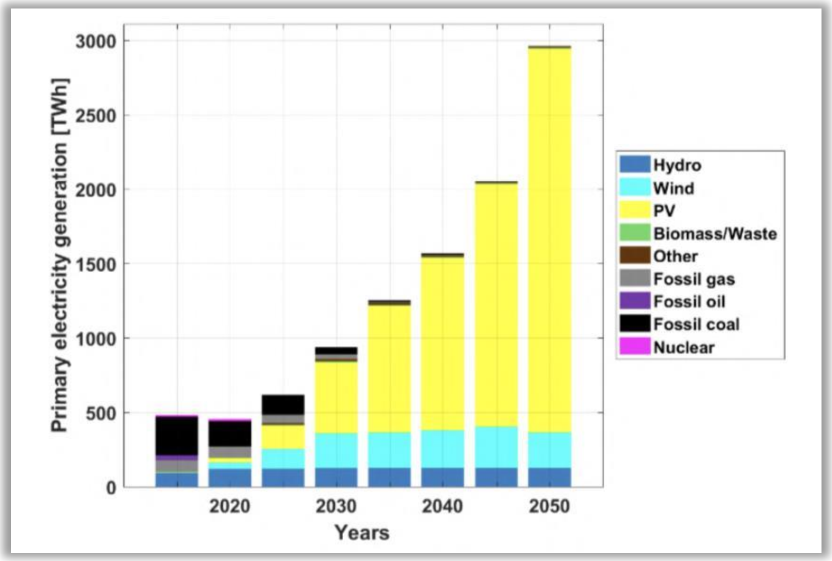

Figure 3: Sub-Saharan Africa - Primary electricity generation

Still, predictions greatly vary depending on the entity. In terms of energy demand, we can see in the next graph, Figure 4, how Energy Agency's predictions position Sub-Saharan Africa as an emerging region in non-sustainable energy (barrels of oil). The curve rises from 5 billion barrels of oil equivalent up to almost 20 billion in 2065, which indicates a very different energy outcome for the region.

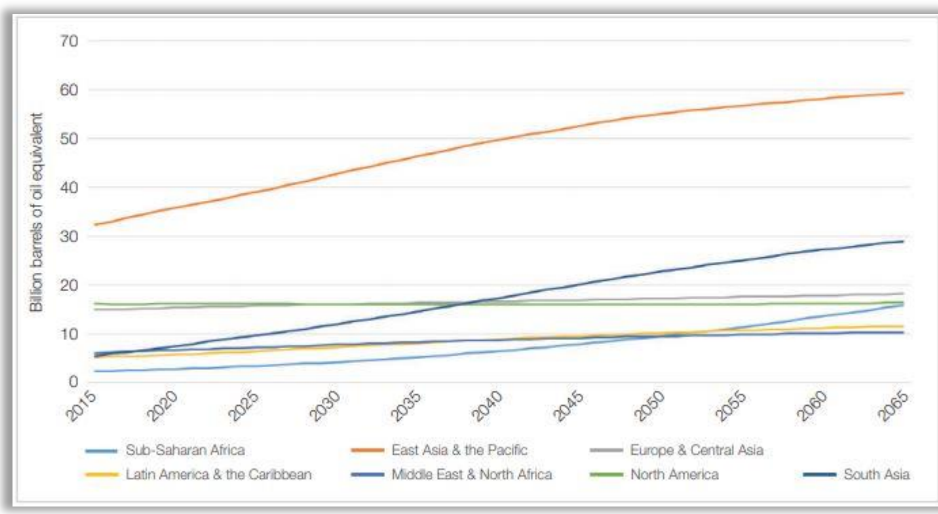

Figure 4: Energy demand in the world. Energy Agency predictions.

In that sense, it is important to be aware of the type of energy that will lead the growth. As population trends show, there will be more people in need of energy, and the development of energy resources should not only be sustainable but also accessible. In other words, “For the purpose of addressing these problems effectively, we can summarize the fundamental energy question facing Africa as: providing and maintaining widespread access of the population to reliable and affordable supplies of environmentally cleaner energy” (Iwayemi, 2018).

3.4. Microgrid features, current situation and outlook

Microgrids are not new. In fact, all current centralized grid systems started being decentralized and isolated, like the Microgrids (Bank, Three Generations of Mini Grids, 2019). As technologies evolved, systems started to be interconnected and centralized, aiming to improve the telecommunication tools available at the time.

At the moment, there are approximately 47 million people connected to Microgrids (Bank, 2019). Surprisingly, the geographical areas in which the devices are displayed are not Europe or Northern America: as we can see in Figure 5, out of the 19.000 Microgrids installed, almost half of them can be found in South Asia, and following the lead, the regions of East Asia, the Pacific and Africa (ESMAP, 2019). Moreover, Africa is expected to overthrow South Asia, as the number of planned systems will almost double those of the Asian states, amounting to more than 4.000 Microgrids (ESMAP, 2019).

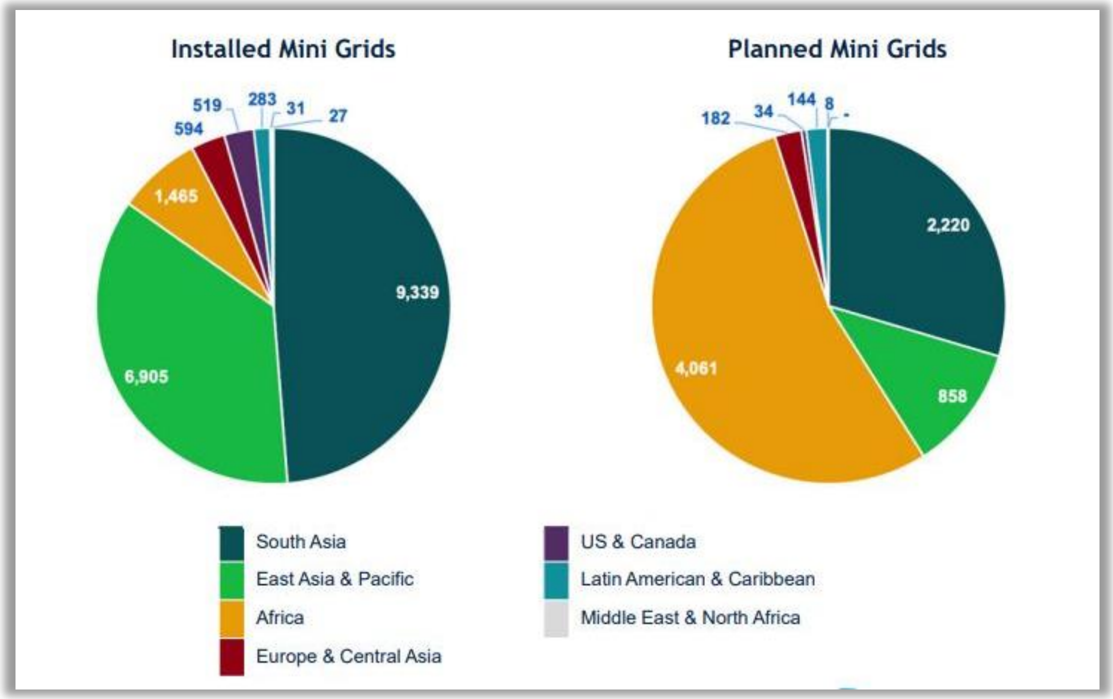

Figure 5: Comparison of Installed and Planned Mini Grids by Region

Nearly all the Microgrids identified around the globe currently are 2nd generation, meaning that their energetic resources are diesel and hydro Microgrids. Still, the future planned installations are mostly 3rd generation, which are based on renewable energy (Bank, Three Generations of Mini Grids, 2019). In this research, I will mainly focus on the third generation, as it is the technology that future Microgrids will use, and the one that better adapts to the sustainable development goals.

These Microgrid developers can be found on Nepal, the US, and Mali - between others, but the number skyrockets when we take a closer look at Myanmar. This country does not only have the largest number of developers but is also the second state in the world in terms of number of Microgrids (Bank, Three Generations of Mini Grids, 2019).

In terms of the outlook, Microgrids are increasingly becoming attractive to governments and private investors for many reasons: First of all, the sharp fall of PV /battery energy storage thanks to technological improvements. According to the International Renewable

Energy Agency, solar PV module prices have dropped by 90% since 2009 (IRENA, 2020). Furthermore, Bloomberg New Energy Finance report on 2019 Battery Price Survey explained that costs in batteries have lowered to 87% in the past 10 years (BloombergNEF, 2019). In addition, not only Microgrid components have gone through technology advances: appliances and devices in general (refrigerators, computers, agrarian machines…) have improved their energy-efficiency, demanding less power to the electric system (IEA, Energy Efficiency , 2019).

Secondly, government policies and regulations have been developing on the last years, making investments on Microgrids more secure and attractive. Although many countries still lack the regulatory rules, some others like Nigeria, Myanmar, India or Kenya have already implemented laws regarding this new technology (Bank, Three Generations of Mini Grids, 2019). This opens the path for private investors and other stakeholders to take action, as the agreed directives stabilize the legal framework of incumbent states. The impact of globalization on national policy greatly affects this decision-making process, pushing states to advance in the topic.

All these factors have contributed to the quick expansion of Microgrids around the world.

Figure 6: Number of Microgrids installed each year

It is also noticeable that solar and solar hybrid Microgrids have taken the lead. Due to economic and environmental factors, the 3rd generation (related to renewable energy) is overriding the diesel and hydro-based 1st and 2nd. As it is visible in Figure 6, it is in 2013 when the shift to renewables is especially visible, taking the lead.

The interests on Microgrids are laid not only on states, but also global companies and numerous organizations. In terms of investors and stakeholders, we see an increasing growth of institutions, organizations and enterprises in this sector (Insights, 2019) (Energy E. , 2012) (Knowledge, 2018). According to the market research report "Microgrid Market - Global Forecast to 2025", the Microgrid market is expected to grow from USD 28.6 billion in 2020 to 47.4 billion in 2025 (Markets, 2020).

Still, the Covid-19 crisis has hampered off-grid energy solutions, as finance dedicated for this cause has been redirected to health efforts. Sales have fallen 20% on the first 2020 semester. (IEA, The pandemic is already significantly impacting energy access trends in Africa, 2020).

We can’t forget that improving the current status of linear unsustainable consumption goes hand to hand with improving the situation of those who don’t have access to energy resources. Fortunately, in those terms, the actual international framework is one that supports and encourages developing and emergent countries in their path to economic, social and political development (UNDP, United Nations Development Programme, 2020) (Bank, World Bank Development Projects, 2020) (USAID, United States Agency for International Development, 2020) (Oxfam, 2020) (IDB, 2020).

4. **Theoretical Framework**

As the objective of the solar Microgrid projects is to focus on a sustainable energy resource development and access in Sub-Saharan Africa, this research will base its foundations on the theories of development in Africa, natural capital, climate change, sustainable development and renewable resources. These topics are interrelated, creating a close relationship between human development through earth's resources. Through this approach, we will analyze and observe the role of Microgrids, one of the key solutions for the Sustainable Development Goal #7: to ensure access to affordable, reliable, sustainable and modern energy for all.

4.1. Development theories in Africa

The debates on development in Africa are closely linked to the debates that take place in the global development field. It is important, as far as possible, to reflect that connection so as not to pose Africa as an exception. However, it is totally pertinent to ask about the specific casuistry of the continent, and within this of each region, country, or locality. This will lead us to comprehend the role of Microgrids in the development area.

Although colonization in Africa left a legacy of authoritarian regimes, corruption, and instability that baulked internal processes of evolution, the continent has been in a constant effort for advancement. The African countries have historically undergone different development stages that have transformed the region into the approach that we can now observe.

In the 1950s, great importance was given to the Anglo-Saxon approach with the Keynesian and the Arthur Lewis economic models, taking inspiration from the post-world war reconstruction era in the West. These western theories aimed to be reproduced in the African continent through demand management, structural change, modernization, and industrialization. Finding new ways of advancement, in the next decade, the rise of the

Prebisch and Singer theory of import substitution industrialization model (ISI) added up to the evolutionary perceptions of the region (Soko & Lehmann, 2010).

However, it is in the economic and social crisis in the 70s and 80s that the directions of the African continent, in terms of development, dramatically changed. The strategy aligned with the "Washington Consensus" program, focusing on interdependency policies to reform the economies of the developing countries. This decade prompted the creation of the Organization of African Union, the Lagos Plan of Action, and the Structural Adjustment Programs, marked by a neoliberal approach that aimed to overcome structural flaws and promote social wellbeing through opening markets, lowering tariffs, and encouraging foreign investment. Topics such as poverty, unemployment, inequality, and political freedoms started to become central in political debates and development efforts (Kahn, 2004). Later in the 1990s, the start of the reconfiguration of the African development system moved towards sustainable development, local community strengthening, social progress, environmental concerns, and enhancing responsibilities of state institutions beyond merely economic approaches (Irwin, 2006). This is particularly interesting in the study, as we see there is a favorable development trend towards environmental action and sustainability.

Today, there is a large debate on foreign aid and the connection to the colonial legacies. Authors such as Dambisa Moyo explain through her book *Dead Aid* that aid only perseverates inequality and impedes countries' improvement (Moyo, 2009). This self-dependency theory argues that the African academia should "liberate and educate" the people ensuring a three-step process of repuding foreign aid, restructuring the colonial territorial barriers, and strengthening the African supranational political efforts (Fonchingong, 2005). This concept of self-sufficiency also aligns with the autonomy theory that guides Microgrid projects, as they are designed to provide a technology that will generate, distribute, and consume the electricity within a community, creating a circular and self-reliant cycle.

4.2. Natural capital and climate change

Earth's natural assets compose the natural capital. It is the stock of renewable and non-renewable resources that are vital for ecosystems to function. Examples can be water, soil, or petroleum. Humans largely profit from them, as they provide numerous benefits: economic, social, medical, environmental, spiritual… (NACC, 2020). The issue around natural capital arises in relation with the human use of it. Earth's carrying capacity surpassed its limits in the 1970s and humanity's ecological footprint is still higher than the natural recovery process of resources, making human activities largely unsustainable (David Lin, 2018).

As the well-known 1972 MIT report "Limits to Growth" exposes, there was (and still is, as it will be exposed later) an exponential economic and population growth that does not encompass the natural processes of regeneration (Meadows, Donella, & Randers, 1972). This report measured the human consumption in relation with the natural reserves, aiming to quantify the limits of sustainable growth. The objectives of the study were to foster awareness, identify the dominant elements, and to warn of the negative outcomes that economic and industrial policies produce in advantage of natural capital. Their conclusion was that if the growth trends remained constant, limits to growth would become visible in 2072.

This urge to modify human behavior towards the environment dramatically grew in the next years. In 1992, around 1.700 prestigious scientists signed a document called "World Scientists' Warning to Humanity" in which they emphasized on the critical state of the environment. In the recommendations to address the environmental issues there is a clear urge to effectively manage resources crucial to human welfare (Scientists U. o., 1992). Years later, in 2017 the second "World Scientists' Warning to Humanity" was signed by 15,364 scientists all around the globe, claiming that the efforts made were largely insufficient, and insisting on restructuring humans' energy trends. To date, it conforms the document with the most scientist signatures in history (Scientists, 2017).

Although limitations of the natural capital pose a large global problem, it is not the only issue relating human activities and energetic resources that should be examined. Following the lead of the first global warming theorist, Swedish chemist Svante Arrhenius (1859 – 1927), climate change theories do not only warn us of the limits of Earth's resources, but also explain the negative impact of over-using them. This explains the necessity to move towards renewable and clean energies, in order to preserve natural resources.

Climate change theories agree that greenhouse gas emissions are the cause of global warming [2] and explain how human activities accelerate the accumulation of GHG in the atmosphere (Shanahan, 1992) (Rosa, 2012) (Comyns, 2016). Carbon Dioxide, Methane and Nitrous Oxide are the three main GHG, and the major sources of these gases are fossil fuel combustion, deforestation, agriculture and industrial processes – between others (C2ES, 2021) , meaning that the world's actual main energy source (fossil fuel) is the major responsible for global warming.

According to the most recent NASA reports, the consequences include the increase of extreme weather events, sea level rise or alteration of ecosystems – between many others, which at the time lead to human-related effects such as food insecurity, water scarcity or health aggravation (NASA, 2021).

The international community first focused on this issue in the 1992 Rio de Janeiro Earth Summit. This major conference recognized the need to cooperate to achieve joint development and sustainable issues and led to the creation of the UNFCC (United Nations Framework Convention on Climate Change). UNFCC's main objective is to stabilize Greenhouse Gas concentrations, and it means to direct funds and technological "know-how" from the industrialized nations to the developing countries[3]. In this convention, 195 countries ratified and acknowledged human impact to climate change (UN, 2021) (UNFCC, 2021). Five years later, the 1997 Kyoto Protocol of the UNFCC created specific national reduction targets to each country, aiming to change the behavior of all nations to an eco-

[2] Due to the greenhouse effect.
[3] The UNFCC recognizes the responsibility of industrialized countries for the rise of Greenhouse Gases.

friendly economy (UNFCCC, Kyoto Protocol to the United Nations Framework Convention on Climate Change, 1998). Finally, the 2015 Paris Agreement established the framework that constituted binding objectives and goals. It set the objective to keep the increase of the global average temperature below 2°C, committed developed countries to financial assistance, and called developing states for enhanced mitigation efforts (UNFCCC, Paris Agreement, 2015).

4.3. Sustainability and renewable resources

The acknowledgment of the limits of natural capital pushed for the urge of the sustainable exploitation of resources, such as solar power. Moreover, sustainability englobes not only the environment, but also the economic and social spheres of society. Through the study of relevant historical environment literature, this three-pillar theory of sustainability results to be the result of a gradual theoretical construction rather than a punctual realization (Purvis, Mao, & & Robinson, 2019).

The debate around sustainability pointed out the need to preserve and foster development without compromising natural resources.

Leading ecologists like Barry Commoner (1917 – 2012), considered by many to be the founder of the environmental movement, introduced the issue of sustainability, giving crucial importance to it (Environment, 2021). In one of his most famous books, *The Closing Circle*, Commoner explains how everything is interconnected, and asserts that the economy should be restructured to conform the laws of ecology. For example, he claimed that polluting products like detergents should be replaced with natural ones like natural soap. (Commoner, 1972).

Environmental politician René Dumont (1904 – 2001), advocated for international cooperation to help underdeveloped nations. He believed that demographic control, energy saving, and soil quality preservation were key for the sustainable development of these states (Dumont, 1966).

International frameworks such as the United Nations Conference on the Human Environment held in Stockholm, Sweden in 1972, demonstrated the global interest on the issue of environmental and developmental problems, and on the need for a consensus to address them. The ‘72 Stockholm Conference It was the first international convention that started a global agenda working towards development and environment (UN, Declaration of the United Nations Conference on the Human Environment, 1972). The declaration includes 26 principles regarding environment and development, an Action Plan conformed by 109 recommendations and a Resolution. Some of the principles include that “The capacity of the earth to produce vital renewable resources must be maintained and, wherever practicable, restored or improved”, “The non-renewable resources of the earth must be employed in such a way as to guard against the danger of their future exhaustion and to ensure that benefits from such employment are shared by all mankind” or that “Economic and social development is essential for ensuring a favorable living and working environment for man and for creating conditions on earth that are necessary for the improvement of the quality of life” (UN, Declaration of the United Nations Conference on the Human Environment, 1972). Another decisive outcome is the creation of the United Nations Environment Program (UNEP, 2021).

Furthermore, sustainable development objectives are clearly reflected on the 2000 Millenium Development Goals and the 2015 Sustainable Development Goals.

There are many ways to tackle climate change: a very important one is renewable energies. Renewables are an alternative for the use of fossil fuels for energy generation, thus avoiding the emission of greenhouse gases (such as CO2 or methane) that create the greenhouse effect (heating up the atmosphere).

Although renewable energy is seen as a futuristic and innovating concept, it has been humanity’s main energetic source (and most frequently the only option) until the industrial revolutions (Sørensen, 1991). From windmills to hot springs, societies have evolved and optimized processes thanks to this type of energy. The main sources include wind power, hydropower, solar energy, geothermal energy, and bioenergy (Alrikabi, 2014).

These resources produce significant opportunities for nations to improve their energy security, to take action regarding climate change mitigation, and to benefit economically from it (Kumar, 2019).

Renewables mainly come into place with the realization of fossil fuels' limitations and their fast depletion as non-renewables. Therefore, not only renewable energies contribute to alleviate environmental issues, but will also eventually be necessary for energy production when fossil fuels become scarce. As their name clearly indicate, they are rapidly renewed through natural processes.

5. Goals

The general goal of this project is to study sustainable models of development that substitute the traditional carbon-intensive model. Therefore, it aims to look at renewable energies in developing African states, specifically at the Microgrid technology. For that reason, it aims to answer to the question: **What countries facilitate the most efficient and favorable development of Microgrids in Sub-Saharan Africa?**

In order to answer to this question, there are some specific objectives that must be covered to properly address this issue:

- Find the aspects that positively affect the establishment and development of Microgrid projects.
- Measure and analyze these aspects, making a comparative study between the states in order to observe the preferred outcomes.
- Discover the Sub-Saharan countries that meet the eligible criteria and that cover the most favorable elements.
- Study the impact that Microgrid projects can have in economic, social and environmental terms.

6. Methodology

This study uses mixed methods in the analysis, focusing on aspects that enable Microgrid projects feasibility in Sub-Saharan Africa.

In order to do so, qualitative and quantitative approaches, together with case study research, allow us to investigate this topic and better understand the actual paradigm. Most of the quantitative data is gathered from the World Bank. Moreover, qualitative information from international organizations, academics, and private entities is used.

In order to further understand the status of the countries with enabling environments for Microgrids to work, the following website should be visited: https://microgridtrial.weebly.com/ .This website, created by the author, visually represents the rating that each Sub-Saharan country has. Once on the website, a display of six indicators will appear. The six indicators will be bolded and numbered through the analysis on this paper for clarification and easier follow-up. The navigation is simple: a click on the top buttons will modify the map to the selected indicator. When the cursor is on top of a country, it will automatically show the specific data from each state.

Each indicator shows a key aspect for Microgrids to be developed. From electricity access to economic aspects, including population rates. The colors presented are calculated through the average number of each indicator. Blue is used for the most preferable status and red for the least desired one.

The analyzed countries are: Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Congo, Dem. Rep., Congo, Rep., Cote d'Ivoire, Equatorial Guinea, Eritrea, Eswatini, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, South Sudan, Sudan, Tanzania, Togo, Uganda, Zambia and Zimbabwe.

The research process started with the study of main factors that affected the success and sustainability of Microgrid projects through academic papers, case studies and reports from international organizations and NGOs. Once these key elements were found, a compilation of the data relating each factor was made, creating tables of content that was processed first in Excel and then in Tableau. Tableau is a software for data analysis and visualization, where the coding and programming of the data to maps was possible. Throughout this task, the analysis of non-quantifiable data was also made, including policy and regulatory indicators. As a result of the analysis and visualization of the data, conclusions lead to further study and investigation, in order to understand the outcomes. Lastly, the final conclusions were conducted.

7. Analysis

Microgrids are becoming increasingly known and used, as we have seen. Nevertheless, this technology has evolved in some places more than in others. Getting into a more specific scheme, there are certain aspects that can improve or hamper the means to bring about a Microgrid project.

There are some interesting conclusions regarding this topic that have been studied by the Minigrid Partnership (MGP), a partnership including 320 Microgrid stakeholders; by Sustainable Energy for All (SEforALL), an international organization in partnership with the UN, governments, the private sector, financial institutions and civil society that works in line with SDG7 and the Paris Agreement on climate change; by BloombergNEF, a department of a private enterprise that specializes in research on power, transport, buildings, industry, and agriculture sectors to adapt to the sustainable energy transition; and by Microgrid Knowledge, a website dedicated to inform about the multiple aspects involving Microgrid technology. All these actors agree that the perceived risks that add uncertainty to the feasibility of the projects are the limited power demand, the inability to pay in the rural/isolated areas, and the lack of a regulatory national framework (MGP, SEforALL, & BloombergNEF, 2020) (Knowledge, 2018).

Through an analysis of the information coming from these organizations, we could subtract six different aspects that benefit the improvement of Microgrid projects. These elements will be analyzed in three levels of analysis: electricity access and demand, willingness to pay and financing, and policies and regulations affecting Microgrids.

These conditions will be the guide to discover the Sub-Saharan countries with the most favorable environment for Microgrid projects.

7.1. Electricity access and demand

There are two very important aspects to start observing the energy reality in Sub-Saharan Africa: the population's access to electricity and their power demand.

First of all, we will begin with the **(1) population's access to electricity**. After reviewing the 2020 African Energy Atlas and observing that only around half of the African population has access to electricity (Energy A. , 2020), it is decisive to focus on the countries that have a lower access. The problem of electricity poverty can be seen in a bigger and more urgent scale in these states, and it can lead to a higher initiative from their own governments or through other actors that give great relevance to improve the quality of life through electricity access.

According to data retrieved from the World Bank, the average value in terms of percentage of population with access to electricity stands out at 47.7% (WB, Access to electricity (% of population) - Sub-Saharan Africa, 2021). Thus, taking into consideration every state that is under the average number, out of the 58 countries, there are 25 that fall below the line. These are Angola, Benin, Burkina Faso, Burundi, Central African Republic, Chad, Dem. Rep. Congo, Ethiopia, Guinea, Guinea Bissau, Lesotho, Liberia, Madagascar, Malawi, Mauritania, Mozambique, Niger, Rwanda, Sierra leone, Somalia, South Sudan, Tanzania, Uganda, Zambia and Zimbabwe. These states are positioned as the least developed in terms of electricity access and need a more urgent response.

While these values are not an essential indicator of an enabling environment for Microgrids to be implemented or developed, they express the countries with the worst electrification rates, reflecting which states could be interested in the Microgrid technology.

Secondly, we will analyze the power demand, a more relevant figure for the study in line with the idea that Microgrid projects are more likely to be successful if there is a higher power demand. This feature is vital in order for the technology to be useful and profitable, as lack of willingness to consume electricity would systematically mean failure of any Microgrid project. Here, the interest is on the amount of the power demand. The more power a community demands, the more possibilities for a developer to invest in these types of projects, as larger involvement relates to a higher impact. Power demand is usually measured through the "average revenue per user" (ARPU), which indicates the generation capability and growth level in accordance with the number of users.

In the case of remote areas in Sub-Saharan Africa, we are referring to providing electricity access to communities that have never been connected, and because at present there are not any users, there is no current data on ARPU. Nevertheless, even though it is hard to predict the potential usage of electricity due to the heterogeneous nature of economic models and cultures, we can instead look at rural population, especially the variable of density. This factor will provide us with information about the concentration or dispersion rates of a population within a state, deducing that the higher the population density, the more chances for a higher demand of energy.

As there is no accessible Sub-Saharan Africa rural population density index, I analyzed World Bank's data to create a correlation between **(2) population density** and **(3) percentage of rural population**. Taking the mean of both variables, I organized the data as higher or lower than the mean, which means the state above the mean is in a better position – in this study – compared to the rest of the nations in the region. The perfect scenario would be a country with a high population density and a high percentage of rural population.

Analyzing the data, the countries that have a higher population density in Sub-Saharan Africa are the following: Burundi, Cape Verde, Comoros, Ethiopia (in the limits), Gambia, Ghana, Malawi, Mauritius, Nigeria, Rwanda, Sao Tome and Principe, Seychelles, Togo and Uganda. Regarding the other variable, % of rural population, the highest values relate to Burkina Faso, Burundi, Central African Republic, Chad, Comoros, Eritrea, Eswatini, Ethiopia, Guinea, Guinea-Bissau (in the limits), Kenya, Lesotho, Madagascar, Malawi, Mali, Mauritius, Mozambique, Niger, Rwanda, Sierra Leone, South Sudan, Sudan, Tanzania, Togo, Uganda, Zambia (in the limits) and Zimbabwe.

Out of the 58 countries analyzed, only 8 coincide in having both a high population density and percentage of rural population. These are: Burundi, Comoros, Ethiopia, Malawi, Mauritius, Rwanda, Togo and Uganda.

All things considered, there are three countries whose population's access to electricity is notably low and whose possibilities of a higher electricity demand according to the rural population density numbers are high compared to the other Sub-Saharan African countries. These countries are Ethiopia, Rwanda and Uganda.

7.2. Willingness to pay and financing

We cannot assume that a high Microgrid demand leads to a high eagerness to spend on this technology. In order to know rural population's willingness to pay for a Microgrid service, it is important to understand the value that the rural population assign to electricity.

Globally, electricity is a valuable service that can change and facilitate common actions, and this advantage is widely recognized in Africa too. A study published in the journal of World Development regarding electricity impacts in Rwanda found that "most people with the opportunity to access the grid in fact got connected" (Lenz, Munyehirwe, Peters, & Sievert, 2017). Besides, a paper written by the same authors on demand for off-grid solar electricity discovered though experimental evidence that households are willing to allocate a considerable part of their expenditures on electricity (Lenz, Luciane; Munyehirwe, Anicet;

Peters, Jörg; Sievert, Maximiliane, 2016). In effect, as much as there is demand for it, there is a strong feeling of personal investment.

Following the assumption that the Sub-Saharan rural population values access to electricity and that is willing to pay for it, we continue to the next layer of analysis.

To discover the countries whose rural population has a higher purchasing capability, we will contrast **(4) Purchasing Power Parity** and **(5) GINI** indexes. In order to do so, we will do the same methodology used in the previous rural population density section and differentiate between higher and lower indicators according to the average number. The Purchasing Power Parity (PPP) is a popular macroeconomic index to analyze states' living standards and economic values. This measurement aims to indicate the currency value through the "basket of goods", doing a comparison between the average national economies. And through it, we can see which countries could have advantage over others in economic terms. This value also reflects the countries' capability to participate in global commerce, as a higher purchasing power offers more opportunities to import, in this case, off-grid technology.

Moreover, I decided to include the GINI coefficient to measure the wealth distribution. Thanks to this indicator, we will be able to approximate the economic level of the rural population or those living in isolated areas. High numbers relate to income inequality, whereas low indicators align with more equality. Thus, using the GINI coefficient, we will look at countries with the relative most equal wealth distribution. This index complements the PPP measurement, as even if a country has a high PPP, a substantial dispersion of the money within a state would impede the access of economic resources to the lowest socioeconomic stratum.

Comparing these two measurements in Sub-Saharan nations, the countries with both a higher average on Purchasing Power Parity and GINI indexes are the Democratic Republic of Congo, Côte d'Ivoire, Ethiopia, Ghana, Kenya, Nigeria, Sudan, Tanzania and Uganda. These 9 countries represent the regions in which rural economic capability is most likely to be high, thus displaying the most sympathetic environment for Microgrids to work.

Still, it can't be taken for granted that the rural household's budget would cover the price of Microgrid electricity. In fact, the same study mentioned before by Lenz and and co-authors (Lenz, Luciane; Munyehirwe, Anicet; Peters, Jörg; Sievert, Maximiliane, 2016) claims that the vast majority does not have enough economic resources to cover the costs of Microgrid electricity, which suggests that subsidies would be necessary. However, the costs involved are significantly lower than an extension of a Macro-grid. Therefore, it would be a cost-effective way for electricity-access in rural and remote areas.

This financial insufficiency does not mean that the economic values calculated before are irrelevant, instead it highlights the importance of considering further funding. Evidently, aid is more likely to succeed if the country has a reasonable economic context.

Up to date, most Microgrid projects have relied on public funding (Normandeau, 2015). This includes development finance institutions, donor agencies or governments. Examples of key funders that have already disbursed capital for Microgrid projects include the German Agency for International Cooperation, the French Development Agency, the Renewable Energy Performance Platform or the Department for International Development. Thus, it is logical to think that countries with larger **(6) net official development assistance and official aid** received are more likely to get further funding.

Following the methodology that I have been using, taking the average values in terms of aid, there are 18 countries that receive larger amounts of official assistance relatively compared with the other Sub-Saharan countries. These include Burkina Faso, Cameroon, Democratic Rep. Congo, Côte d'Ivoire, Ethiopia, Kenya, Malawi, Mali, Mozambique, Niger, Nigeria, Rwanda, Senegal, Somalia, South Sudan, Sudan, Tanzania and Uganda.

Still, there are some limitations regarding financing in the Microgrid sector. A relevant one is the slow deployment of funding, as only 14% of the approved financing is disbursed (MGP, SEforALL, & BloombergNEF, 2020).

As perceived in Figure 7, we can observe that there is a clear interest toward financing Microgrid projects, as $ millions are approved to conduct this activity. Furthermore, there are some aspects that disrupt the appropriate operating expenses once the project has been approved, thus, the disbursed amounts are limited and scarce. For example, in 2019, we can barely see the value of disbursed financing, contrasting the more than 300$ million approved.

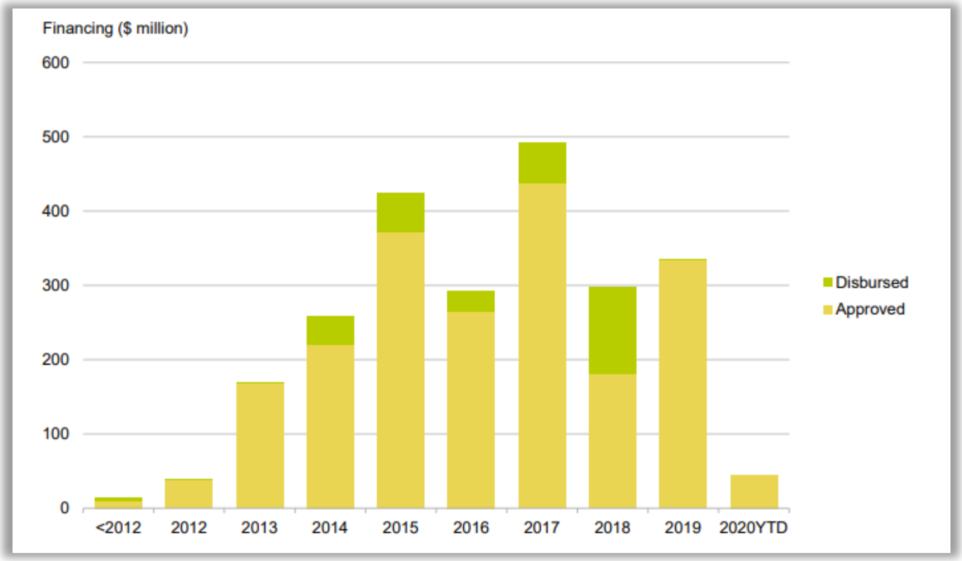

Figure 7: Approved and disbursed financing in the Microgrid sector (MGP, SEforALL, & BloombergNEF, 2020)

The reasons underlying this issue relate to various aspects. First of all, the immaturity of the market takes away confidence from the sector, finding projects in which oversized Microgrids down-size profitability or where the rural community lacks sufficient power demand. This last mention relates to the stringent demands for the projects, that can make it impossible for them to evolve and comply with the requirements. Bureaucratic processes also take a relevant position on the delay of capital deployment: long negotiations, complex procurements, and corrupt proceedings difficult a speedy process. As a result, these projects, even if they have been approved, face a convoluted course in which they get stuck. Moreover, policy changes also negatively effect Microgrids, because they can alter the political agenda in which these projects take place (MGP, SEforALL, & BloombergNEF, 2020).

To improve the possibilities for a successful financing assistance, there are some types of procedures that can appeal to public funding. According to the 2020 Report on the State of the Global Mini Grid Market, the most successful methodology is the results-based financing (RBF). This practice “improves returns, reduces risks of early-stage debt or equity finance, and potentially unlocks private capital”, attracting more funding (MGP, SEforALL, & BloombergNEF, 2020). Contrary to up-front expenditure, RBF offers the possibility for grants in exchange of proof on a reliable and operational Microgrid, lowering the chances of mismeasurements.

Summing up, the possibilities are larger on higher purchase-power countries, as developers select locations in which there is a considerable level of economic activity. Moreover, those states that already have important figures in terms of development assistance and official aid are also more prone to receive funding, which again reinforces the prospect of the development of Microgrid projects. Therefore, it would be right to say that Ethiopia, Kenya, Nigeria, Tanzania, and Uganda are the only countries that coincide in both aspects, and thus the most relevant countries for our study.

7.3. Policy and regulations affecting Microgrids

A necessary indicator for Microgrid projects to be successful is an appropriate regulatory framework, as countries with clear regulations are more attractive to Microgrid projects. Having a facilitative policy process does not only clarify and speed the procedure, but also invites investment.

In order to be able to conduct the micro grid project, a distribution and sales license needs to be awarded, which involves tariff approvals, importation authorization, consent to use land for the construction and operation of the Microgrid, and environmental certificates, between others (AMDA & ECA, 2020). Historically, these licenses have hampered the evolution of renewable energy projects in African countries for two main reasons: First, traditional over-regulations made it hardly impossible for projects to penetrate the African market, and secondly, the time required to submit and perform the Microgrid proposals were slow and arduous (USAID; Africa, Power; NREL, 2018). Several countries have recognized this issue and have consequently been improving on the last years the current regulations and the average timings to get the licenses, as we can see in Figure 8.

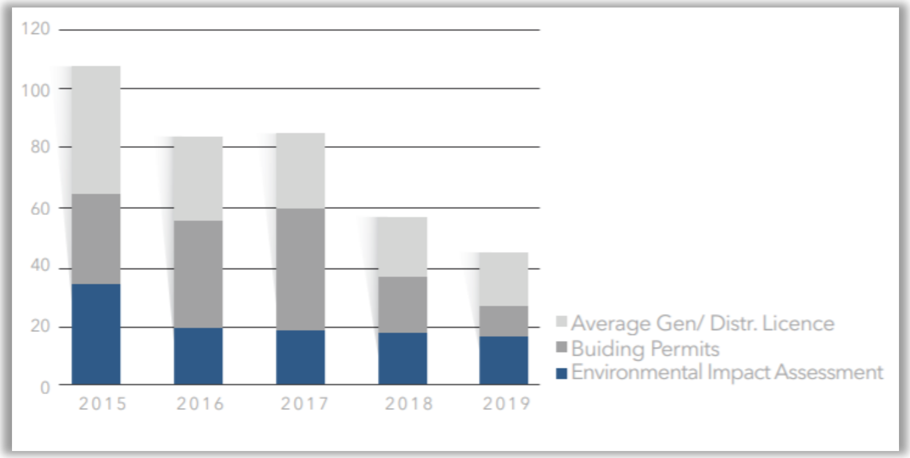

Figure 8: Average Microgrid licensing timing in Sub-Saharan Africa

There are three factors to take into account: policy framework on Microgrids, the regulation environment, taxation on renewable energy importations, and foreign investment in renewable energy projects. In terms of regulation and renewable energy/Microgrids, there are many African states that do not contemplate this topic in their legal framework. Thus, I will be observing only the countries that have adopted or considered adopting a policy framework within the micro grid sector. In this case, the best option would be the countries that have a policy framework, an import duty waiver (no taxation) and get significant investment.

For the purpose of this study, only the countries that have been eligible in either the electricity access and demand, or the willingness to pay and financing (or both) will be analyzed.

7.3.1. Ethiopia

On the last years, Ethiopia has considerably improved the regulatory context in which Microgrids take place. It has increased the number of initiatives favoring the implementation and development of these energy projects through enhanced policy framework, quality standards, cuts in the customs duties for renewable related imports and reduced requirements for testing (IPE, 2019).

The central implementation body is the Ethiopian Energy Authority (EEA). The EEA is responsible for establishing regulations for public and private sectors. It oversights the activities related to the micro grid value chain, taking into consideration political, social, security and environmental issues (EEA, 2021). The principal policies that are directly related or affect Microgrids are the following: National Electrification Program-Implementation Road Map and Financing Prospectus; National Electrification Program 2.0; Ethiopian Energy Policy (1994); Electricity Proclamation, no. 86-1997; Electricity Operations Regulations, no. 49/1999; Pricing procedure for small and very small self-contained system (SCS), no. 2/200; Climate-Resilient Green Economy (CRGE) strategy, 2011; Electricity Feed-In-Tariff Law, 2012; Investment Proclamation, no. 769/2012; Energy Proclamation, Proclamation 810/2013; Growth and Transformation Plan II (GTP II), 2015; Ethiopia National Electricity Transmission and Distribution Grid Code, 2016; Council of Ministers Energy Regulation, 2016; investment incentive policies of bureau of economic and business affairs Ethiopia investment climate statement 2016; Energy Efficiency Program- Ethiopian Energy Authority; Proclamation No. 1085/2018 and the Amendment of Energy Proclamation and the Investment law (IPE, 2019).

These policies favor micro grid implementation by allowing the involvement of competent actors in the generation, transmission, and supply of electrical off-grid energy. In the Ethiopian Integrated National Grid System (main national grid), transmission and supply of energy is an exclusive competence of the Government of Ethiopia, and only the generation process can be developed by non-governmental actors. Thus, it is a remarkable process for the Ethiopian government to delegate competences in the case of Microgrids.

In terms of import duties, there is a privilege stand for Microgrids. Goods directly related to the off-grid project such as solar panels are duty-free if the local options are not competitive (IPE, 2019). In addition, spare parts are also allowed if they don't account for more than the 15% of the total imports. This factor undoubtedly encourages the micro grid market, lowering the costs of implementation. Still, there is progress to be done in terms of the application process, as there are apparent inconsistencies on implementation problems.

The last parameter also involves positive connotations. Up to date, the Development Bank of Ethiopia, with the support of the World Bank, has offered loans to private sector businesses and micro finance organizations for the financing of micro grid solar projects. Since the creation of the financing facility in 2013, more than US$30 million has been dedicated to these systems. Still, it is important to mention that outside the previously mentioned financing facility, private investment has struggled to obtain loans because of high interest rates (Gogla, Country Brief: Ethiopia , 2019).

7.3.2. Kenya

Kenya represents East Africa's emerging Microgrid hub, as it facilitates investment, and its economic environment eases financial self-sustainability. Due to the fact that Kenya's Energy Regulatory Commission has kept promoting off-grids through supportive policies, its renewable energy policy landscape is conductive for increased investment and universal electricity access.

The 2006 Energy Act was, for long, the main document in terms of electricity regulation in Kenya, anchored with the old ways of energy management. Later on, in 2015, the government issued the National Energy Policy, in which there was an emphasis on environmental aspects of energy generation, distribution, and consumption. This concerns for the use of natural resources led to the execution of the Climate Change Act in 2016. In March 2019, the 2006 Energy Act was finally remodeled, bringing a larger focus on renewable energies (Part 6). The 2019 Energy Act supported the idea of energetic self-sufficiency and encouraged both households and businesses to invest in these clean energies. Furthermore, under this Act, the Kenyan government replaced the Rural Electrification Agency for the Rural Electrification and Renewable Energy Corporation (REREC), making obvious the interest for this new source of energy. Nowadays, not only does the REREC concentrate on the electrification of rural and isolated areas, but it is also involved in international cooperation, conducting research, and promoting renewables in the whole territory (Janho, 2020).

In 2016, tariffs have increased up to around 30% of the total cost of the imported solar system products. Although the increase on tariffs hampers the feasibility of Microgrid developments in Kenya, this country counters the import obstacles with feed-in long-term financial agreements that are attractive for developers.

Thanks to the enabling regulatory framework, Kenya is the African country that has been able to attract the most private investment. In addition, the World Bank has created the Kenya Off-Grid Solar Project (KOSAP), an initiative that promotes a results-based financing and, in general terms, a local financing facilitation.

7.3.3. Nigeria

One of Africa's most robust regulatory framework is Nigeria. This is largely a result of the Microgrid regulation developed in 2016 and 2017's Electric Power Sector Reform Act, in which it sought to promote electricity access around the region. The Nigerian Electricity Regulatory Commission (NERC) is the organ that issued in 2016 the Nigerian Electricity Regulatory Commission Regulation for Mini-Grids, which was created as a framework for investment on the field, encouraging rural electrification. Years later, in 2019, the Commission created a web tool to facilitate the Microgrid registration process and is working to further promote access to electricity (Nwoke, 2020). The Nigerian Rural Electrification Agency is also a responsible entity, working on grid extensions and highlighting the need of Microgrids to achieve their goals.

Rooting from 2005's Electric Power Sector Reform Act (EPSR) and the National Grid and Distribution Codes, the policies regarding Microgrids, renewables, and rural electrification have skyrocketed, transforming Nigeria into a prosperous country in this topic. The most important policies and plans in the regulatory framework include the Regulations for Independent Electricity Distribution Network (IEDN) of 2012; the National Renewable Energy and Energy Efficiency Policy (NREEEP) of 2015; the Rural Electrification Strategy and Implementation Plan (RESIP) of 2016; the National Renewable Energy Action Plan (NREAP, 2015 -2030) issued in 2016, the 2017's Electric Power Sector Reform Act mentioned earlier, and the 2018's Nigeria Electrification Project (Africa & ADB, 2018).

In terms of taxation, the solar systems are accompanied by a 25% good-equivalent tariff, which does not scale up to the tariffs in Kenya or Uganda, but that still can disincentive the developer. Still, in this country, the current cost tariffs depend on the size of the off-grid system, making it difficult to make average calculations. Independently from these costs, the licensing process in Nigeria is one of the fastest in the continent, due to its technological and regulatory facilities (REA, 2017).

In 2018, a USD350 million loan was provided to carry out the Nigeria Electrification Project, which aims to improve electricity access. Two years later, the African Development Bank (ADB) together with the Africa Growing Together Fund (AGTF) disbursed USD 200 million for the Nigeria Electrification Project (WB, Nigeria Electrification Project, 2021). The strong regulatory context of this country highly favors this financing and attracts both public and private investment.

7.3.4. Rwanda

In the case of Rwanda, we can also observe a supportive policy environment ruled by the RURA, "Rwanda Utilities Regulatory Authority", the main entity regarding energy regulation. It is the competent organism for establishing, enforcing, licensing and price-setting (RURA, 2021). Up to date, it continues improving the enabling regulatory framework.

Rwanda has a wide range of policies involving Microgrids. Even future objectives include this framework, including Rwanda's Vision 2020 and Vision 2050. Furthermore, the most relevant policies and strategies are the National Strategy for Transformation 1 (NST1) 2017; Energy Sector Strategic Plan (ESSP) 2018 8; National Electrification Plan (NEP) 8; Electricity Law (Law N°21/2011 of 23/06/2011 Governing 8 Electricity in Rwanda; modified in 2018); Rwanda Energy Policy (2015); Regulation No 03/R/EL-EWS/RURA/2019 Governing the Simplified Electricity Licensing Framework for Rural Electrification in Rwanda; Guidelines No 02/GL/EL-EWS/RURA/2019 on Minimum Technical Requirements for Mini-grids in Rwanda; Electricity Safety Regulations; Regulations on Rwanda renewable energy feed in tariff; Regulations Governing Electrical Installations, 2012; Regulations Governing Electricity Licensing, 2013; Rwanda Grid Code; Regulations on Solar Water Heating, 2015; Guidelines on Right-of-Way for Power Lines, 2016; and Regulation Governing Electricity Quality of Service in Rwanda, 2016 (USAID, Off-Grid Solar Market Assesment: Rwanda, 2019) (RURA, 2021).

Import duties in Rwanda are friendly with micro grid projects. The products related to solar or other renewable equipment are free of tax, and other specialized parts that are related with the implementation of the micro grid technology are also exempted of value added tax (USAID, Off-Grid Solar Market Assesment: Rwanda, 2019). Through the recent facilitation of this import process, Rwanda has managed to attract investors.

Emerging as a key technology and investment hub in Africa, Rwanda offers an important set of investments. There are two main organisms related to micro grid investment that must be observed. First of all, the National Fund for Environment in Rwanda (Fonds National Pour L'environnement au Rwanda), that supports the Rwandan transition to sustainability and green energy through renewable projects. Although there is no accessible information about the amount delivered for the programs, the fund has obtained more than US$50 million to endorse private and public renewable programs. Secondly, the Development Bank of Rwanda (Banque Rwandaise De Development), which accounts up to US$48 million from the World Bank Renewable Energy Fund, has decided to prioritize energy as a national sector positioning (USAID, Off-Grid Solar Market Assesment: Rwanda, 2019).

7.3.5. Tanzania

In 2008, Tanzania exponentially grew the energy access development projects by adopting a favoring regulatory Microgrid policy framework. Appliance of systems such as the dollarization of incomes and even just regulating the eligible projects made an incredible advance. The technical and economic regulatory authority in Tanzania IS EWURA (Energy and Water Utilities Regulatory Authority (EWURA), the responsible organism for electricity projects, thus overseeing the Microgrid processes (EWURA, 2021). However, weak implementation of these policies, ambiguity and the unexpected policy changes are hampering the regulatory framework in Tanzania.

In terms of the policies that guide Microgrid, we can find the National Energy Policy, developed in 2015, as the main one. Other important policies are the EWURA Act, 2001; The Public Private Partnership Act, 2010; Mini grid rules 2017; The Electricity Act, 2008; The Rural Energy Act, 2005; Renewable Energy Fund (REF); National Energy Policy, 2015 and the Power System Master Plan (2016) (Administration, 2021). All these policies have been progressively implemented in the legal framework, easing the path for the improvement of processes involved in Microgrid development.

This country also shows supportive measures through import duties developed in the form of feed-in tariffs. This type of payment favors renewable energy actors by offering long-term contracts to producers. Through cost-based compensation, the financing turns out to be considerably affordable. Most of the investment comes from equity and loans of the private sector. However, there is an important contribution by the government through the Rural Energy Fund, as much as international financing though the World Bank, European Union, African Development Bank, United Nations Development Program, the United States Agency for International Development, and the governments of Sweden, Norway and the United Kingdom (Administration, 2021).

7.3.6. Uganda

Energy policies in Uganda have prioritized grid extension rather than off-grid solutions (MGP, SEforALL, & BloombergNEF, 2020). Still, on recent years, the government has worked on improving the situation of Microgrids. There was an important push towards favoring regulation of Microgrids in 2016, when the Ugandan government, together with the German International Development Cooperation Agency (GIZ), developed the “Pro Mini-Grids project”, aiming to fasten institutional processes and to improve the financial and political Microgrid environment. Here, The Ugandan Ministry of Energy & Mineral Development (MEMD) leads the initiative, working with the Energy Regulation Authority and the Rural Electrification Agency. Still, the largest barrier to Microgrid development in Uganda is the deficient regulations.

In Uganda, the main policies involved in renewable energy are the Electricity Act, 1999; the Energy Policy for Uganda, 2002; Rural Electrification Strategy and Plan (RESP), 2013 to 2022; Renewable Energy Policy for Uganda, 2007.

The tariffs in Uganda are similar to the ones in Tanzania, having feed-in tariffs that foster Microgrid investment. Still, the actual taxation is not completely beneficial for off-grid technologies. For solar systems and related products, there is a tariff of around 30% of the cost of total goods, discouraging developers and investors (Gogla, Country Brief: Uganda, 2021). But despite the needs to improve the current regulation for Microgrids, Uganda has prosperously attracted investment. The GIZ is one of the main financing actors contributing to the development of Microgrids. Both the GIZ and the European Union have committed to around €5 million each, and with the help of organizations like the World Wide Fund for Nature (WWF), they have developed plans to increase solar Microgrids in Uganda (SeforALL & ADB, 2018). The World Bank is also providing the west African country through a line of credit and guarantee support to local banks. In addition, United Nations Capital Development Fund provides loans and grants to finance Microgrid projects (Gogla, Country Brief: Uganda, 2021).

Ultimately, to implement and develop effective Microgrid policy structures, there is a need of each state to set the regulations that will best fit their status, lowering tariffs and the licensing timings to attract investment and prompt these projects.

7.4. Impacts

There is not a common metric to evaluate the precise impact of Microgrids (MGP, SEforALL, & BloombergNEF, 2020). Still, there is a general knowledge of the consequences of electricity access, and many studies focus on the possible outcomes brought specifically by the Microgrid technology.

Socially, the expansion of Microgrids reflects on the possible improvement of basic services such as sanitation or education. This is not only by lighting up hospitals and schools, but also facilitating the use of electronic devices like computers and medical machinery to enrich these exercises. Moreover, electricity in the household can lead to refrigeration of food and medicine, greater access to television, and even facilitate a possible access to internet. Additionally, it empowers women by reducing their time doing chores and enabling this time to generate employment opportunities, study, or focus on other activities like getting involved in mass media (WB; FDA, 2021).

A study made by the United Nations Industrial Development Organization, together with the African Development Bank, the Alliance for Rural Electrification, African Minigrid Developers Association, and Insensus, states that there are perceptible macroeconomic and microeconomic plausible repercussions. Some important macroeconomic effects are the acceleration of productivity, increase of employment, augmentation of entrepreneurship, reduction of rural-urban migration, and can further increase foreign direct investment. In the microeconomic level, two relevant aspects are the advancement on local infrastructure and the local economic growth (UNIDO, ADB, ARE, AMDA, & Insensus, 2020). These economic factors then increase of the demand for electricity. This is caused by three main consecutive elements. The first and most obvious one is explained by the new users that start to operate with electric devices. Secondly, there is an increasing number of machines per costumer, which drives us to the last aspect, that is the incrementation of the electricity expenditure. These reasons enlarge the demand, intensifying the not only the economic but also the social impacts.

In environmental terms, the generation of affordable and clean energy reduces the traditional use of charcoal or biomass consumption for lighting and cooking. This has a direct impact on the air quality and on the greenhouse gas emissions.

Moreover, Microgrids can also create positive impacts through other forms of participation, like generating energy to pump fresh water. An example of this can be the agreement made in 2019 by the World Bank and the Government of Tanzania to finance off-grid solar pumping systems in 165 rural and isolated areas in Tanzania.

Finally, it is important to focus on the close relationship between electricity access and human development index (HDI). There is a direct association, as the higher the percentage of people with access to electricity in a country, the higher the HDI will be.

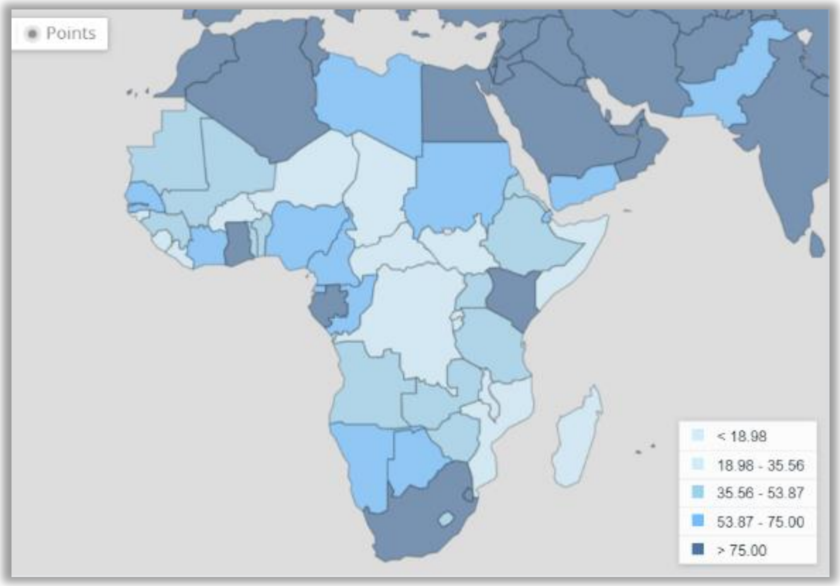

Figure 9: Access to electricity (% of population) in SSA

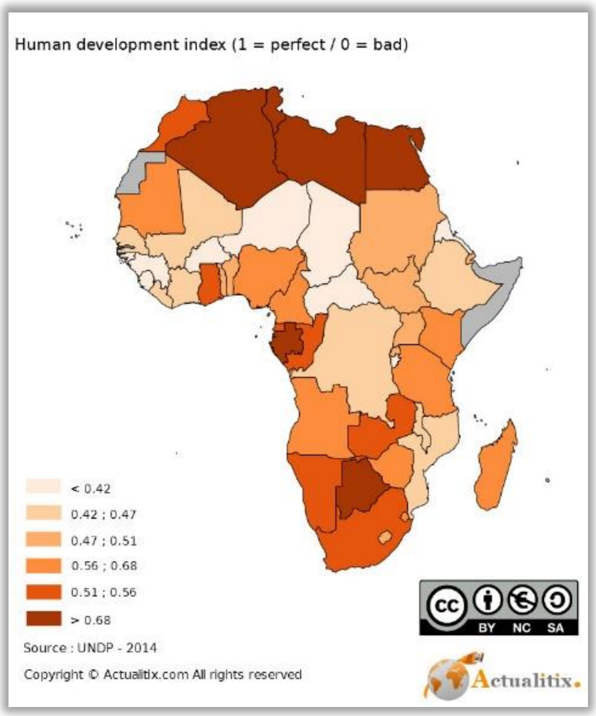

Figure 10: Human Development Index in SSA

8. Conclusion

Out of the 58 Sub-Saharan states investigated, the author sees Ethiopia, Kenya, Nigeria, Rwanda, Tanzania and Uganda as the most supportive states to develop Microgrids due to the presence of facilitating elements. Through this technology, the previously mentioned countries are the most indicated to benefit from this sustainable energy source, improving their poverty rates and ameliorating the causes of climate change.

In the first place, the aspects that positively affect the establishment and development of Microgrid projects were found to be related to the electricity access and demand, the willingness to pay and financing, and the policies and regulations. Microgrid developers have shown to be interested in places with high electricity demand, as it proves to have a larger impact, reduce costs and improve profitability. In addition, there is great attention towards the economic capability of the communities subject to these energetic projects. The most competent areas have higher chances of generating greater economic outputs, increasing the feasibility of the program. Moreover, the lack of a regulatory framework obstructs the process, leading developers to withdraw their interest. With consolidated policies, there are added securities and quicker processes, which also enhance the chances to conduct a Microgrid project.

Concerning electricity access and demand, three indicators were measured through their average values: (1) Access to electricity, (2) population density, and (3) rural population. Access to electricity expresses the countries with the worst electrification rates, thus showing the ones that are most in need this technology. In terms of power demand, the study aims to find the countries that could potentially have the most electricity usage. Although this information is usually found through the study of ARPU, this data was not available in the examined rural areas, therefore a correlation between population density (people per sq. km of land area) and rural population (% of total population) was done, showing the states with the highest rural population density.

Doing a comparison between the Sub-Saharan states that had low electricity access and high rural population density (therefore, potential electricity demand), Ethiopia, Rwanda and Uganda turned out to be the only countries meeting both requirements.

Relevant to the willingness to pay and financing, the indicators used were: (4) Power purchasing parity, (5) income inequality coefficient, and (6) net official development assistance and official aid received. After evidencing that households are willing to allocate a considerable part of their expenditures on electricity, the aim of the study was to determine the countries with the highest eagerness to pay for electricity in rural areas. Considering that this study focuses on rural population, the PPP was not sufficient, as this value demonstrates the economic power of the whole country without taking into account different socio-economic aspects. Therefore, in order to measure the potential economy in the non-financial areas, a correlation between PPP and the GINI coefficient was conducted, distinguishing the countries with high income inequality. As a result, the countries selected have relatively high purchasing power parity values and low income inequality, which in other words means the rural population has more possibilities to pay the electricity. Still, as we have seen, the vast majority of the households' budgets do not cover the costs of Microgrid electricity, meaning that even though the client's economic power is still relevant, further financial aid is necessary. For this reason, we looked at the net official development assistance and official aid received of each country.

Accordingly, the countries that both coincide to have the largest economic values in the rural areas and with the highest foreign aid received are Ethiopia, Kenya, Nigeria, Tanzania, and Uganda.

Lastly, with reference to policies and regulations, it is noticeable how many countries in the region lack the necessary regulatory frameworks or, in the contrary, have traditional over-regulations that difficult the penetration of projects in the African market. The timings to get the necessary licenses also complicate the situation. Thus, it is important to take into account the legal implications related to Microgrids. For the purpose of this study, three features were observed: the policy framework on Microgrids, the regulation environment, taxation on renewable energy importations, and foreign investment in renewable energy projects. Except Uganda, where energy policies have prioritized grid extension rather than off-grid solutions (but that still manages to have a powerful policy structure), the rest of the examined countries (Ethiopia Kenya, Nigeria, Rwanda and Tanzania), have shown to adopt favoring regulatory frameworks for Microgrid projects. Of course, the levels of development and involvement vary in each country, as covered in the policy and regulations section.

Summarizing, we can differentiate in three different groups: The first one is formed by Ethiopia and Uganda. Both countries present positive results in all three aspects (electricity access and demand, the willingness to pay and financing, and the policies and regulations). The second group includes Rwanda, a country that has advantageous numbers in two out of the three aspects. In terms of power demand due to a lack of electrification and high rural population, and in policies and regulations towards Microgrids. Finally, the third formation is composed by Tanzania, Nigeria, and Kenya, that also sum up two aspects of the three. These three countries have a favoring economic and regulatory environment.

Although the focus of this study is to identify the best parameters and discover the most favorable countries through analysis, for expanded knowledge about the feasibility of Microgrid project development, a country assessment of each state should be conducted. Each country has its own peculiarities, having considerable variations between each other that should be studied in their own particular context.

Nevertheless, some generalizations can be made in terms of the impact that Microgrids can create in communities and, overall, countries. Focusing in social, economic, and environmental terms, the repercussions are perceptible. As we have seen, socially, the consequences are greatly beneficial, including refrigeration of food and medicine or lighting study areas. Furthermore, we have observed how both micro and macroeconomic effects take place, such as a steady increase of employment. The environmental repercussions are also striking, starting with the generation of clean energy, which impacts on air quality and GHG emissions.

Most importantly, access to electricity directly relates to human development; thus Microgrids can undoubtedly lead to human development through sustainable energy resources.

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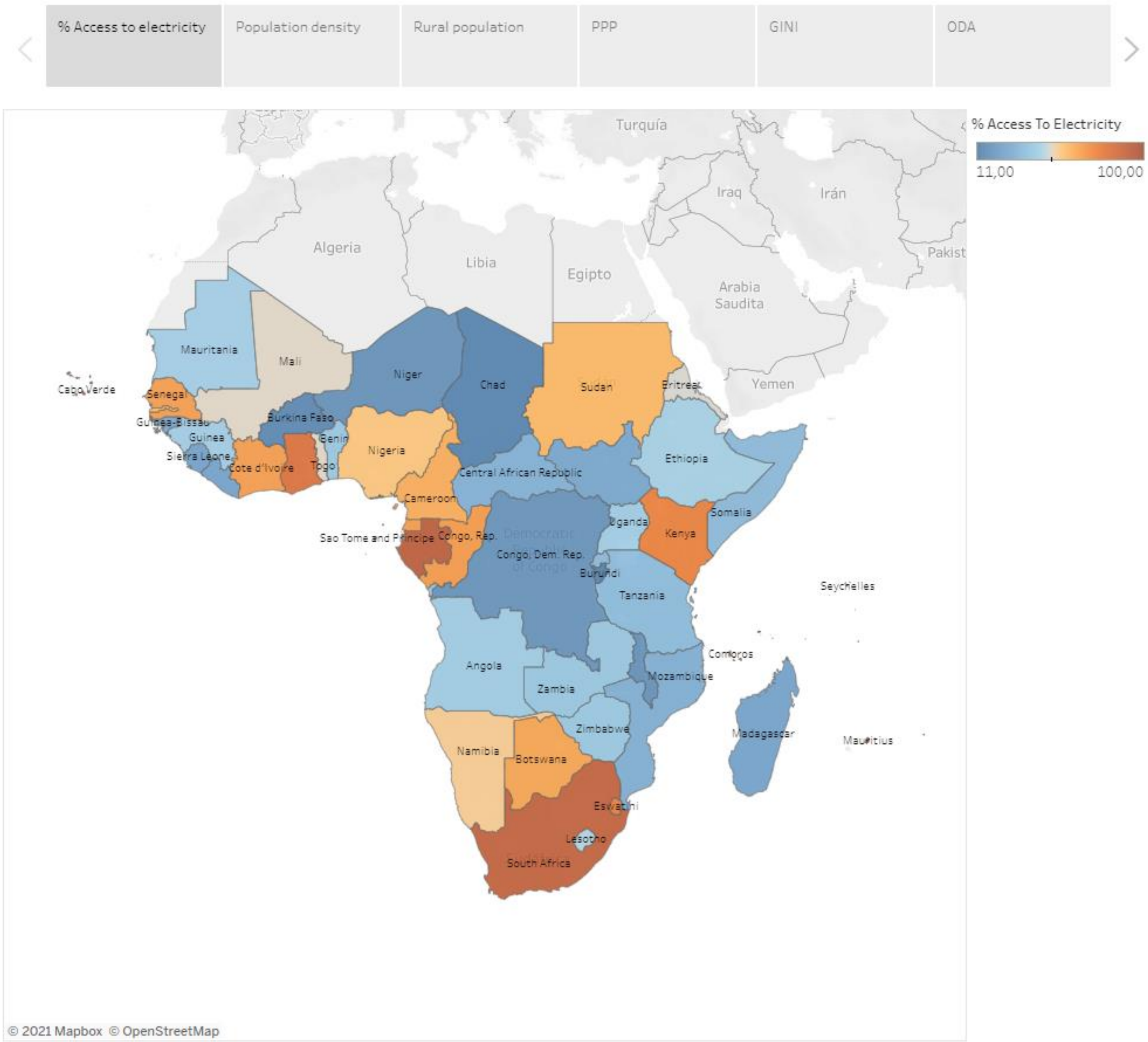
10. Annexes


% Access to electricity
Population density
Rural population
PPP
GINI
ODA
% Access To Electricity
11,00
100,00
Turquía
Iraq
Irán
Algeria
Libia
Egipto
Arabia Saudita
Mauritania
Mali
Niger
Chad
Sudan
Eritrea
Yemen
Cabo Verde
Senegal
Guinea-Bissau
Guinea
Sierra Leone
Burkina Faso
Benin
Nigeria
Togo
Cote d'Ivoire
Ethiopia
Central African Republic
Cameroon
Somalia
Uganda
Kenya
Sao Tome and Principe
Congo, Rep.
Congo, Dem. Rep.
Burundi
Tanzania
Seychelles
Comoros
Angola
Zambia
Mozambique
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Mauritius
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Botswana
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Lesotho
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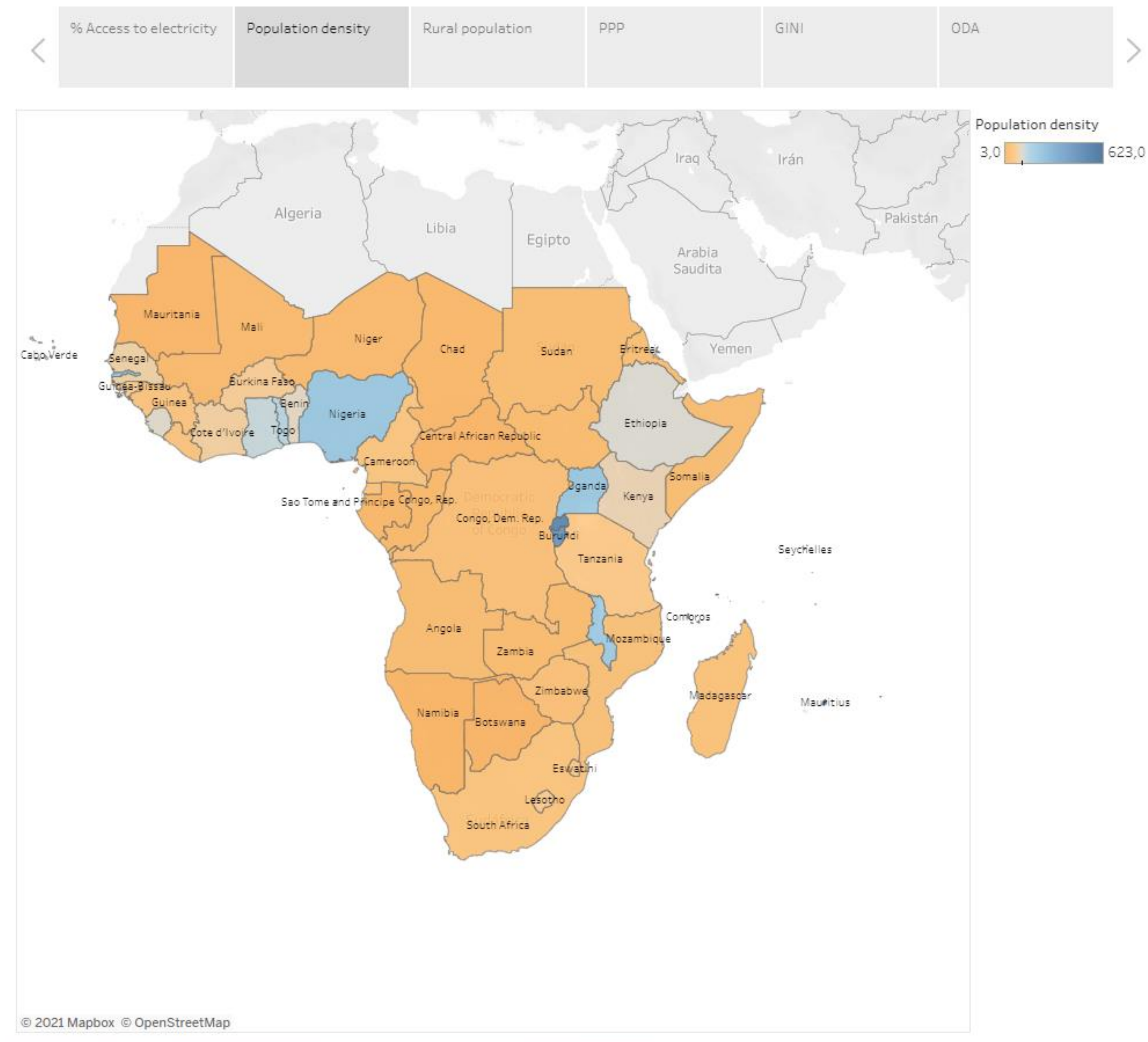
% Access to electricity
Population density
Rural population
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GINI
ODA
Population density
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623,0
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Libia
Egipto
Iraq
Irán
Arabia Saudita
Pakistán
Yemen
Mauritania
Mali
Niger
Chad
Sudan
Eritrea
Cabo Verde
Senegal
Guinea-Bissau
Guinea
Burkina Faso
Benin
Nigeria
Cote d'Ivoire
Togo
Ethiopia
Central African Republic
Cameroon
Somalia
Uganda
Kenya
Sao Tome and Principe
Congo, Rep.
Congo, Dem. Rep.
Burundi
Tanzania
Seychelles
Comoros
Angola
Zambia
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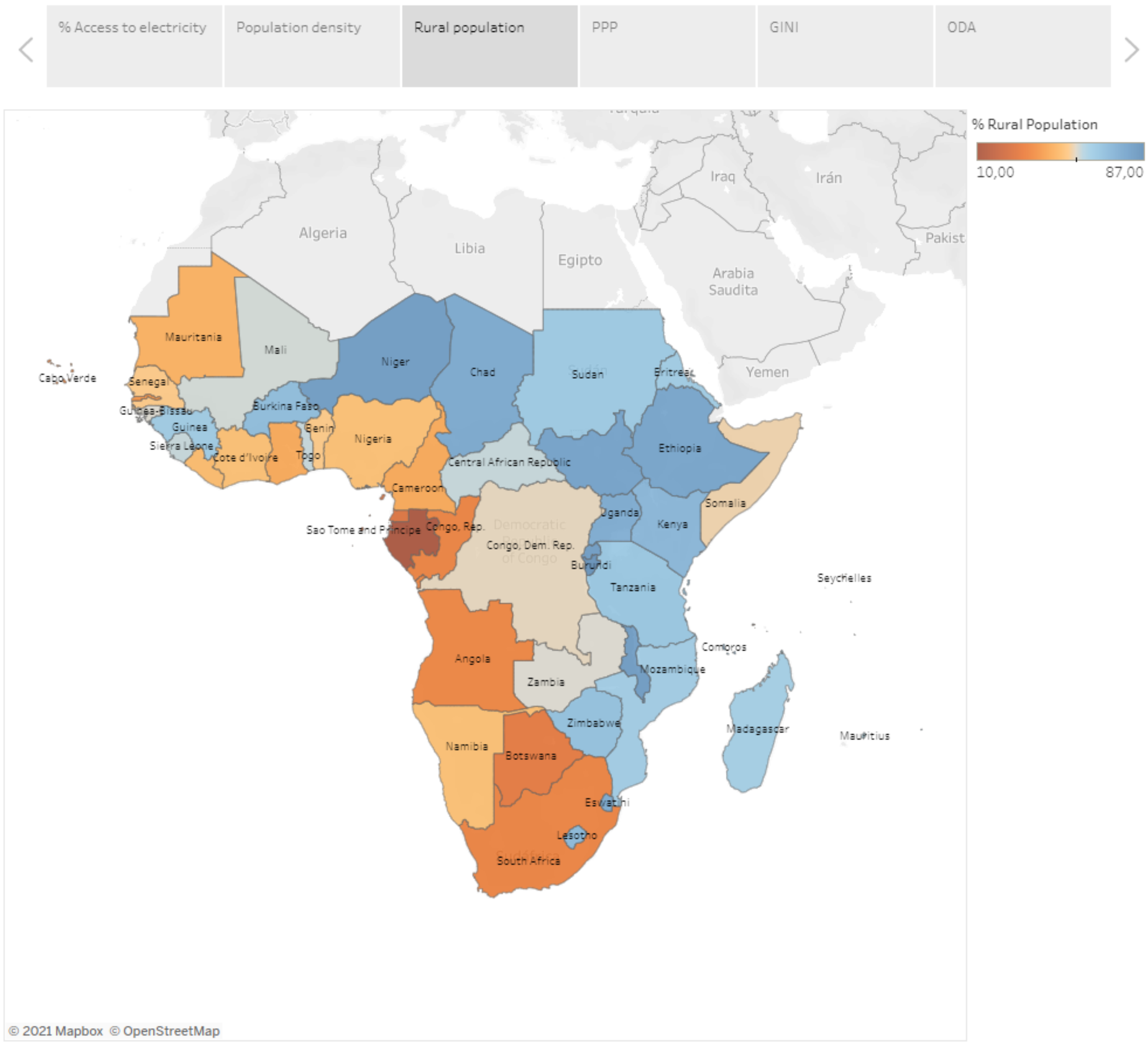
% Access to electricity
Population density
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% Rural Population
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Algeria
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Egipto
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Irán
Arabia Saudita
Yemen
Mauritania
Mali
Niger
Chad
Sudan
Eritrea
Ethiopia
Somalia
Kenya
Uganda
Cabo Verde
Senegal
Guinea-Bissau
Guinea
Sierra Leone
Burkina Faso
Benin
Togo
Cote d'Ivoire
Nigeria
Cameroon
Central African Republic
Sao Tome and Principe
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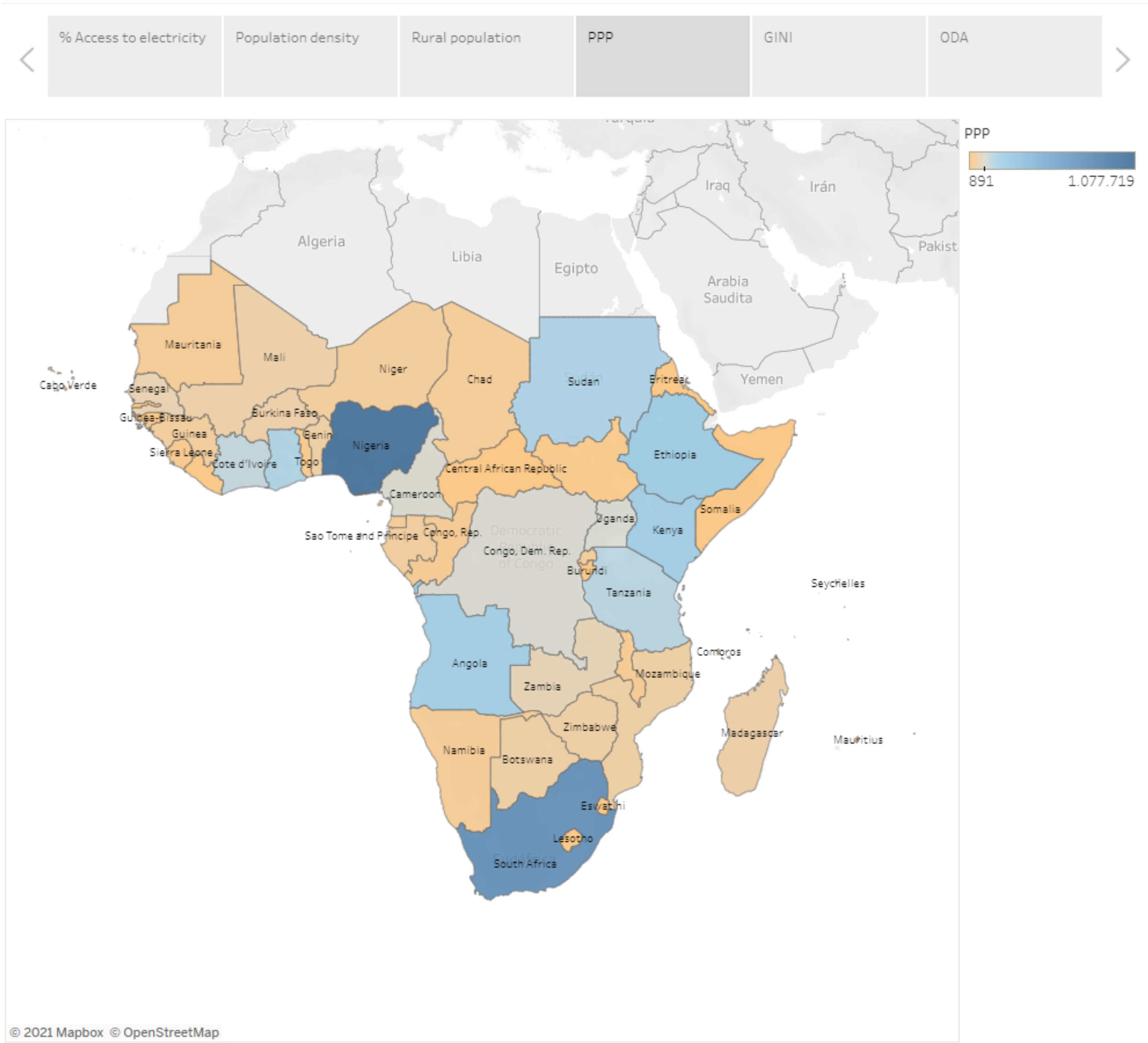

% Access to electricity
Population density
Rural population
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GINI
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Mauritania
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Cabo Verde
Senegal
Burkina Faso
Nigeria
Ethiopia
Guinea
Sierra Leone
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Somalia
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Uganda
Kenya
Sao Tome and Principe
Congo, Rep.
Congo, Dem. Rep.
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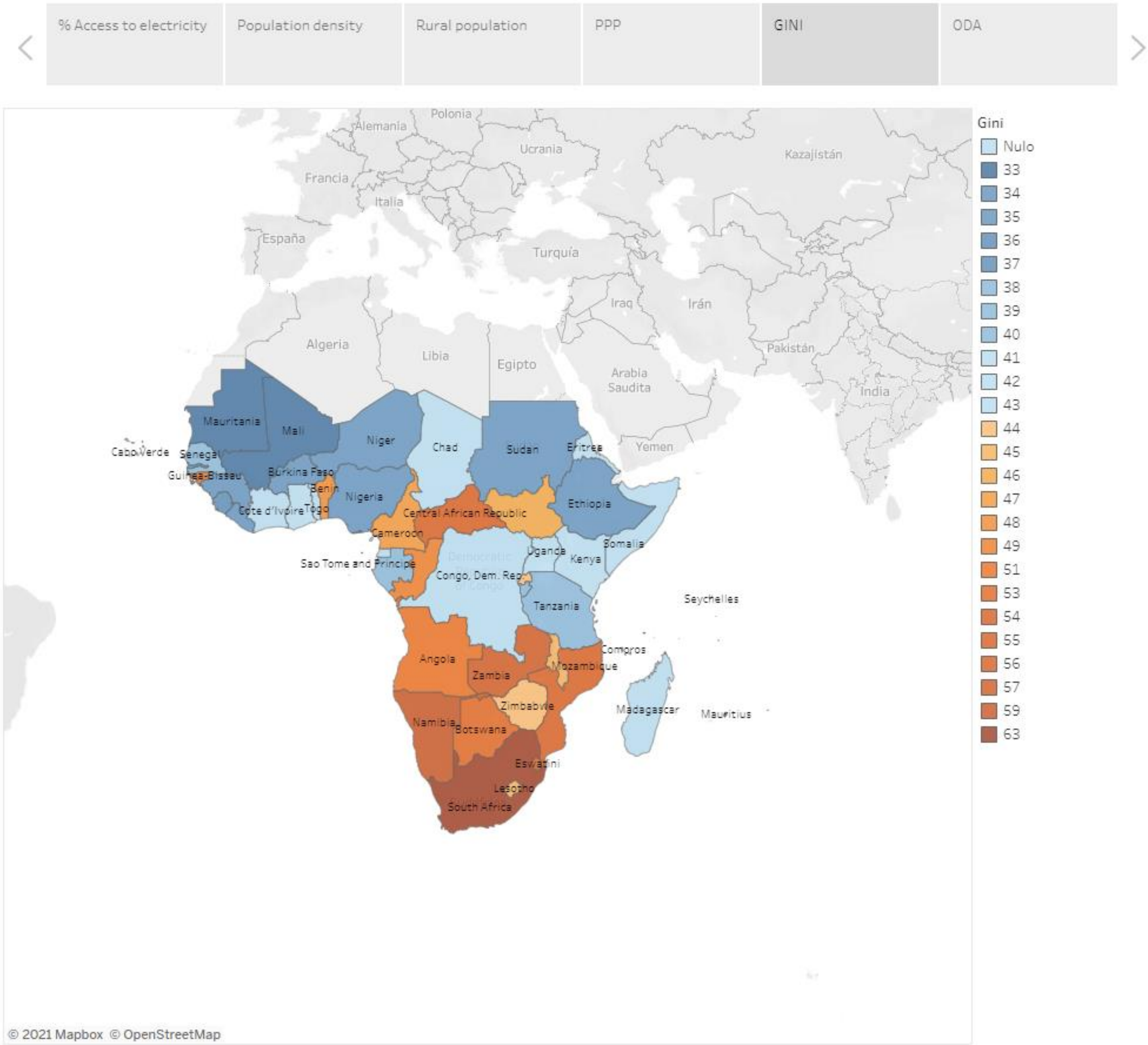
% Access to electricity
Population density
Rural population
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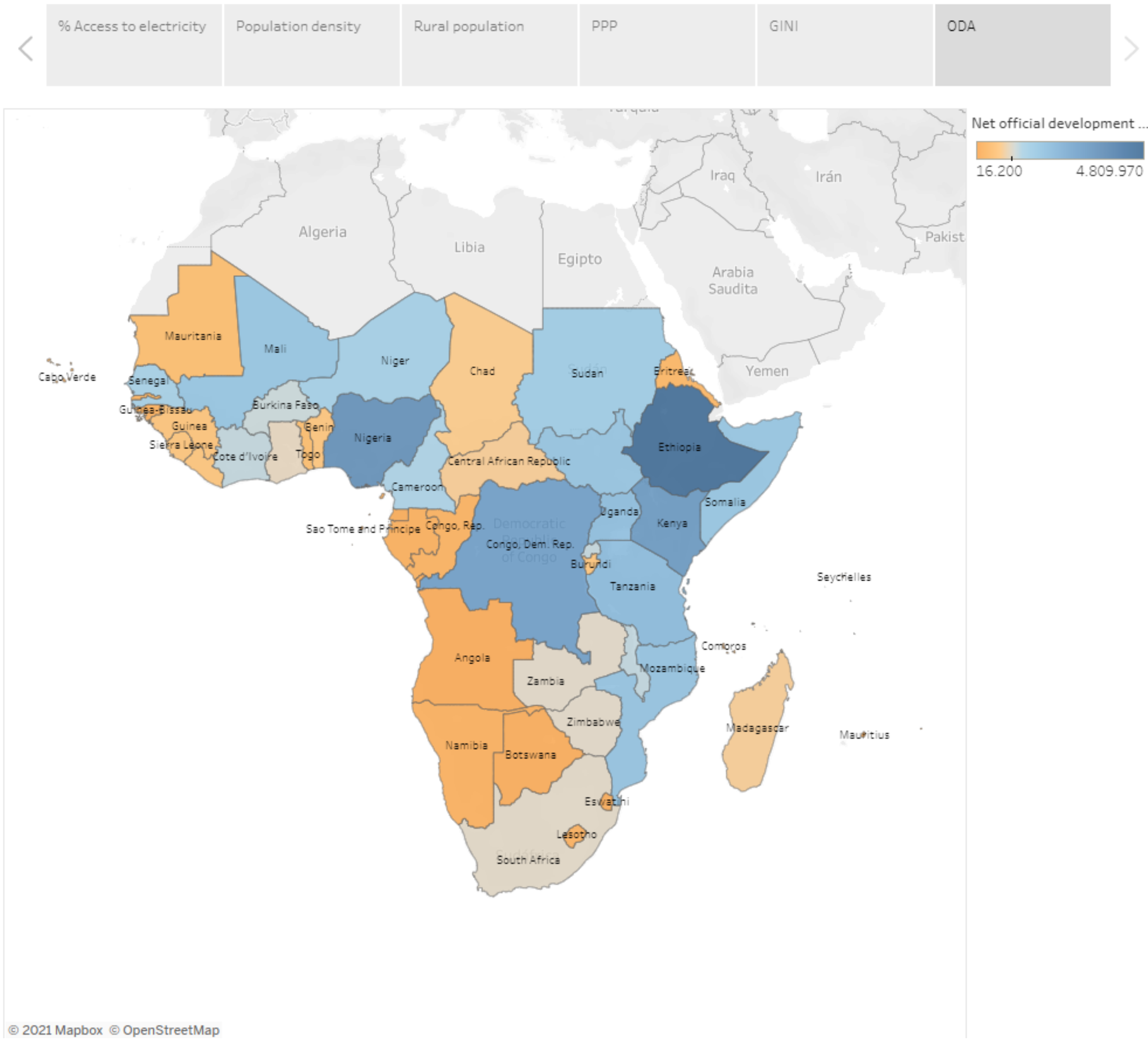

% Access to electricity
Population density
Rural population
PPP
GINI
ODA
Net official development ...
16.200
4.809.970
Algeria
Libia
Egipto
Iraq
Irán
Arabia Saudita
Pakist
Yemen
Mauritania
Mali
Niger
Chad
Sudan
Eritrea
Ethiopia
Somalia
Cabo Verde
Senegal
Guinea-Bissau
Guinea
Sierra Leone
Burkina Faso
Benin
Togo
Cote d'Ivoire
Nigeria
Cameroon
Central African Republic
Sao Tome and Principe
Congo, Rep.
Congo, Dem. Rep.
Uganda
Kenya
Burundi
Tanzania
Seychelles
Comoros
Angola
Zambia
Mozambique
Zimbabwe
Namibia
Botswana
Madagascar
Mauritius
Eswatini
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