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TOWARD ACCESS TO ELECTRICITY IN AFRICAN RURAL AREAS

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Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título

TOWARD ACCESS TO ELECTRICITY IN AFRICAN RURAL AREAS

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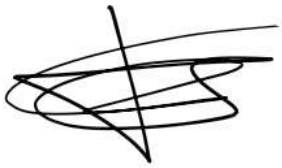

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RESUMEN EJECUTIVO DEL PROYECTO

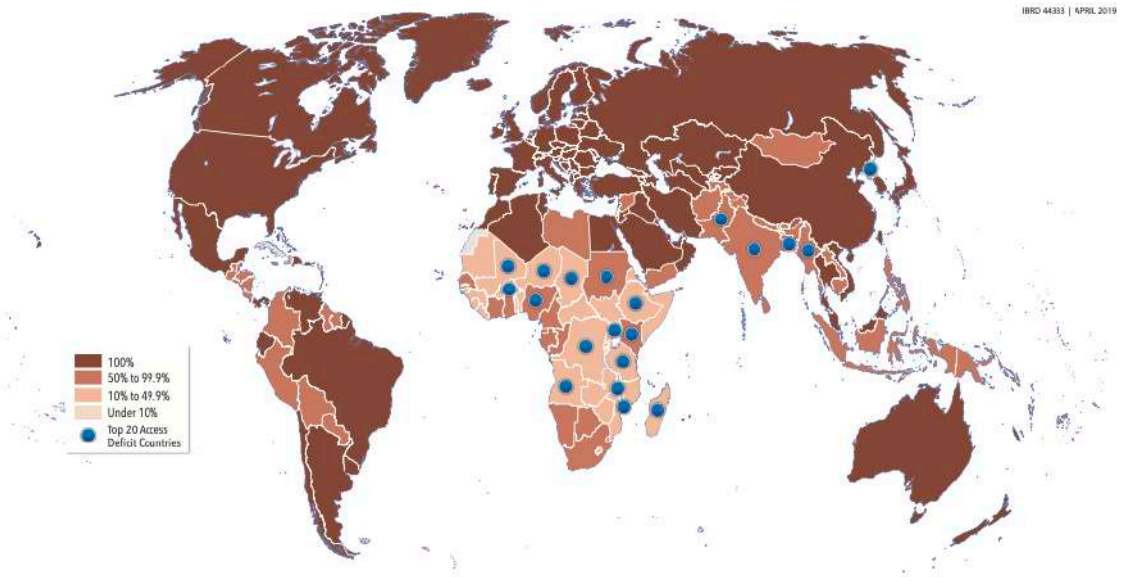
1. INTRODUCCIÓN

La electricidad es uno de los mecanismos que hace posible la entrada al mundo moderno y se asume como algo innegociable en un país desarrollado. La tasa de acceso a la electricidad es uno de los indicadores de desarrollo más directos y simples. Aunque este porcentaje no ha parado de crecer hasta 2018, año en el que el 89 % de la población mundial tenía acceso a una fuente de electricidad fiable, aún se estima que existen en torno a 840 millones de personas que no disfrutan de este bien tan necesario [1]. La mayoría de estas personas se localizan en África y Asia. Algunos países que destacan particularmente son la República Democrática del Congo, Nigeria o Pakistán con más de 50 millones de personas sin acceso en cada uno de ellos. La última década significó un gran avance. El porcentaje de la población mundial con acceso a electricidad pasó de un 83 % en 2010 a un 89 % en 2017, lo que en términos reales supone que en torno a 920 millones de personas consiguieron acceso. Particularmente, el ritmo de crecimiento comenzó a acelerarse en 2015 y, en apenas dos años, un mayor número de personas consiguió acceso que en el lustro anterior.

Multitud de organizaciones internacionales como la Agencia Internacional de la Energía, Naciones Unidas o el Banco Mundial colaboran con un único objetivo: acceso universal a la electricidad en 2030. El crecimiento porcentual anual necesario para lograr este aventurado objetivo se sitúa como mínimo en un 0.86 % y aunque es un propósito excelente, incluso en los años donde el progreso fue mayor (2015-2017), el incremento anual alcanzó solamente el 0.8 %. Además, otro punto a tener en cuenta es que el progreso no es uniforme en todas las regiones y hay algunos países donde el acceso se está alcanzando a mayor velocidad que en otros. Debido a esto, han surgido dos categorías bien diferenciadas: Por un lado, los países en los que la tasa de acceso a electricidad está aumentando de forma notable año a año. Estos países se sitúan en su mayoría en Asia.

Por otro lado, países donde apenas se aprecia una mejora significativa a lo largo de la última década. Este es el caso de muchas naciones en África y, particularmente, en el África Subsahariana, zona en la cual se desarrollan los contenidos de este proyecto.

Las razones por las cuales el acceso no se ha incrementado notablemente en esta región de África como sí ha ocurrido en el continente asiático son muy diversas. El principal motivo es la inestabilidad existente en todos los ámbitos en la mayoría de los países del África Subsahariana cuyo origen se puede situar en el colonialismo europeo durante los siglos XIX y XX. La falta de infraestructuras nacionales y una industria completamente organizada en torno a un enorme sector primario con el único fin de exportar minerales, tejidos y otros materiales al continente europeo, distorsionó totalmente el sistema productivo de cada uno de estos países así como el desarrollo del mismo.



Acceso a electricidad por países en 2017

Otro aspecto preocupante es la frecuente práctica de sobornos, corrupción y la existencia de monopolios en el continente. Encuestas elaboradas por Transparencia Internacional sobre la percepción de corrupción entre la clase política y funcionarios, sitúan a la región del África Subsahariana entre los países más corruptos del mundo [2]. En muchos países africanos la ley es bastante indulgente frente a prácticas corruptas por lo que no existe un gran temor a las condenas. Enriquecerse a costa del pobre es un denominador común en

la mayoría de los países subdesarrollados. La corrupción y el nepotismo son demasiado usuales entre la clase gobernante, el ámbito militar y llegando incluso a los negocios. Sin embargo, los ciudadanos de estos países son cada vez más conscientes de estas malas prácticas y muchos sectores exigen leyes más firmes y sentencias más severas [3]. A esto hay que sumar las enormes trabas políticas y regulatorias que eliminan cualquier intento del sector privado por invertir en la región, aunque es algo que está cambiando progresivamente.

Otros problemas que afronta el continente africano en la actualidad son el terrorismo y las continuas guerras civiles entre sus grupos étnicos. Estos enfrentamientos suponen el desplome de la ya débil economía, la destrucción de bienes públicos como carreteras, la desestructuración de la juventud que es captada para fines militares y, en definitiva, el nulo interés por parte de los inversores y empresas internacionales en proyectos en dichos países.

2. ACCESO EN EL AFRICA RURAL

El incremento en la tasa de acceso en zonas rurales fue mayor que en núcleos urbanos entre 2015 y 2017, pero existe aún un enorme desfase. De hecho, el déficit de acceso rural supone un 87 % del total. Esta situación dibuja un panorama desolador en la región. Intentar alcanzar el pleno acceso en 2030 es poco realista ya que las áreas donde la situación tiene que mejorar más rápido son aquellas de mayor dificultad, tanto en acceso como en medios disponibles.

Otro enorme problema a remediar es la falta de acceso a medios para cocinar de forma limpia. El porcentaje de población sin acceso a combustibles limpios para cocinar no ha parado de incrementarse ya que el aumenta de población es más rápido que la cantidad de personas que consiguen acceso a este tipo de combustibles. Cualquier avance en el acceso a electricidad supondrá también una mejora en este campo. Entre los combustibles contaminantes empleados en la región están la madera, el carbón o el queroseno. Por otro lado, entre los combustibles no dañinos para la salud se encuentran el gas natural, el gas licuado, el biogás o la electricidad. Se estima que en torno a 2960 millones de personas cocinaban usando combustibles dañinos en 2017 [1]. De acuerdo con estudios realizados por la Universidad de Oxford, el uso de combustibles fósiles para el cocinado es

responsable de multitud de enfermedades pulmonares como podrían ser el cáncer pulmonar o la neumonía. En 2010 el 80 % de la población africana utilizaba este tipo de combustibles [4]. La llegada de la electricidad a estas comunidades supondría un enorme avance en algo tan fundamental como la forma de cocinar, lo cual acarrearía una gran mejora de salud en sus habitantes y, a su vez, un menor requerimiento incluso de personal sanitario para tratar dichas enfermedades. A esto se le podría añadir la utilización de sistemas de bombeo que faciliten la obtención de agua potable en lugares donde antes sería impensable extraer agua. Este es otro objetivo de desarrollo sostenible de Naciones Unidas.

Otro punto a considerar es la naturaleza del proyecto a implementar. La gran mayoría de los proyectos actuales se basan en la red eléctrica nacional existente o en la extensión de esta. A pesar de que es un proyecto ambicioso para lograr el acceso total en zonas urbanas por medio de interconexiones de medio y alto voltaje entre grandes núcleos de población, esta práctica deja los entornos rurales al margen. Las zonas rurales no conseguirían acceso a la red hasta que esta se expandiera y alcanzara cada núcleo de población, lo cual podría tardar décadas en ocurrir. Este hecho se puede apreciar en el Capítulo 5, donde se hace una comparativa de la densidad de población y la red de medio voltaje, la cual es estimada mediante la irradiación nocturna recogida por satélites y después a partir de un mapa de la República Democrática del Congo generado mediante Python.

Mientras estos planes se desarrollan, es necesario encontrar una solución que adelante la llegada de la electricidad a estos núcleos de población de una forma viable. Por tanto, un punto fundamental a considerar es la financiación de estos proyectos. La renta media es bastante más baja en estas zonas aisladas que en entornos urbanos. Particularmente en el África Subsahariana, incluso la población que reside en grandes ciudades vive bajo el umbral de la extrema pobreza. Por lo tanto, es necesario encontrar un procedimiento que haga posible que estas comunidades consigan un sistema de pagos que haga posible sufragar el coste de las instalaciones, así como conseguir credibilidad de cara a la solicitud de préstamos u otras formas de financiación.

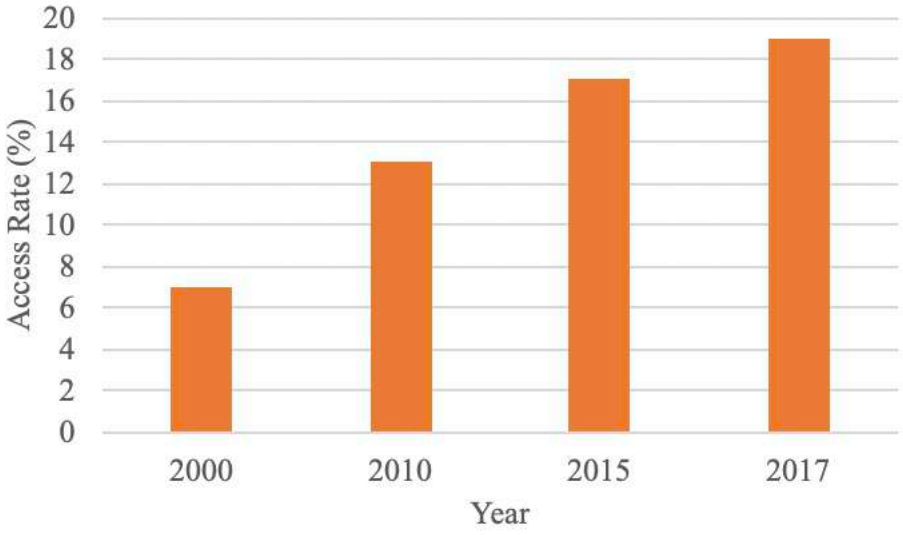
Entre los beneficios que la electricidad trae consigo hay algunos que son realmente urgentes en la región. La situación sanitaria en el África Subsahariana es particularmente dramática. Con la electrificación de instalaciones sanitarias, muchas más vidas podrían

ser salvadas. El ámbito educativo también sufriría una enorme mejora con la llegada de la electricidad a los centros de enseñanza. Esto supondría un gran avance tanto para alumnos como profesores.

3. EL CASO PARTICULAR DE LA REPUBLICA DEMOCRATICA DEL CONGO

La segunda mitad de este proyecto se centra en uno de los países mas subdesarrollados del mundo a pesar de ser considerado el más rico en recursos naturales: La República Democrática del Congo. Los conflictos étnicos en el país son una constante desde que existen datos. El desarrollo desigual en el país ya era significativo antes del siglo XIX. Una vez Bélgica colonizó el país, este fue totalmente devastado. La economía se centró exclusivamente en la extracción de caucho, minerales y café para ser exportados a Europa. No hubo un desarrollo industrial debido a los enormes monopolios tomados por las autoridades belgas. Una vez el colonialismo concluyó, multitud de conflictos estallaron y varias guerras civiles concluyeron con miles de inocentes fallecidos. Los estallidos de violencia producidos en las 3 últimas décadas entre las diferentes regiones han dejado a un lado las reformas necesarias que el país necesitaba. De esta forma, es posible entender la baja tasa de acceso en el país y por qué es tan pobre actualmente.

La situación en la República Democrática del Congo es dramática. La tasa de acceso a electricidad en entornos urbanos se sitúa en torno al 49 % mientras que en zonas rurales es nula [5]. Existen en torno a 13 millones de hogares sin acceso a electricidad lo cual significa un 84 % de la población [6]. Estos hogares se distribuyen de forma desigual a lo largo del territorio del país por lo que es necesario encontrar una solución adaptable a las necesidades de cada rincón de su territorio.



Tasa de acceso a la electricidad en *DRC* [8]

En áreas urbanas solamente el 9 % de la población del país tiene acceso a combustibles para cocinar de forma limpia; mientras que en zonas rurales este porcentaje no llega al 5 %.

Para reflejar una imagen a grandes rasgos del clima político y económico del país, diversas instituciones elaboran rankings que se mencionan a lo largo del proyecto. De acuerdo con el Instituto para la Economía y la Paz, la República Democrática del Congo ocupa el puesto 155 de los 163 países considerados [7]. El Banco Mundial sitúa al país en el puesto 183 de 190 encuestados en su Índice de Facilidad para el Negocio [8]. Finalmente, el Índice de Libertad Económica elaborado por la Fundación Heritage y que es publicado en el periódico estadounidense The Wall Street Journal mide el grado de libertad económica en cada país del mundo. Este ranking sitúa al país en la posición 162 de 180 países totales [9].

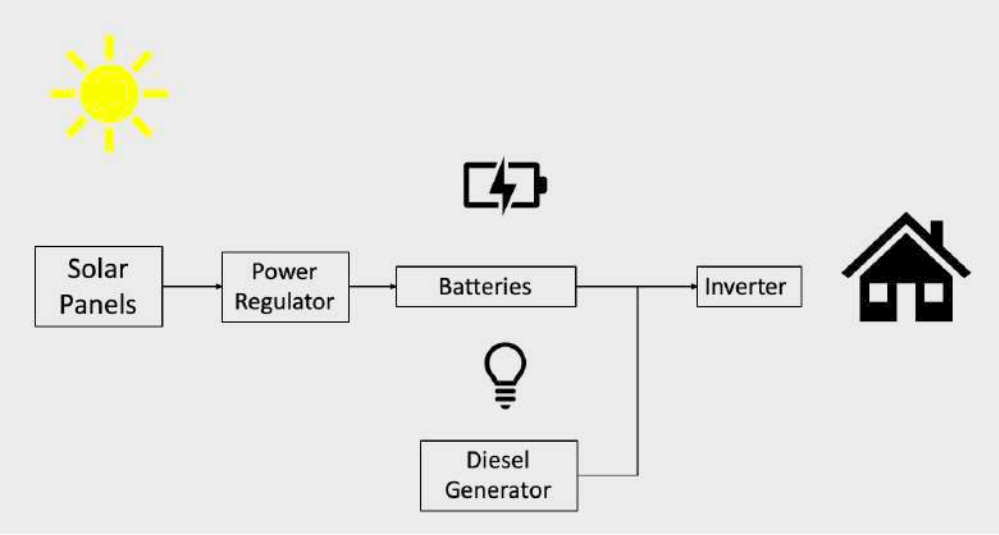
4. METODOLOGIA A IMPLEMENTAR

Con el fin de encontrar una solución para comunidades aisladas hasta que el Gobierno de la República Democrática del Congo consiga expandir la red nacional, una opción adecuada es aprovechar la excelente irradiación que el país presenta. Para ello, se propone

una instalación aislada, es decir, externa a la red. La característica de independencia de la instalación requiere que la comunidad en cuestión se organice como una cooperativa para dividir los costes fijos de la instalación para de tal forma hacer el proyecto viable. Para ello, también será necesario un préstamo para lo cual se sugiere un sistema de micro pagos para solventar dicha deuda en un plazo que dicha comunidad pueda afrontar.

Otra característica clave de la instalación es su aspecto modular para permitir de tal modo que la instalación incremente su capacidad si la comunidad aumenta su consumo. Esto se conseguiría con un incremento del número de paneles fotovoltaicos y se aprovecharía que en el cálculo de los elementos de la instalación se deja cierto margen para que la comunidad pueda incrementar en una magnitud considerable el consumo sin tener que hacer un enorme desembolso para rediseñar la instalación.

Finalmente, el sistema debe contar con una conexión a la red para que una vez llegue a dicha población, esta pueda ser anexionada a la red nacional. De esta manera, el sistema fotovoltaico se convertirá en un nuevo actor en sistema eléctrico nacional.



Esquema simplificado de la instalación general

Para el pago de la instalación se propone un sistema de pagos conocido como “Pay-as-you-go”, mediante el cual hay un monto principal previo a la instalación de la planta y, posteriormente, una serie de micro pagos adaptados a las posibilidades de la comunidad. Un hecho al que se le da gran importancia en este proyecto es la figura del filántropo. Para que el proyecto sea viable a largo plazo, únicamente se considera una aportación

benéfica para el pago principal de la instalación, el cual es considerado bastante elevado teniendo en cuenta que la comunidad apenas sobrepasa un ingreso diario por individuo de $1. A partir de ese momento, la suscripción mensual se recomienda sea abonada por los consumidores ya que esto supondrá una mayor valoración de lo que representa este gran avance y como puede suponer la puerta de entrada al mundo moderno.

5. CONCLUSIONES

Aunque la tasa de acceso ha mejorado, los proyectos hasta la fecha se han centrado en su mayoría en las situaciones más sencillas de solventar. Por ejemplo, enormes proyectos hidráulicos han sido apoyados tanto por los gobiernos nacionales como por la financiación de organismos internacionales. Sin embargo, se ha dejado al margen a un enorme número de núcleos de población menores que, por norma general, se encuentran aislados. Estas comunidades tardarán décadas en tener acceso a la electricidad si su única esperanza es la extensión de la red eléctrica nacional. Sin embargo, existen metodologías que pueden adelantar la llegada de la conexión eléctrica mucho antes. El pilar en el que se debe sustentar todo proyecto es la financiación de este, ya que estas pequeñas comunidades apenas tienen formas de financiarse o de exponer sus necesidades particulares a la sociedad occidental. Partiendo de que los habitantes de estos pequeños asentamientos viven muy por debajo del umbral de la extrema pobreza es necesario un sistema de micro pagos que haga posible la viabilidad de cualquier proyecto.

Cualquier comunidad que planee embarcarse en este tipo de micro red debe reconocer el valor del proyecto y, para ello, se recomienda una suscripción mensual que sirva tanto para pagar la deuda como para valorar los beneficios del sistema instalado y como este cambia su modo de vida. La figura de un filántropo es poco recomendable, por tanto, salvo para el pago previo a la instalación del sistema.

La idea central del proyecto es desarrollar una red eléctrica donde no existía. El aspecto modular de la planta permite extenderla significativamente sin tener que volver a hacer un enorme desembolso que este tipo de comunidad no podría sufragar. Por tanto, no es una solución temporal sino a largo plazo. Además, esta planta podría ser conectada al sistema eléctrico nacional una vez que la red eléctrica alcance este tipo de asentamientos. De esta forma, el inicio del desarrollo de zonas totalmente aisladas estaría asegurado.

6. REFERENCIAS

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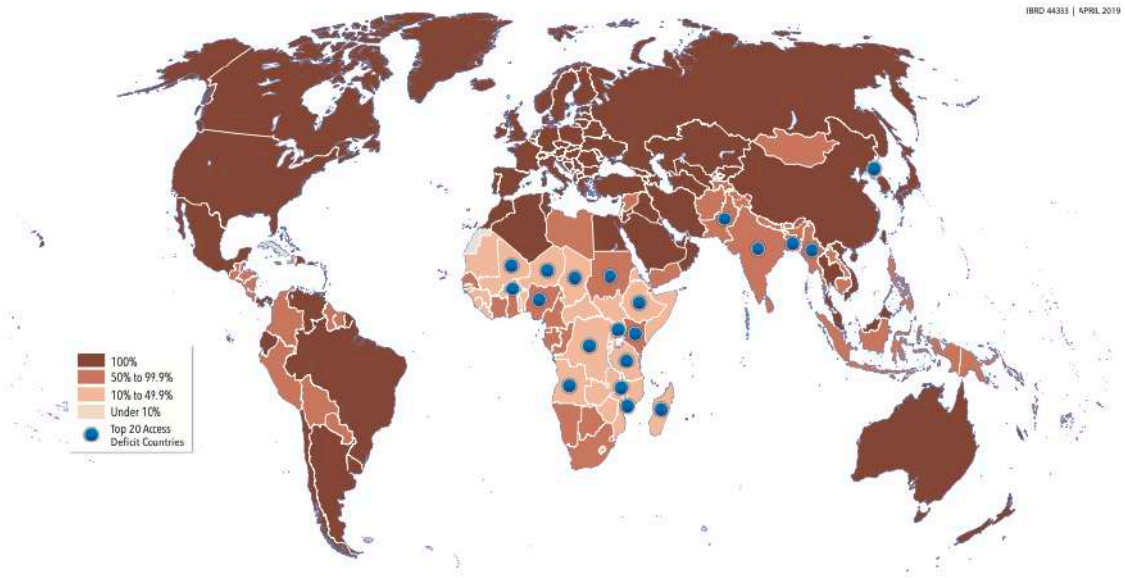
EXECUTIVE SUMMARY OF THE PROJECT

1. INTRODUCTION

Electricity is the mechanism that makes possible to enter the modern world and it is taken for granted at any point in a developed country. The access to electricity is one of the simplest and clearest indicators of development. Although the global rate of electrification has been increasing until 2018 when 89 % of the world population had access to a reliable source of electricity, there are still around 840 million people lacking access [1]. The majority of them are located in Africa and Asia and some cases that must be pointed out are the Democratic Republic of Congo, Nigeria and Pakistan with more than 50 million unserved people each. The last decade meant a great advance. The share of global population with access to electricity rose from 83 % in 2010 to 89 % in 2017, that in real numbers means around 920 million people got access. Particularly, the electrification path started to accelerate in 2015 and in only two years, more people gained access than during the previous lustrum.

Multiple international organizations such as the International Energy Agency, United Nations or the World Bank are currently working together with the same objective as goal: universal access by 2030. The annual rate to achieve it must be at least 0.86 % and although it is an excellent purpose, even during the years when the progress was the fastest (2015-2017), the annual increase was 0.8 %. To sum up, another point to consider is that the progress is not uniform and there are some countries that are improving faster than others. This is why two different categories have emerged. On the one hand, countries where the path is very high: fast-electrifying countries. They are located mainly in Asia. On the other hand, countries where little improvement was achieved during the last decade. This is the case in many countries in Africa and, particularly, in sub-Saharan Africa. This area is the main concern in this project.

The reasons why the improvement in Africa is so slow are many if compared to different regions in Asia are very diverse. The main cause of this situation is the particular instability in the majority of sub-Saharan countries whose origin could be the European colonialism in the 19th and 20th centuries. The lack of national infrastructures and an industry completely focused on a huge primary sector to export minerals, fabrics or other materials to Europe, absolutely distorted the production system of every country in the region and the development of the country itself.



Access to electricity per countries in 2017 [12]

Another concern in the region is the usual practice of briberies, corruption or the remaining monopolies in the continent. Through public polls, Transparency International remarks on the perception of corruption of politics and public servants by worldwide citizens [2]. The most affected continent is Africa and the numbers are alarming. In many African countries, the laws regarding corruption are quite lenient, so those involved are not very scared of them. To benefit at the expense of the poor is a common denominator in many underdeveloped countries. Corruption and nepotism are too usual among their leaders from the government to the military, including also business. However, African citizens are increasingly aware of corruption and many sectors are asking for more severe laws [3]. To sum up, political roadblocks and legal regulations have greatly hindered investments that could have been carried out by the private sector, but it is something that is progressively changing.

Other great problem that the African continent faces is violence: terrorism and the recurrent civil wars among the different ethnic groups. Both of them mean the devastation of weak economies, roads and railroads are destroyed, the recruitment of the youth for the raise of guerrillas and, definitely, investors completely avoid looking for investment opportunities in the affected areas.

2. ACCESS IN RURAL AFRICA

The increase in rural areas was greater than in urban ones between 2015 and 2017, but there is still an enormous gap. In fact, the rural deficit means 87 % of the total lack of access to electricity. This situation paints a bleak picture of the situation. Trying to achieve universal access by 2030 seems to be unrealistic since the places where the situation has to improve the most are those where it is very difficult to reach.

Another great problem to solve is clean cooking. The rate of population without access to clean fuels to cook has never stopped increasing since the population growth is outpacing the increase in access. Around 2.90 billion people were estimated to cook using polluting fuels in 2017. This is another sustainable development goal and it is quite associated with electricity, so any particular advance in the rate of access to electricity would mean an improvement in this issue as well. Not clean cooking practices are those which utilize polluting fuels such as wood, charcoal or kerosene. On the other hand, natural gas, liquified petroleum gas, biogas or electricity are considered clean cooking. Around 2.90 billion people were estimated to live using non-clean cooking fuels in 2017 [1]. According to the University of Oxford, the usage of solid fuels for cooking is responsible for multiple kinds of pulmonary diseases such as lung cancer or pneumonia. In 2010, the percentage of the population using this sort of fuel to cook was around 80 % in Africa [4]. Electricity would mean an enormous advance in clean cooking and less diseases. This is one of the main goals that a reliable electric system brings and it could also allow the possibility to purify water too as well as its extraction from wells in places where its extraction was not feasible.

Another point to consider is the approach of the implemented solution. Many current projects are based on the existing national grid whereas others rely on the extension of that grid. Despite it is a great methodology to achieve total access in urban areas by means of high and medium-voltage interconnections among great towns, it leaves rural areas completely aside. Remote villages will not get access until the grid expands and reaches where they are, this issue could take decades. This point is discussed in Chapter 5, where there exists a comparison between the population density and the medium voltage grid which is estimated by the nighttime radiance captured by satellites and then a map is generated with Python.

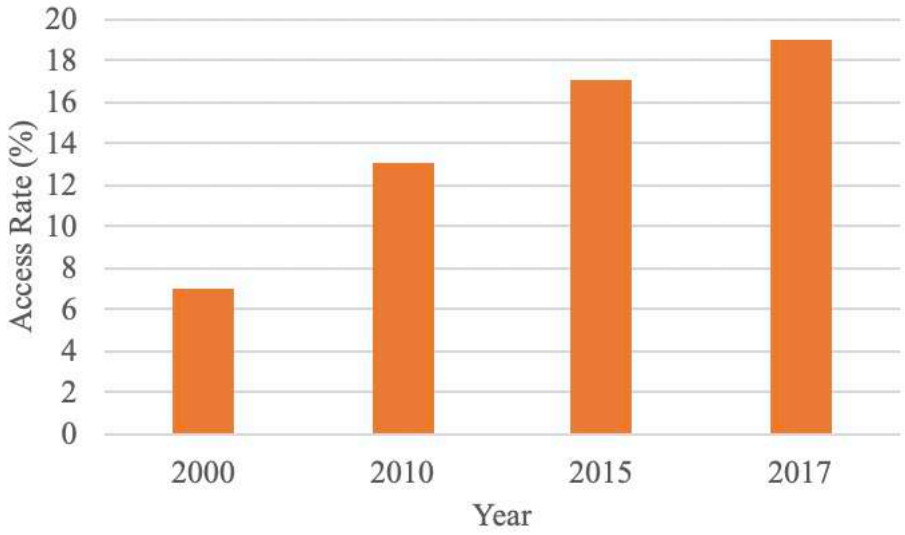
In the meanwhile, it is necessary to find a solution that makes possible to electrify these locations in a reliable manner. Another point to consider is how to finance this kind of project. The average income is quite lower in isolated locations than in urban areas. Particularly in sub-Saharan Africa, even the population in cities lives below the threshold of extreme poverty. Therefore, it is necessary to find an approach to find a way for these people to achieve an affordable system to provide enough energy to ease their lives and make possible to finance the cost of the installations and gain credibility in order to ask for loans or any other way to finance this kind of project.

Among the benefits that electricity brings there are some of them that are particularly urgent in the region. The healthcare situation in Sub-Saharan Africa is dramatic. By electrificating healthcare facilities, many more lives could be saved. In the same way, education would suffer a great improvement

3. THE PARTICULAR CASE OF THE DEMOCRATIC REPUBLIC OF CONGO

The second part of this project focuses on one of the most underdeveloped countries in the world despite of being considered the richest in natural resources: The Democratic Republic of the Congo. Ethnic conflicts in the country are a constant since the first data were collected. The unequal development was significant before the 19th century. Once Belgium colonized the country, it was totally devastated. The economy was exclusively focused on the extraction of rubber, minerals and coffee to be export to Europe. There was not an equal industrial development due to the enormous monopolies ruled by the Belgian authorities. Once the Colonialism era ended, many conflicts broke out and many civil wars ended up with thousands of innocent people killed. The eruption of violence during the last three decades between the different regions left aside the reforms the country needed. This way, it is possible to understand the low rate of access in the country and why it is so poor nowadays despite of its possibilities.

The situation in the Democratic Republic of the Congo is dramatic. The urban electricity access rate is around 49 % whereas in rural areas is null [5]. There are around 13 million households without access to electricity which means 84 % of the population [6]. They are spread in both urban and rural areas and this is why off-grid solutions are likely to become a great alternative.



Rate of access to electricity in *DRC* [8]

In urban areas only 9 % of the population has access to clean fuels to cook whereas in rural areas this percentage is less than 5 %.

To show a picture regarding the political and economical situation of the country, several institutions create rankings that are mentioned in this project. According to the Institute for Economics and Peace, the Democratic Republic of Congo is ranked the 155th out of the 163 involved countries in the Global State of Peace Index 2019 [7]. The World Bank ranks the Democratic Republic of Congo the 183rd out of 190 countries described in the Ease of Doing Business Ranking [8]. Finally, in the last version of the Index of Economic Freedom created by the Heritage Foundation, the Democratic Republic of Congo's position is 162nd out of 180 considered countries [9].

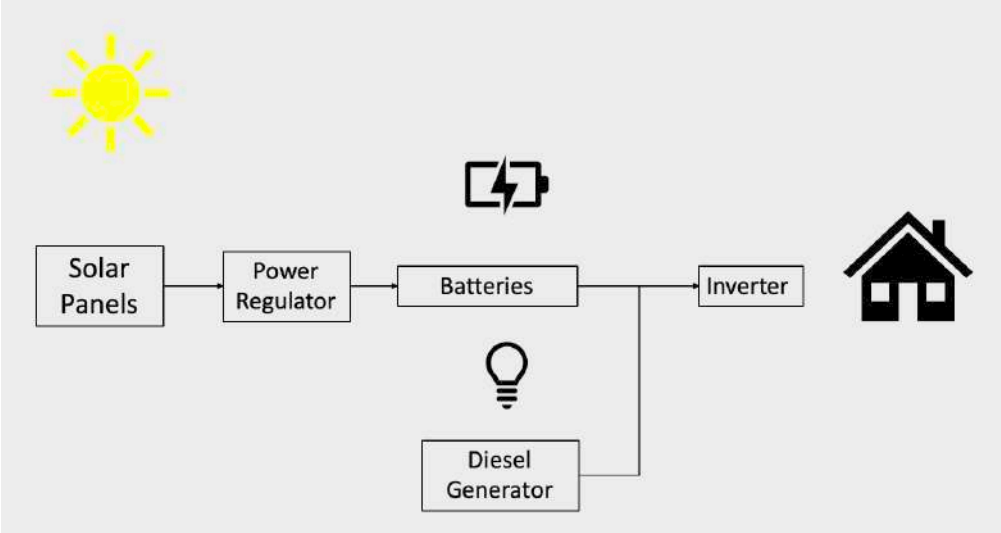
4. FRAMEWORK

In order to find a solution for isolated communities until the Government of the Democratic Republic of Congo manages to expand the national network, an appropriate option is to take advantage of the excellent existing irradiation in the region. To do this, an off-grid installation is proposed. The facility's independence feature requires the community to organize as a cooperative to divide the facility's fixed costs to make the

project viable. A loan will also be necessary and a micro payments system is suggested so the community can pay the debt off.

Another key feature of the facility is its modular aspect that allows to increase its capacity if the community increases its consumption. This would be achieved with an increase in the number of photovoltaic panels and also by taking advantage of the certain margin that the installation's gadgets were given. This makes possible that the community can increase its consumption considerably without the necessity to make a huge outlay to redesign the installation.

Finally, the system must have a connection to the grid so that once it reaches this population, it can be annexed to the national grid. In this way, the photovoltaic system will become a new actor in the national electrical system.



Simplified scheme of the general installation

To pay the debt off, a payment system known as "Pay-as-you-go" is proposed, through which there is a principal amount prior to the installation of the plant and, subsequently, a series of micro payments adapted to the community's possibilities. A fact that is given great importance in this project is the figure of the philanthropist. For the project to be viable in the long term, it is only considered a charitable contribution for the initial

payment of the installation, which is considered quite high considering that the community barely earns a daily income per individual of $1. From that moment, the monthly subscription is recommended to be paid by consumers since this will mean a greater appreciation of what this great advance represents and how it may represent the gateway to the modern world.

5. CONCLUSIONS

Although the access rate has improved, the existing projects have focused mostly on the easiest situations to solve. For example, huge hydraulic projects have been supported both by national governments and by funding from international organizations. However, an enormous number of smaller towns that are isolated in general are set aside. It will take decades for these communities to access electricity if their only hope is the extension of the national electricity grid. However, there are methodologies that can anticipate the arrival of the electrical connection much earlier. The pillar on which any project must be sustained is its financing, since these small communities have little way to finance themselves or to expose their particular needs to develop countries' societies. Based on the fact that the inhabitants of these small settlements live well below the threshold of extreme poverty, a micro-payment system is necessary to make possible the viability of any project.

Any community that plans to run this type of micro grid must recognize the value of the project and, to achieve it, a monthly subscription is recommended that serves both to pay the debt and to value the benefits of the installation and how it changes their lives. The figure of a philanthropist is not recommended, therefore, except for the payment prior to the installation of the system.

The central idea of the project is to develop an electrical micro grid where it did not exist. The modular aspect of the plant allows it to be significantly extended without having to make a huge outlay again that this type of community could not afford. Therefore, it is not a temporary solution but a long-term one. Furthermore, this plant could be connected to the national electricity system once the national electricity grid reaches this type of

settlement. In this way, the start of the development of totally isolated areas would be assured.

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GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES (GITI)

TRABAJO FIN DE GRADO

TOWARD ACCESS TO ELECTRICITY IN AFRICAN RURAL AREAS

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Madrid

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ABSTRACT

Electricity is the mechanism that makes possible to enter the modern world and it is taken for granted at any point in a developed country. Although the global rate of electrification has been increasing until 2018 when 89 % of the world population had access to a reliable source of electricity, there are still around 840 million people lacking access. The majority of them are located in Africa and Asia and some cases that must be pointed out are the Democratic Republic of Congo, Nigeria and Pakistan with more than 50 million unserved people each. The last decade meant a great advance. The share of global population with access to electricity rose from 83 % in 2010 to 89 % in 2017, that in real numbers means around 920 million people got access. Particularly, the electrification path started to accelerate in 2015 and in only two years, more people gained access than during the previous lustrum.

Multiple international organizations such as the International Energy Agency, United Nations or the World Bank are currently working together with the same objective as goal: universal access by 2030. The annual rate to achieve it must be 0.86 % and although it is an excellent purpose, even during the years when the progress was the fastest (2015-2017), the annual increase was 0.8 %. To sum up, progress is not uniform and there are some countries that are improving faster than others. This is why two different categories have emerged. On the one hand, countries where the path is very high: fast-electrifying countries. They are located mainly in Asia. On the other hand, countries where little improvement was achieved during the last decade. This is the case in many countries in Africa and, particularly, in sub-Saharan Africa.

The reasons why the improvement in Africa is so slow are many. The main cause of this situation is the particular instability in the majority of sub-Saharan countries whose origin could be the colonialism in the 19th and 20th centuries. The lack of national infrastructures and industry completely focused on a huge primary sector to export minerals, fabrics or other materials to Europe, absolutely distorted the production system of every country in the region. Practices such as corruption, briberies and monopolies became quite popular and are still nowadays in many of these countries.

The increase in rural areas was greater than in urban ones between 2015 and 2017, but there is still an enormous gap. In fact, the rural deficit means 87 % of the total lack of access to

electricity. This situation paints a bleak picture of the situation. Trying to achieve universal access by 2030 seems to be unrealistic since the places where the situation has to improve the most are those where it is very difficult to reach. Another point to consider is the approach of the implemented solution. Many current projects are based on the existing national grid whereas others rely on the creation of a new grid. Despite it is a great methodology to achieve total access in urban areas by means of interconnections among great towns, it leaves rural areas completely aside. Remote villages will not get access until the grid expands and reaches where they are, this issue could take decades. In the meanwhile, it is necessary to find a solution that makes possible to electrify these locations in a reliable manner. Another point to consider is finance. The average income is quite lower in isolated locations and particularly in sub-Saharan Africa, even the population in cities lives below the threshold of extreme poverty. Therefore, it is necessary to find an approach to find a way for these people to achieve an affordable system to provide enough energy to ease their lives.

Another great problem to solve is clean cooking. The rate of population without access to clean fuels to cook has never stopped increasing since the population growth is outpacing the increase in access. Around 2.90 billion people were estimated to cook using polluting fuels in 2017. This is another sustainable development goal and it is quite associated with electricity, so any particular advance in the rate of access to electricity would mean an improvement in this issue as well.

Among the benefits that electricity could bring there are some that are quite urgent. The healthcare situation in sub-Saharan Africa is particularly dramatic. By the electrification of health facilities, many more lives could be saved. Education would get a great improvement by electrifying schools. It would be excellent for children as well as for teachers.

A significant section of the report is focused on one of the most underdeveloped countries in the world, despite being the richest in resources: The Democratic Republic of Congo. The ethnic conflicts in the country are a constant since there is data. The unequal development in the country was significant before the 19th century. Once the Belgian Colonialism began, the country was totally devastated. Its economy was focused only on the extraction of rubber and minerals to be exported to Europe. There was not an industry development because there were monopolies ruled by the Belgian authorities. Once the colonialism concluded, multiple conflicts

erupted and many civil wars killed thousands of innocent people. It is easy to understand the low rate of access to electricity and why this country is so poor nowadays.

To find a solution for those isolated people until the Congolese Government gets to expand the national grid, an adequate option is to take advantage of the excellent insolation the country has. To do it, an off-grid installation is suggested. The standalone feature of the installation requires that the involved community organizes as a cooperative to divide the fixed costs of the farm to make the project affordable. A loan is required so micropayments are recommended to pay off this debt Another important point is that the installation must be modular to allow the system to grow its capacity if the community increases its consumption. Finally, the system must ensure a way to connect it to the grid once it arrives. This way, the photovoltaic farm would become another actor in the national electric system.

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CHAPTER 1: PROBLEM NATURE

Countries where their political evolution has not been gradual suffer the lack of access to electricity the most. In Africa, many factors explain the current situation. Its low technical development because of climate issues and ethnic conflicts turned the continent into a perfect farm for European colonialism. Once the Industrial Revolution dramatically changed Europe, its factories needed more raw materials and labor than ever before. The simplest way to obtain them was invading countries which became colonies. These territories ruled by foreign governors and totally orientated to harvest a certain fabric or mine certain rock developed an economy where the primary sector was predominant and exclusively focused on a specific product. The secondary sector barely existed because all the materials were exported as soon as possible to Europe, so African plants did not manufacture any product. The third sector was only focused on the colonists' welfare. As a consequence, the middle-class possibilities to grow blew up and these in-need countries did not stabilize. As a general rule, once colonialism ended by different reasons, to become a modern democracy was a rare result and the erupt of conflicts and, even wars, was the general rule. This way, the current situation of the African continent is logical according to the previous multidisplicinary precedents. Some extra particularities in this continent need to be considered in this terrific issue and are detailed below.

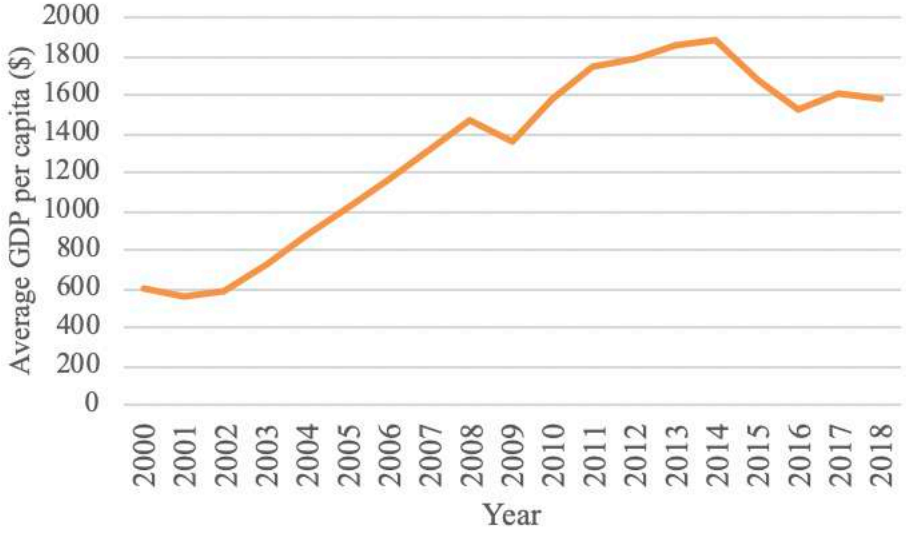

Figure 1: Average *GDP* per capita in sub-Saharan Africa [1]

The increasing average *GDP* per capita cannot lead to a thought that the situation is getting better in the area, but a question wondering how to get better the path of the improvement. To get the whole picture and how dramatic the situation is, some data may be useful: *GDP* per capita in the *US* was around $54,541.70 and in Spain $33,146.40 [2]. Growth in 2020 is projected to be 3.6 %, although the circumstances related to the outbreak of *COVID-19* have completely distorted this projection [3].

Over the past 30 years, the intensity as well as the frequency of natural disasters have increased. The spreading of the Ebola outbreak in 2016 in some countries in this area, particularly in the Democratic Republic of Congo, is one of many uncontrollable factors that have undermined the confidence in these economies due to the decrease of investments and trades. Markets in developing countries are usually characterized by anticompetitive practices such as oligopolies or, even, monopolies. Most of them are state-owned and they operate in key sectors for the economy. This lack of competitiveness affects the poor the most because the inefficiencies it brings mean an increase in costs and make economic growth totally impossible.

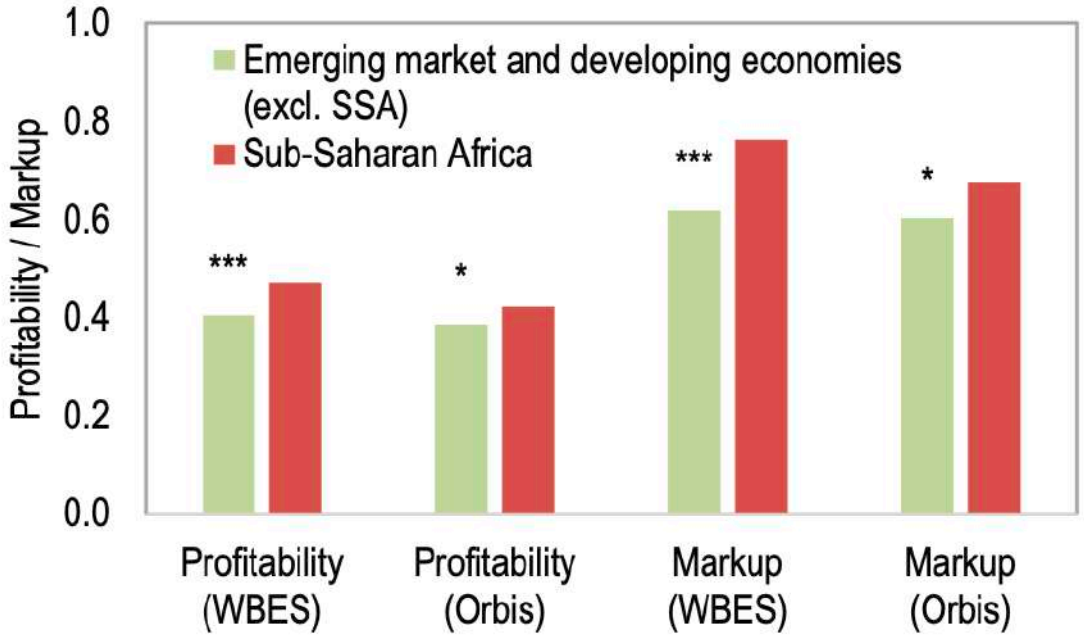

Figure 2: Firm-level competition indicators [3]

To understand this figure, to explain how profitability and markup are calculated is necessary. Profitability is obtained as the difference between revenue and the costs of inputs relative to revenue. Markup is defined as the log ratio of sales to the costs of inputs or as the log ratio of revenue turnover to costs depending on the source.

Firm-Level Competition is slightly higher in sub-Saharan Africa than in other emerging markets and developing economies. However, both markups and profitability vary strongly across countries in the region and markups are usually the highest in the services sector. These studies show a strong relationship between the number of competitors that a firm faces and its profitability and markup and explain that a reduction of the barriers to entry a business could improve market dynamics and boost competition [3].

Terrorism and civil wars are synonyms of poverty. Both of them stop the economy as well as businesses have to close, roads and railroads are destroyed, people lose their way of earning a living and, of course, investors completely avoid looking for investment opportunities in the affected areas. So, the economy is completely devastated. Innocent civilians have been the target of rebel groups and governments alike showing the vulnerability the continent has to international terrorist networks such as Al-Qaida. The lack of infrastructure eases this kind of organization to move across poorly guarded borders as well as recruiting among the youth to create the future generation of terrorists. In this context, a terrorist group belonging to the Islamic State in western Africa, Boko Haram has deteriorated the situation in the region very much. Ongoing conflicts have increased in sub-Saharan Africa since the last records according to the Institute for Economics and Peace. To sum up, loss of property, deaths and wounded people leave a bleak picture in which migration is sometimes a must and completely ruins any attempt to give rise to a stable and prosperous society.

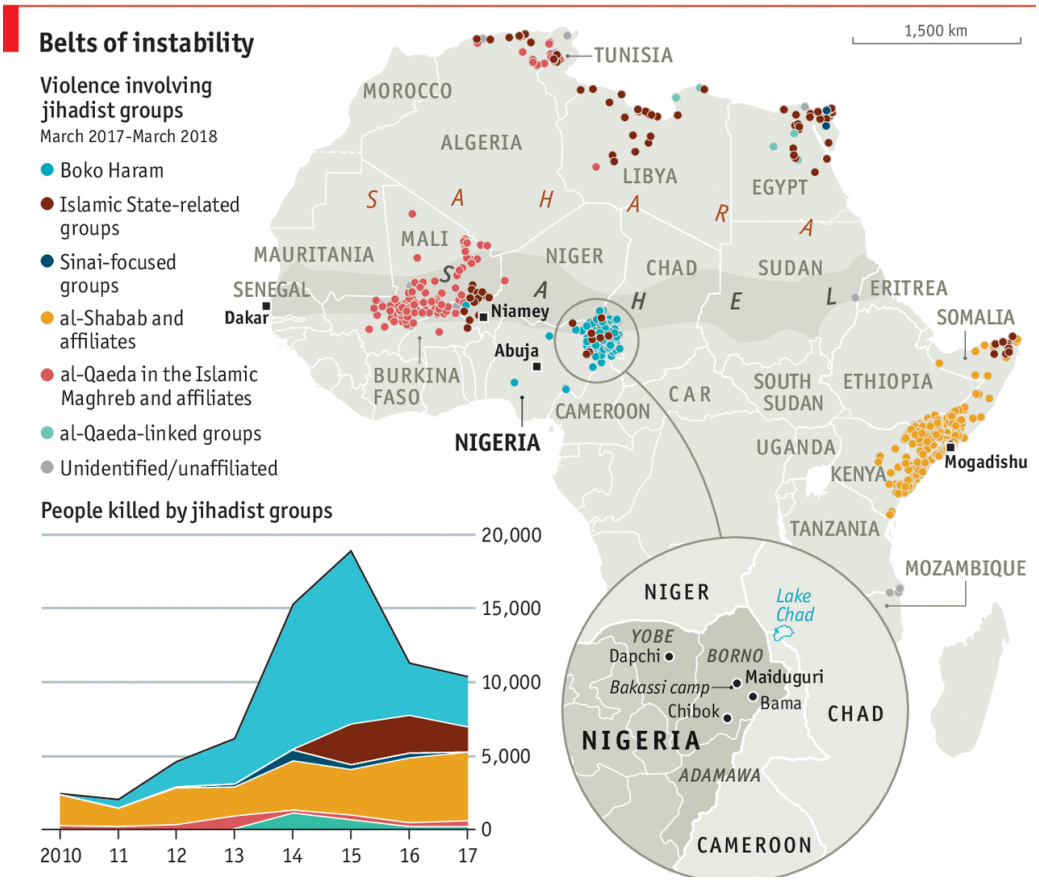

Figure 3: Violence involving jihadist groups (March '17 - March '18) [4]

Another point to consider is corruption. Taking bribes is a very common practice across political and private leaders. Through public polls, Transparency International remarks on the perception of corruption of politics and public servants by worldwide citizens [2]. The most affected continent is Africa and the numbers are alarming. In many African countries, the laws regarding corruption are quite lenient, so those involved are not very scared of them. To benefit at the expense of the poor is a common denominator in many underdeveloped countries. Corruption and nepotism are too usual among their leaders from the government to the military, including also business. However, Africa is increasingly aware of corruption and many sectors are asking for more severe laws [5]. Going through the last Corruption Index published by Transparency International in 2018 which gives a ratio from 0 to 100 (being 100 an ideal clean country), it is shocking to see the results of sub-Saharan Africa.

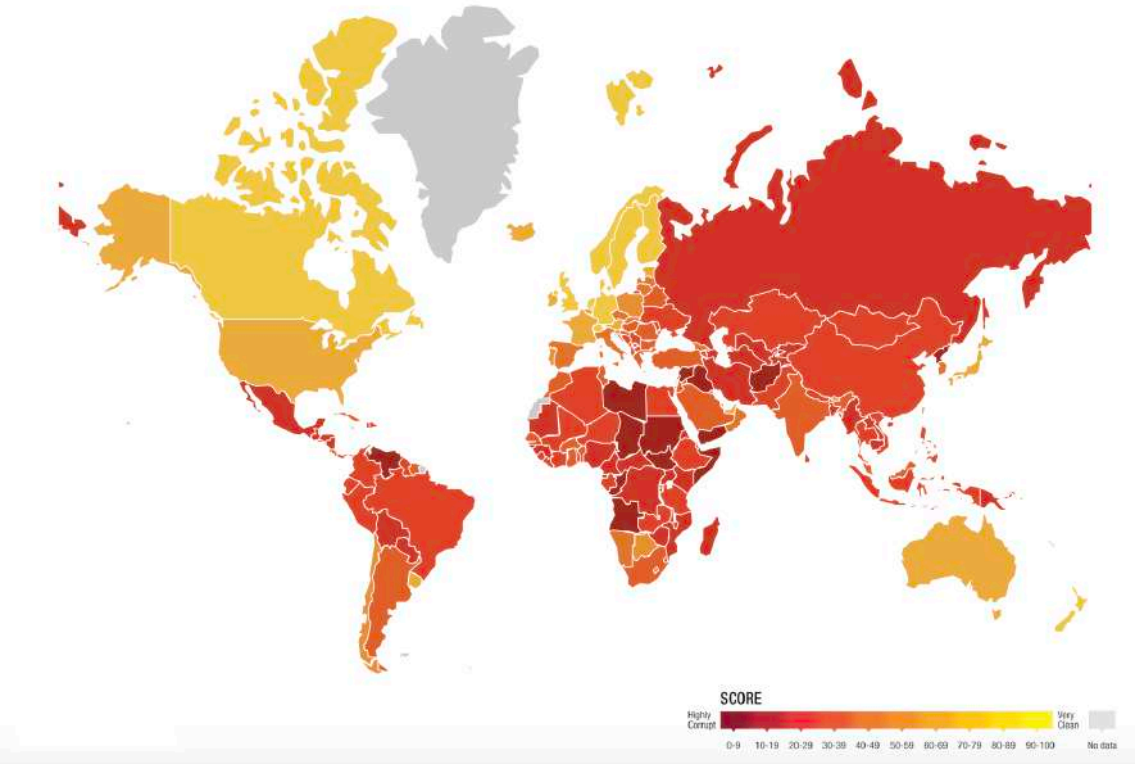

Figure 4: Corruption perception index 2018 [5]

Sub-Saharan Africa is the lowest scoring region in the world with an average perception of 32/100 and has not improved since the previous index was published. In fact, according to this organization, the undemocratic regimes ruling these countries undermine anti-corruption efforts despite of 2018 was supposed to be the African year anti-corruption. The lowest scores are Somalia (10) and South Sudan (13), countries that can only be compared to others such as Syria (13), Yemen (14) or Venezuela (19). The average score cannot hide that there are some countries such as Seychelles (66), Botswana (61) and Cabo Verde (57) that may be considered outliers and completely move up this indicator.

Some countries are still ruled by authoritarian regimes where all efforts to combat corruption are undermined by weak institutions, civil strife and unresponsive political systems. Citizens are not allowed to associate or speak out in some of these countries as well as media is completely dependent on the government and, therefore, free media is pursued [5].

Education is vital in every society. To teach the necessary skills to drive labor in a country and instills in children the necessity of democratic values to progress as a society are some tasks to impulse. Africa requires an education focused on skills and technology that leads to worldwide competition and, thus, to become a strong actor in world trade. To improve it, electricity is fundamental and basic for both students and teachers.

Poverty is a cause of health problems but also a consequence. Indoor air pollution, poor nutrition and lack of health education and access to sanitation generate an enormous percentage of illnesses that could be either avoidable/preventable or appropriately treated with modern medicine and the variety of existing treatments. The current healthcare in sub-Saharan Africa is related to the level of income. Some of the difficulties that professionals have to deal with are related to the existing facilities in hospitals. For instance, some great deficiencies are a system to store vaccines with an adequate cooler or an ultrasound machine to follow the progress of women with children. To achieve it, this cooler or this ultrasound machine require electricity. Diseases like *AIDS* or the spread of malaria mean a devastating reduction in production. The poorer a region is, the easier it is for diseases to spread. Therefore, poverty and health in Africa are like the snake that bites its own tail and to get better, this issue requires from a great improvement to see some change.

The geographical location of the country is nothing where much can be done. The majority of countries are surrounded by other countries with the same needs as theirs or even more. This situation does not help too much to drive reforms that lead to an increase in national *GDP*. These kinds of countries may also be landlocked countries because they have not coastlines, but the general rule is that the surrounding ones are full of conflicts and are quite unstable. Resources are extremely wrong distributed and although many of these countries are rich in natural resources, their governments have not been able to redistribute wealth across their citizens since colonialism ended or to take advantage of the natural possibilities this region has. Another point to consider is the exploitation of resources such as oil or minerals by foreign companies that take all benefits overseas and barely pay taxes in the African country.

International aid must not be relied on infinitely, but its actual mission is to boost the economy to make the country sustainable as well as its institutions. It needs to be

considered as an extra help in this war against poverty. According to Health Poverty Action, Africa suffers net losses of capital because the amounts of foreign companies take away from the continent, mainly in profits, are bigger than money received as an aid or in the form of loans [6]. If corruption is taking into account, the real inflows Africa receives to get the situation better are even lower.

The markets in the region have suffered several changes during the last decades. It wasn't until the 1980's when the first policies liberating the trade were launched. During the 1990's, some policies made possible that the financial and the product market liberalization began. It resulted in a transfer from public to private ownership, the birth of independent regulatory bodies and the elimination of price controls. However, they have not completely disappeared. Two-thirds of these countries affirm the existence of this kind of controls in a survey carried out by the World Bank in 2016. Monopolies, most of them state-owned are too frequent and the lack of competition affects the user in the form of high costs. Trade policies are really tough for Africa. The *US* and the European Union are protecting key sectors where Africa could compete such as agriculture trying to defend their own national production and standards. If their trade agreements were not as strong and Africa could start competing, it would mean an increasing rate of development in African economies.

In short, this complex problem has a great contradiction: Africa is a wealthy continent, but its people are extremely poor. As a region, it is growing, but changes do not arrive in local communities and, even less in rural ones. Many factors slow down growth: selfish personal interest and so corruption, religious and ethnic differences and thirst of power. Africa has an enormous potential to improve and, to begin with, electricity is fundamental. Therefore, this first contact with the existing problems in the region leads to the next chapter in which by going deeper into the issue will make possible to find out how necessary electrification is in this region.

CHAPTER 2: EXTENT OF THE PROBLEM

The rate of electrification is one of the simplest indicators of development. United Nations Sustainable Development Goal 7 (*SDG7*) focuses on the assurance of access to affordable, reliable, sustainable and modern energy to all. The poorest countries are increasing their efforts to meet the targets by 2030. To meet these requirements, it is estimated that the region will have to spend around 15 % of *GDP* a year on this matter [7]. These accelerated changes promoted by their governments attracting private equity let look optimistically to the future where some indicators seem to be hopeful. Child mortality rates are declining as well as life-expectancy does not stop increasing and the middle-class is rising worldwide.

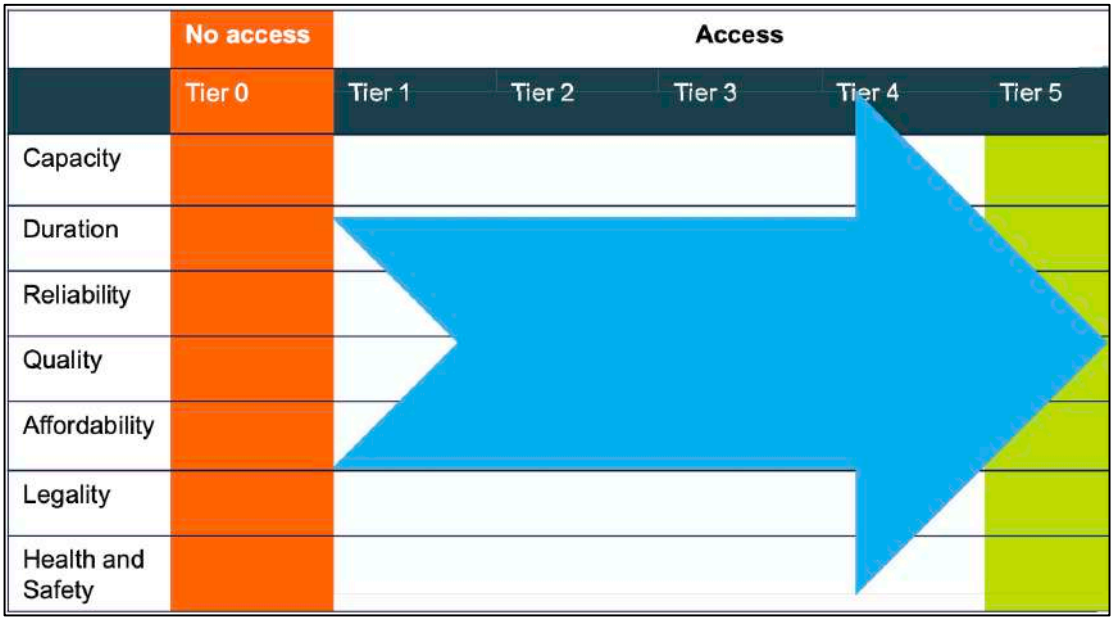

Figure 5: Multi-tier chart for access to household electricity supply [9]

To measure access and how the users receive energy services, United Nations created a framework called Multi-Tier Framework for Electricity Access to divide the different steps that a community needs to climb to reach the level of electrification modern societies have. This system not only considers if the facilities are ready or not, but also wonders about the quality of the service and its reliability. The financial aspect of this issue is as important as the technical one. This is why this framework also takes into account its affordability. The safeness of the system is another fundamental point and is

also evaluated. Obviously, the movement along the scale is due to an increase in the level of income the community achieves [8].

Tier 0 means no access and this is where many communities in sub-Saharan Africa are located. From here on, the energetic ladder starts. Capacity is not a qualitative difference. Households with different capacity are not differentiated here and they go from 3 *kW* to above 2 *kW*. Duration does not divide these five Tiers, but it splits into duration-day and duration-evening. Duration-day goes from at least 4 hours a day to 23 hours whereas duration-evening is at least one hour to 4 hours in the evening. Reliability does separate the first three tiers from Tier 4 and Tier 5 focusing on the number and duration of outages. Quality is a division between these two well differentiated groups of tiers. Tiers 4 and 5 include installations where desired appliances are not affected by voltage problems. Affordability is a key aspect as it was mentioned before and this is why Tiers 1 and 2 are separated from Tiers 3, 4 and 5. In the last three tiers, the basic service is considered to account for less than 3-5 % of the household income. Legality is not too important when a community starts wondering if it is possible to afford electricity, but once the system grows, it may be something to consider. This is why Tiers 4 and 5 include legal installations. Health and safety are only considered in Tiers 4 and 5.

Electricity powers prosperity. It is essential for modern life and without it, life opportunities are highly reduced. It is the unifying thread running through social, technological and economic evolution for every country. It allows entrepreneurs to rely on an effective system to operate their equipment. Instead of relying on expensive diesel generators, factories and offices prefer to electrify themselves. This way they can boost profit which means a chain reaction for underdeveloped countries that results in an increase in *GDP*. It eases education during dark hours of the day and drives students to effective learning environments. Health is radically improved making possible to store vaccines and medication as well as technical equipment. It means a revolution in agriculture with the birth of a strong and mechanized primary sector. Public safety is not compromised at night anymore. Modern healthcare is not limited. As an example, to realize the magnitude of this issue, a refrigerator in the *US* consumes six times the energy a Tanzanian citizen in a year. At the same time, an Ethiopian would spend a couple of years to consume the amount of energy an American does in only three days [10].

To analyze numbers, two main institutions are providing them: The World Bank and The International Energy Agency (*IEA*). Their databases have been constructed in a different way which results in a little disparity of results and then put together.
On the one hand, The World Bank estimation has been developed by standardized household surveys conducted in most countries every two to three years. This system analyzes the reality of communities including off-grid access or self-supply.
On the other hand, The *IEA* develops its own Energy Access Database which combines government-reported values for electrification based on utility connections.

The most recent data regarding access to electricity worldwide was gathered in 2017 by the Sustainable Energy for All (*SE4ALL)* Global Tracking Framework with the World Bank, the *IEA*, and the Energy Sector Management Assistance Program. Going through numbers and comparing 2010 data to 2017's, the evolution is evident. From an 83 % global electrification rate in 2010 to 89 % in 2018. This results in still 840 million people lacking access to electricity [11]. It means an increase of 0.8 % a year and the fortunate individuals account for 920 million. These improvements are mainly allocated in Asian countries with the largest population of affected people. As a result, 91 % of Central and Southern Asia population had access to electricity in 2017. Some particular cases have stood out like India, Bangladesh or Myanmar. Despite the advances, the share of people in Asia without access to electricity is smaller but considering the population of this continent, it is also an enormous quantity. The problem focuses on Sub-Saharan Africa and some countries in Asia. The lowest percentage of electrification is allocated in Africa with percentages that fall below 20 %. A clear example is Chad where 8.8 % of people had access.

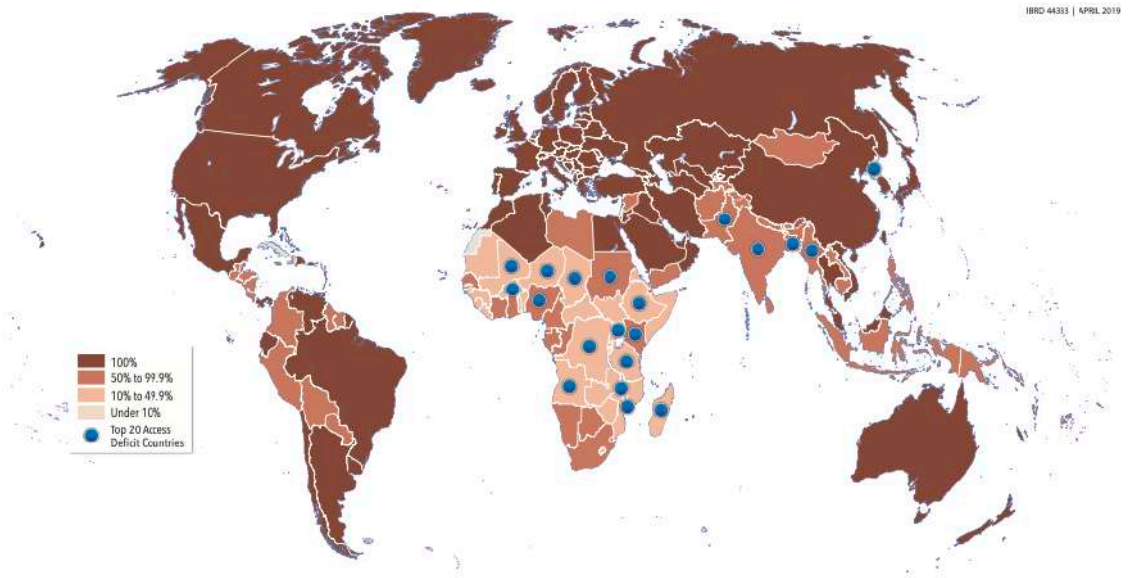

Figure 6: Access to electricity per countries in 2017 [12]

As can be seen in the upper figure, the most affected countries are in the sub-Saharan Africa. Fifteen out of the top twenty access deficit countries are in Africa and are the following:

Table 1: Countries in Africa with the lowest rate of access [8]

Country	Population (M)	Total Electricity Access Rate (%)			Urban Rate(%)	Rural Rate (%)
		2000	2010	2017	2017	2017
Angola	32	-	33	42	73	0
Benin	12	21	34	43	73	17
Chad	16	3	6	11	39	2
DR Congo	90	7	13	19	49	0
Ethiopia	115	13	33	44	97	31
Kenya	54	15	19	64	81	58
Madagascar	28	14	17	24	69	0
Malawi	19	5	9	13	58	4
Mali	20	10	25	43	87	12
Mozambique	31	7	18	27	73	2
Niger	24	6	13	20	67	11
Nigeria	206	43	48	54	87	23
Sudan	44	-	2	25	42	21
Tanzania	60	10	15	33	65	17
Uganda	46	8	12	22	57	11

The rural progression in electrification was faster from 2015 to 2017, however, the rural access rate of 79 % was still far away from the urban access rate of 97 % in 2017. There are 732 million rural people affected which represents 87 % of the total affected population [8]. Most people lacking electricity in rural settings live in the less accessible parts and represent the greatest challenge in this issue, requiring specific solutions. While

the biggest annual increment in Asia focused on rural areas, 48 million, in Africa took place in urban settings, 22 million. The incremental rural electrification in sub-Saharan Africa was 16 million people a year.

Political roadblocks and legal regulations have greatly hindered investments that could have been carried out by the private sector, but it is something that is progressively changing. As well as in Europe or North America, implementing public sector reforms and new regulations is a long way towards the establishment of a market economy in these Asian and African countries. Several examples prove this statement. Nigeria developed a historic transfer of ownership of power sector to private companies, Ethiopia was engaged in negotiations to set the bases of its first private power producer and opening the market to new investors, the Government of Ghana started attracting some power sector investors [10]. As a result, the beneficiary of this change of tendency in underdeveloped countries is not just its population, but the whole world because a new actor with an enormous population and potential joins the global market.

This issue required an immense amount of credit flowing through every affected country. Billions of dollars are required to achieve the Sustainable Development Goal 7. According to one of United Nations last publication (Energizing Finance: Understanding the Landscape 2019*)*, there was an increase in finance funding [13]. However, it shows that these transactions were not towards the people most in need. This report affirms that some other financing methods such as pay-per-service models, crowdfunding or results-based financing are going to get popularity during the next years, unlocking the required capital to reach the most in-need ones. The financial aspect of the issue is quite important because no project can be carried out without enough funds. The system will require an initial investment from the government, organizations or philanthropists and some periodic payments according to usage to avoid a waste of energy and resources. The large upfront costs mean a barrier for potential customers without disposable cash. Pay-as-you-go systems are becoming more and more common in this kind of project. Through these payments, the customer pays a monthly bill that in a medium-term will cover the costs of the plant and the customer will become the owner. The lack of skills in local communities is another barrier to the development of sustainable mini-grid systems.

As can be seen in the below figure, Figure 7, the region is not the one that makes things the easiest for investors and entrepreneurs. The World Bank elaborates this ranking to show the ease of doing business across the world as an indicator for companies to know by taking a quick look whether the next country to expand into is a profitable option. To create it, they give each economy a score following two main steps. First, the 41 individual component indicators are normalized to a common unit using a linear transformation that compares the best and the worst indicators. Second, the scores are aggregated and averaged into one score. The score can vary from 0 to 100, where 0 represents the worst economy to do business and 100 the ideal one with low barriers for companies. The relation between Figure 6 and Figure 7 is quite meaningful and, particularly, the almost exact relation between them, overall in Africa. This is why many international institutions are advising a great change in legislation.

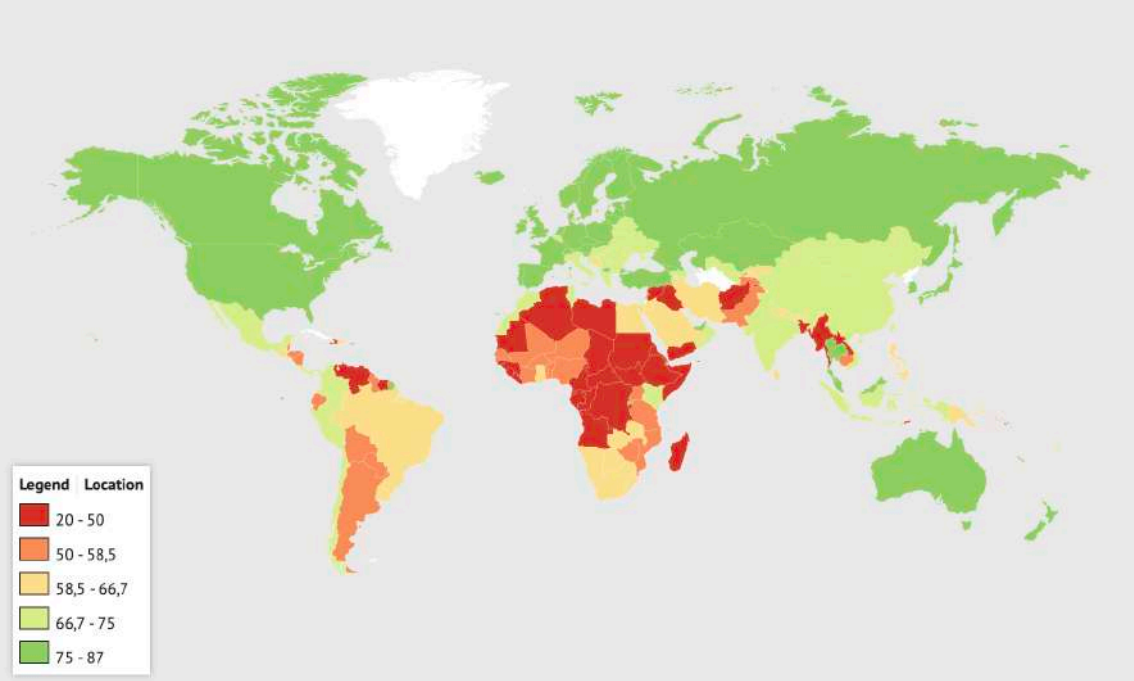

Figure 7: Ease of doing business economies [14]

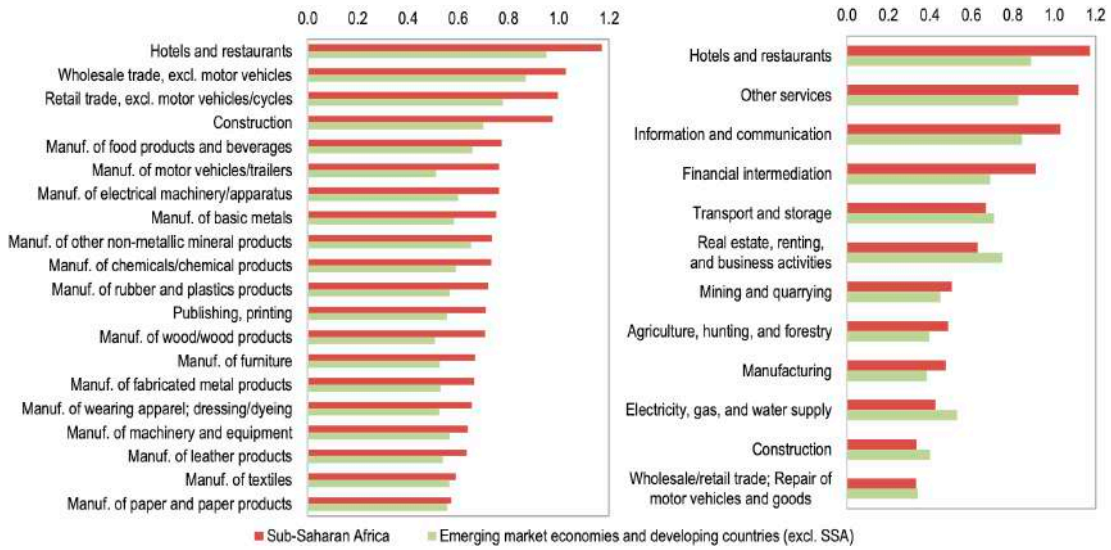

Figure 8: Firm markups by sector in sub-Saharan Africa [15]

For instance, the International Monetary Fund recommends the region to liberalize product markets, that is significantly low according to the World Economic Forum´s, by transferring a part of the production from state-owned companies to private ones, to get rid of price control as well as to facilitate the activities of the private sector. The main idea is to boost competition in domestic markets. In fact, according to their data sources, more than 70 % of the countries in the region are located at the bottom of the rankings of domestic and foreign competition indicators. It is due to the reduced number of companies competing which usually results in oligopolies and their consequent pricing power and great barriers to entry the business. An international comparison between price levels shows that price levels in sub-Saharan Africa are about 20 % higher in the region than in other emerging economies. Their recommendations are clear: To create an effective competition policy framework and an adequate competition law; to reduce barriers to international trade and foreign investment; to reduce product market barriers.

Addressing access to energy also covers another vast problem: clean cooking. This is the second key area in energy access. Not clean cooking practices are those which utilize polluting fuels such as wood, charcoal or kerosene. On the other hand, natural gas, liquified petroleum gas and biogas are considered clean cooking. In sub-Saharan Africa, the use of wood is decreasing; however, it is being substituted by charcoal. The usage of kerosene is also declining worldwide. Clean cooking fuels are becoming mainstream both in Asia and Africa, but this change is much more pronounced in urban settings. The rate

of improvement in this issue has not been as fast as electrification. In 2010, there were 2.96 billion people without access to clean cooking whereas in 2017, 2.90 billion [11]. This reduction is considerable because there is a circumstance that blows up this statistic: The world population during these years has increased by more than 800 million [16] and these affected countries are the ones with the greatest increments, while Occidental population is decreasing. Therefore, despite the little change in real terms, the improvement in percentage terms is quite representative. According to the University of Oxford's "Our world in data" programme, the usage of solid fuels for cooking is responsible for multiple kinds of pulmonary diseases such as lung cancer or pneumonia. In 2010, the percentage of the population using this sort of fuel to cook was around 80 % in Africa and 60 % in Southern Asia [17]. Clean cooking is one of the main goals of achieving a reliable electric system which allows the possibility to purify water too as well as its extraction from wells.

Tiers are also considered when measuring the quality of each way of cooking. Tier 0 considers no information regarding the affected community. The rest of Tiers include households whose concentration of *PM2.5* and *CO* aligned with the recommendations of the World Health Organization (*WHO*). Tiers have not found a way to measure effectiveness yet and it is under development. From Tiers 2 to 5 there is a prerequisite that considers the existence of stove preparation time and fuel collection and preparation. These Tiers also include households in which there exists an absence of accidents and alignment with the *ISO* process. Affordability is fundamental when talking about cooking. Tiers 4 and 5 include those whose levelized cost of the cooking solution is lower than 5 % of household income. The quality and availability of the fuel that makes possible cooking is considered in Tiers 4 and 5 and they focus on those households in which cooking is not affected by seasonal variations in fuel quality and amount [9].

Definitively, electrification is the best way to solve this horrific issue. Moreover, it will bring an almost totally clean fuel. The rate of improvement will depend on the strength of partnerships between African governments, the private sector, institutions and donors. These governments are required to achieve multilateral reforms to attract investment. They have already transitioned from a completely publicly-owned power sector to invite private capital to participate and even to privatize a part of generation, transmission and distribution facilities. To sum up, investors are also making possible the innovation and

achievement of off-grid solutions to maximize the range of electrification and helping those in rural areas.

The lack of access to electricity is not only an energetic problem but a barrier to development. In multiple countries, governments, organizations and *NGOs* are worried about extending the grid. It is a long-term solution and, obviously, the best one if every village were reached. However, extending the grid may lead to a functional problem. There are some countries in sub-Saharan Africa where the length of the existing grid is tiny. Thus, enlarging it even in a western country would take several years. These projects are carried out in Africa and sub-Saharan countries are ranked among the most difficult economies to do business as it was explained in Figure 7, so this point is critical to prepare a framework to accomplish the mentioned objectives. This solution is a real necessity of every country because not only it means to distribute energy and control the system instantaneously, but a way to interconnect countries and develop a reliable multi-grid system.

This is the point where this project starts. Most of the people without access to electricity do not live in urban areas because big cities are electrified enough worldwide. The core of the problem is located in rural areas where the grid is not expected to arrive or it will take decades. Sub-Saharan governments along with international institutions and, ultimately, private firms are already involved in several plants such as hydro, solar or biomass which are located next to urban areas and whose production will flow through the existing or future grid. On the other hand, there are other plans to expand the grid using aid funds. Some of these big projects are the 2,070 *MW* Lauca Hydropower Project in Angola, the Great Ethiopian Renaissance Dam (*GERD*) expected to reach 6,350 *MW* of installed capacity in Ethiopia or the Isimba Hydroelectric Dam and the Karuma projects that will double Uganda's installed capacity [18]. But many forget about rural ones because maybe private equity is not interested in plans which returns are not clear or are not high, or governments do not care about a certain ethnic population that lives far away from the grid. These people require electricity as much as others and this project provides a way for them to achieve this goal meanwhile the grid keeps its expansion. This framework is a way for them to achieve access to electricity on their own and once the grid arrived where they live, they could connect their microgrid to the entire grid. With this system they will reach United Nations *SE4ALL* tiers and depending on the depth of

each project it would be from Tier 1 to 3. The following chapter will show which improvements could be achieved in multiple aspects.

CHAPTER 3: BENEFITS

Reliable access to electricity supports all kinds of improvements in multilateral aspects of society and without it, they are impossible to reach. The rate of improvement in the different points depends on the capacity of the installation and the scale of the system. Access to electricity is one of the key factors that the sub-Saharan population needs for the middle class to raise. The reduction of poverty will mean an increase in the power the society has and it is completely necessary to stabilize these conflictive territories.

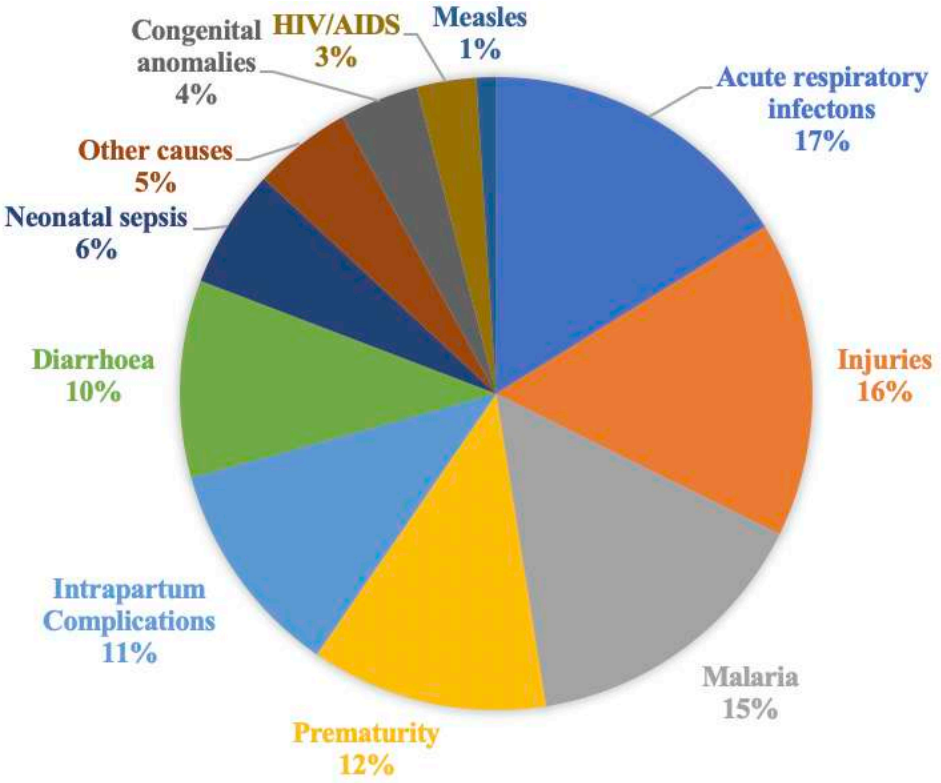

Figure 9: Causes of death among children <5 years in sub-Saharan Africa [19]

The nexus between healthcare and energy is evident and both are things Africa lacks. Addressing access to electricity is key to healthcare delivery and the overreaching goal of universal health coverage. To prevent as well as to treat infection in healthcare facilities and to achieve Sustainable Development Goal (*SDG*) targets for health and water, hygiene and sanitation. Electricity is necessary for the operation of basic facilities like lighting, information and communications technology *(ICT*), ventilation, temperature

control, water, etcetera. Also, it makes possible to offer ill people night-time service and diagnosis. Cooling is completely key to ensure the cold chain to store and preserve vaccines, blood and other medicines. During childbirth, lighting and medical equipment such as ultrasound and heart rate monitors can be life-saving both for women and children.

Communication is completely key, particularly in Africa, in access to critical information like disease transmission or extreme weather. Data administration is another point to consider because it makes possible to manage patient records, health statistics of the population with computer-based systems. To maintain qualified professionals, electrified facilities are a point for them to decide as well as to reduce absenteeism. Another fundamental point to take into account is reliability in order to reduce outages and to have a regular power source that does not oscillate throughout the day. Data regarding electricity access in health facilities is rarely collected, only particular surveys in specific locations. Data from 78 low-and-middle-income countries (*LMICs*) representing 129,557 healthcare facilities were compiled in 2017 to obtain information on conditions, service levels and inequalities. The results were: 50 % of facilities lacked piped water; 33 % lacked improved sanitation, 39 % lacked adequate infectious waste disposal, 39 % lacked handwashing soap, 73 % lacked sterilization equipment and 59 % lacked reliable energy services. The differences were greater between urban or rural healthcare facilities, depending on managing authority, facility type or subnational region [20].

There is a great relationship between energy and education as well as between education and development of course. The most recent data regarding this issue reflects how dramatic the situation is. Estimates gathered by *UNESCO* in 2017 suggest that only 35.1 % of sub-Saharan primary schools have access to electricity and there is no data about lower and upper secondary education [20]. The benefits in the education sector are multiple. For students, it enables them to prolong the studying hours as well as illuminating school facilities to improve the quality of classes. Also, it allows teachers to prepare their classes and research during the evenings. *ICT* development is key in education too. It may help professors because they can use audiovisual material such as computers or printers and, obviously, get access to the internet. Basic facilities in schools are also improved: clean water, cooling, lighting and sanitation. Like related to health, energy access may enable the retention of teachers in rural areas or urban teachers are

willing to move into the rural world. As a result, education may result in a reduction of migration and strengthen resilience.

Clean cooking is another objective of the United Nations *SEE4ALL* Programme. Although the use of wood is decreasing, it is being substituted by charcoal in sub-Saharan Africa. The use of kerosene, which is inefficient and also dangerous, is decreasing too and cleaner cooking fuels such as natural gas and biogas are becoming more and more popular in sub-Saharan Africa [13]. Modern cookstoves reduce the amount of fuel needed, reducing the expense on it as well as reducing the smoke emissions. It enables to enhance inclusive economic growth and productivity. Around 25 % of black carbon emissions are produced in households, so clean cooking objective also delivers climate benefits. Forest degradation is impulse by wood fuel harvesting as it is up to 34 % unsustainable [21].

The primary sector is also affected. In these rural areas, the primary sector is mainly the only way of making a living. It is manual-based and although a great change cannot be achieved with mini-grids, a little improvement in production may mean the survivance of a village or the non-necessity to emigrate. Some light bulbs in farms may lead to an ease of typical jobs or little-power equipment may start operating thanks to mini-grids.

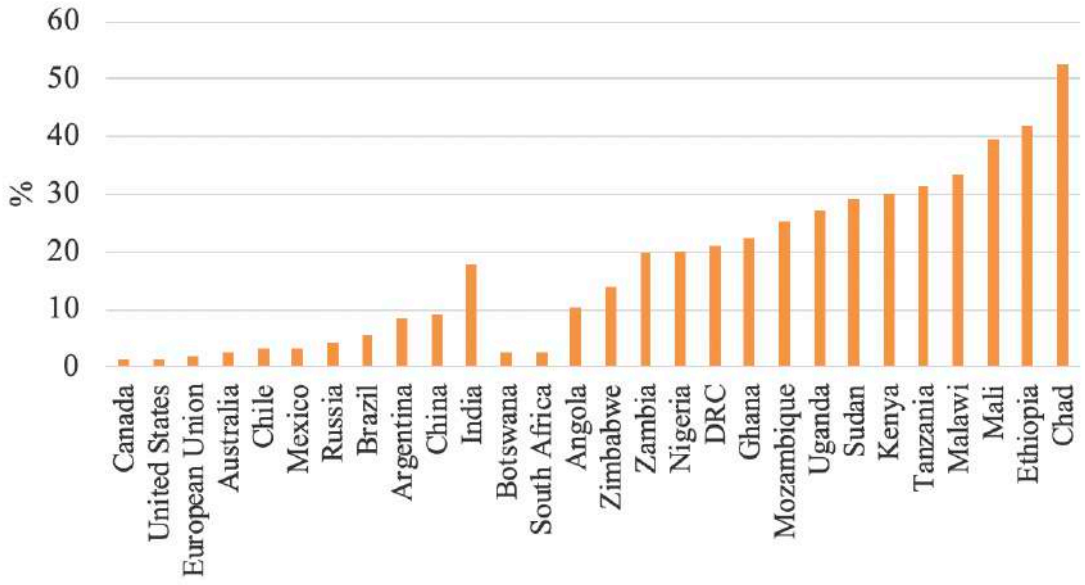

Figure 10: Agriculture as a share of total *GDP* in 2014 [22]

As an emerging actor in the international economy, these countries need to adapt their energetic resources to the sustainable global trend. As rural areas do not usually have access to electricity nowadays, the first time they can afford it, it will be renewable power. Relying on a renewable resource as solar power will maintain rural areas inside the required standards of sustainability. Growth in sub-Saharan Africa is projected to rise to 3.6 % in 2020. This will result in a faster per capita increase rate for about 500 million people than the rest of the world. These projections are expected to decrease due to the outbreak of *COVID-19* and its economic consequences [3].

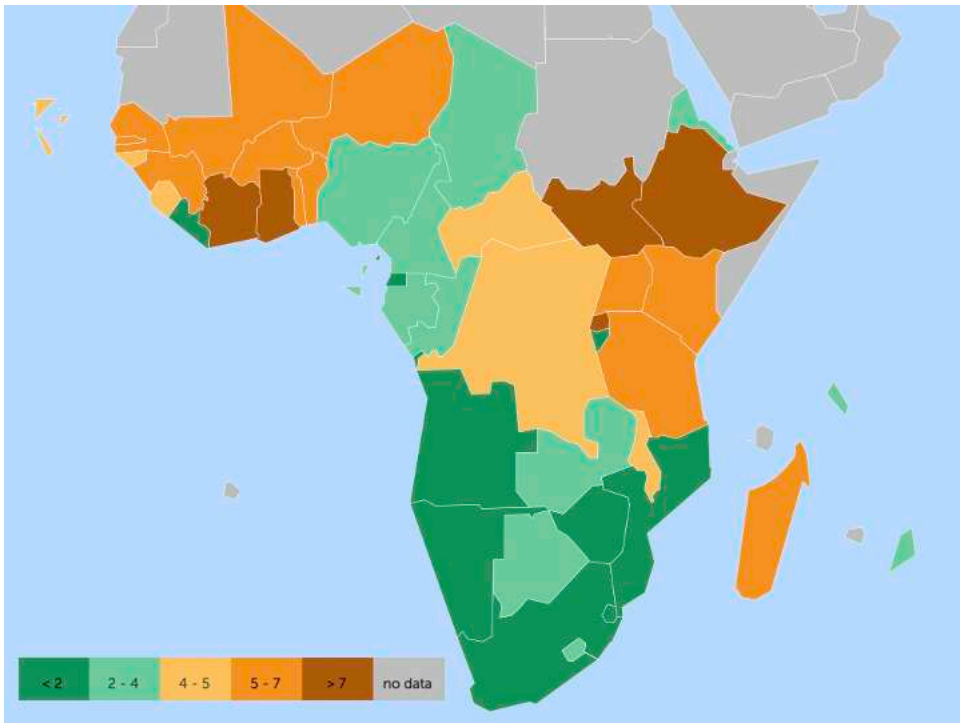

Figure 11: Real GDP growth in % in sub-Saharan Africa in 2019 [23]

CHAPTER 4: FRAMEWORK

To develop a framework to accomplish the mentioned objectives, both the financial and the technological aspects have to be considered. Both sections are completely related because the existing technology has to be adapted to the income possibilities of the customer.

4.1 Finance

Finance is one of the main challenges to get access to electricity in rural areas of Africa. Although the reasons why these areas lack electricity may slightly vary between one area and another, the economic issue is the unifying thread. To face up this situation there are several possible solutions and a combination of them would mean a great advance. Remarkable progress will be made only if all participants work in the same direction. The mechanism to solve this problem is based on innovation to create an autonomous standalone microgrid.

Philanthropists may play an important role in this issue, but to try to rely on them the whole finance of the projects all around the continent is too optimistic. Their help has always to be considered when received, but it would be not credible if funds were taken for granted in advance. This kind of aid has to find the right channels to get the highest benefits. Corruption is a tremendous phenomenon in the whole continent as it was mentioned in Figure 4 and the fewer parties that participate in the flow of funds, the less risky the project will be. Therefore, the preferable procedure is to prepare a network to directly send this kind of help to the affected community as well as to consider benefactors as an extra piece, but no project can be based solely on their philanthropy.

Another point to consider related to external aid is the value of the system. It is popularly accepted that the most aid flowing to Africa, the more improvement it would be reached. However, in this case, although a particular solar farm could be totally financed by a benefactor both at the early installation and during the operation stage, it would be completely counterproductive. An essential point in this project that individuals value each watt they consume as it is a mean to an end which is development. They are going

to be the supervisor in this system and they need to care for it and consider the farm as something tremendously valuable that opens a window to a technology-based future. Therefore, it is a must in this project to install a system of payments that works as a subscription and every household has to pay a fee to keep access. Thus, it is not only a way to appreciate the system but to sustain it. These payments have to be related to the income possibilities each area has as well as the size of the photovoltaic system itself.

International organizations are already involved in multiple projects across the continent. However, the majority of them are treating this problem focusing on the expansion of existing grids and collaborating with local governments on how to develop a reliable grid-based system that covers the whole surface of the country. This is completely suitable for national governments far more worried about reducing their own access rates which are more related to a nineteenth-century society than a modern one. For them, the main objective is to increase the access to electricity rates with regard to the international community. However, while this process is in motion, many people are left aside as they do not account for a great number of people to be a priority for national governments. Therefore, they will be completely isolated until the grid arrive where they live and it could take decades.

Remote areas whose access to the grid is considerably uncertain also need to address this dramatic situation. Once the fact that the grid will spend decades until they benefit has been stated, some other options have to be considered. As has been explained it must be a solution that they can run themselves as well as the necessity of funds is small. Thus, solar power accomplishes all required features. On the one hand, it is high enough in most African countries and also cost-effective considering that the demand is not enormous and the levelized cost of energy could be considered to check which installation is better among the considered alternatives in each particular case and prove that numbers approve the photovoltaic system. On the other hand, these communities will join out of the blue the current trend of clean energy and will remain green-powered until the grid arrives where they live. Then, their farm could be connected to the entire grid and participate in the entire national system as well as be interconnected to neighboring countries. This is why the system is said to be modular due to it can increase if the customer wants to. Therefore, by the implementation of this system, they would get access to electricity before than they otherwise would.

The World Bank targeted energy poverty as the main barrier to development. Once the explanation of the existing circumstances has led to consider the only solution for them nowadays is auto production, the next step is to wonder about the amount of disposable money they have. Assuming that the level of income is related to the access to energy, the poorest areas in Africa are obviously those without access to electricity, so to get the right value, a general assumption will be average income is lower than $1.90 a day that is the rate of extreme poverty. This upper limit is based on the fact that the average village income is below the average of the country and also considering that the *GDP* per capita in these countries is really low. To illustrate this problem, in 2013 there were two countries in Africa whose situations were dramatic: Nigeria and the Democratic Republic of Congo, which accounted for 86 and 55 million people living in extreme poverty [24]. A point to consider is that these two countries are enormous in both extension and population, so those real numbers mean 50.3 % and 77 % of their population, respectively.

The main characteristic of this project is to maximize the limited available options for these people to get the greatest rise in life quality as it is possible. Thus, the main goal is to reduce costs. To achieve this point, to create medium-sized consumer cooperatives to divide fixed costs among as many users as possible is fundamental. This is called community solar. As noticed, even dividing them it might not be affordable because there would still be a large upfront payment. Therefore, an extra model of payments is required.

The system of payments chosen is called pay-as-you-go (*PAYG*). *PAYG* delivery models divide the total sum into affordable small payments because otherwise, these communities could not afford it. Therefore, it runs businesses that would not exist without this flow of payments. It is a way to avoid the barrier that large upfront costs create. In 2015, this technology attracted four times more investment in the region than selling products for cash in half the time [25].

Payments can be made in different ways according to the specific community. Direct cash payments are an option, but it is not the preferred one. Scratch cards are another way to ensure payment, but mobile money is the most popular and easiest option because it incorporates a mechanism to disable the system if a payment is overdue. By using this

method, the customer receives an *SMS* with a specific code to enter in the installation control station once the payment is received.

The system basically includes *PV* panels, a battery (depending on the budget) and equipment. At the beginning of the process, the customer makes an initial payment in the range of $50-100 followed by regular monthly payments that may vary depending on the size of the installation from $0.3 per day to $2 that allows the customer to save from the beginning of the project. Another option if the customer prefers is to top-up their account whenever they can, so they are not worried about the operation of the system for a long time.

The intellectual property of the system is considered a third-party solution because it is an already existing and popular idea that is reusable worldwide. Besides, it can be freely distributed and, particularly free for these needed communities. Therefore, there are two ways for the project to develop: On the one hand, if there already are established companies in the country it would be easier to create partnerships with those existing brands to accelerate the process and avoid bureaucratic barriers. If they do not exist yet, the way ahead would be to acquire third-party licenses if required from international organizations or the charity side of existing companies that most of them have nowadays. Considering the purpose of the project and the size of the installation, it would usually be free.

Although the *PAYG* system reduces the upfront payment, the cooperatives might not afford the initial payment. Thus, if a loan were necessary, it would be so difficult for these communities to finance through equity or raising debt because the risk for investors would ruin any effort. Microfinance is a way to solve this issue if lessors agree to work this way. This option has to be explored appealing to international cooperation programs of developed countries or international organizations which would give loans at even zero rates and divide them into affordable periodic payments. If the community could advertise itself in social networks, they would probably take advantage of crowdfunding. If they are able to show an enormous public their own needs, little help from every corner of the planet may account for a great amount of money to run different projects on the continent. Eventually, this is the point when the aid from benefactors is completely useful because exempts local people from this upfront payment and does not remove the feeling of how

worth the installation is by daily payments. Furthermore, in projects in which there are benefactors, this first payment could directly go from these generous benefactors to the company. Doing this it would be possible to avoid taking unnecessary steps and too many hands moving the funds.

To create a realistic framework, a good idea is to learn about the customers' needs, their actual situation and their expectations. If possible, the best option to research is collecting data through questionnaires and to interview as many people as required. Another complementary option is to rely on already collected data by international organizations but preferring audited information. Local governments may offer their own information regarding their countries. To put this information aside is recommendable and only use it if it is credible because there is a recurrent behavior showing that many African governments may be interested in offering biased information to the international community.
The flexibility of payments can vary from a project to another. An option is to create a system in which there are fixed payments as well as dates and terms. An addition is to extend the payment period and to standardize the grace period. This issue is particular and different in every case and has to be signed in the contract. The close relationship between customer and provider makes possible to create tailored models as well as affordable upgrades as the customer moves upwards the energy ladder and taking into account that no customer is the same.

The lease model is a fundamental aspect of the system and is up to the customer and the operator. Thus, there are two options available: a rent-to-own model or a perpetual lease. A short-term rent-to-own model is preferable for customers whose skills make the revision and substitution of out-of-date equipment feasible. On the other hand, a perpetual lease works as a pure service and the conditions of unexpected expenditures are signed in advance and may be paid by companies.

The installation of the plant is necessary to be done by a technician service because among these remote communities it is difficult to find someone able to do it and the majority of them have never seen a system like that. Another benefit of *PAYG* is that the customer understands that the operator has a financial interest in the proper working of the system.

The activation technology once the payment is submitted can be accomplished by different methods. The most used activation method is a full *GSM* device with a *SIM* card built into the solar farm's control system. The main advantage of this method is that it is comfortably operated because it allows remote payments with which the company can remotely activate the system. The cons of this technology are its costs and that it requires mobile signal and a mobile-money infrastructure. It is usually used for small home systems. To reduce costs, another alternative is to send the unlock code through an *SMS* once the payment is received by mobile-money or scratch cards. Once the code is received it is entered into the system. The disadvantage of this method is that this way the system cannot be remotely monitored. The opposite option is to activate the system manually. If there is a loan through microfinance with regular payments, the system can be activated when the payment is received. By this method, there are not technology costs, but the security is low. It is commonly used for small and large solar systems. Finally, another point that is necessary to consider is that any security protocol can be hacked with enough effort.

In short, in communities where the line is operative, it would be done by *GSM* or a code sent by *SMS*. It could be activated manually too, but there is some risk of cheating. Data collected from customers may be anonymous. Another option is to create personalized payment profiles to recognize each customer's status.

4.2 Technology

Once the financial aspect of the installation has been stated, it is the turn of the technical one. The general model to follow is a standalone modular microgrid based on solar power. The photovoltaic installation is composed of a generator, wiring and devices to make the system work according to the characteristic of the powered consumption. The solar power is captured by photovoltaic panels that turn the energy from the photons into *DC* and it is not until the inverter when it is converted into *AC* power to be utilizable by the household gadgets. A further description of these devices is provided below:

- Generator: The solar panels play the role of generator. During the insolation hours, the panels turn solar rays into electricity by the photoelectric phenomenon as has

been explained. This energy is continuous current (*DC*) and flows into the batteries if they exist or goes directly to the consumer. During the consumption, these batteries discharge and provide the energy they store.

- Power regulator: It controls the amount of power that goes inside the battery and protects from overloads and drops in voltage. It is a key device for the protection and the reliability of the system. It may also include an emergency group which responds to the demand in case it is necessary.
- Batteries: The accumulator stores the energy obtained by the solar panels during the hours of sunshine and keeps it until the user needs it. It is made up of some batteries which may be connected in series or parallel. The importance of this gadget is fundamental in the installation due to its high costs. As it has been already mentioned in this project, the main points are reducing costs, long lifespan, minimum maintenance and simplicity. Therefore, batteries have to be considered only if the cooperative can afford it and have to be designed to be profitable in the long term.
- Diesel generator: It is a secondary source which responds as long as there is no sunlight and the batteries cannot provide enough electricity. It is run with diesel. Its implementation is optional as well as batteries. The target communities are completely isolated as it was mentioned, so this generator requires that someone brings diesel to the isolated village very frequently.
- Inverter: As the source is producing direct current (*DC*) and loading the batteries and the loads (electrical appliances) work with alternating current (*AC)*, it is mandatory to transform that current into sinusoidal. To achieve it, there exists a device called inverter which plays that role. It turns the *DC* produced by the solar panels into 240 *V AC* electricity, which is the required voltage to run all electrical appliances or another different voltage depending on the country where the project is taken. To sum up, it may be used to start the diesel generator too.

A key aspect of the system is its modular operation that allows the operator to enlarge the size of the farm whether the number of customers grows, if the requirements of the customers are higher or both of them. Thus, this is not a temporary solution but the once and for all integration into modern society.

If the community can afford batteries, to choose a model whose capacity and capability is greater than the theoretically required is advisable. There are two reasons why it is recommended. First of all, the importance of overpassing the limit to have a protecting margin of error. So, the capacity of the battery must be enough to storage more than required. Second, this system will provide the community an opportunity to go up in the energetic ladder. Hopefully, the community will increase in consumption and necessities. Thus, the power capability of the battery must not limit the future installation of more complex gadgets, at least for a while until extra funds to run a new project are gathered.

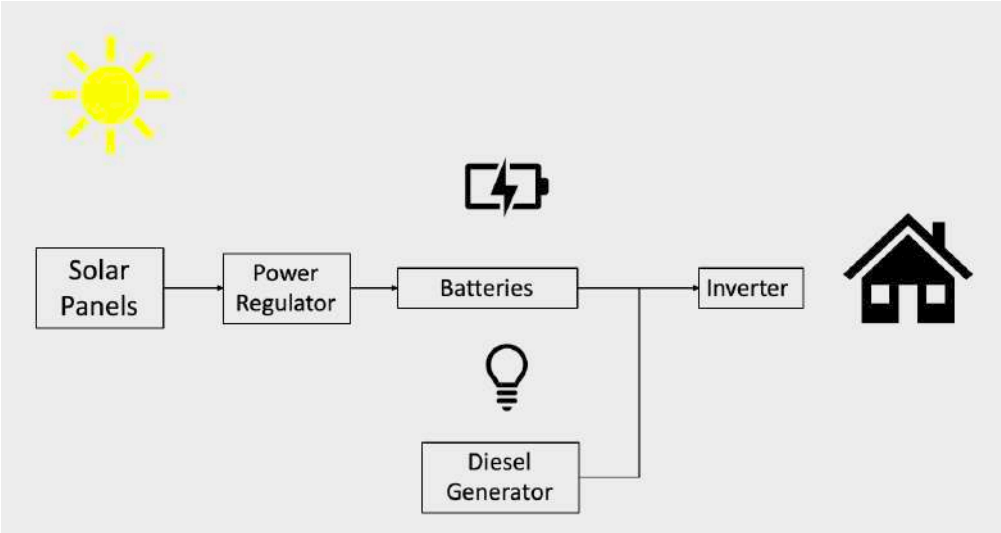

Figure 12: Simplified scheme of the general installation

CHAPTER 5: CASE STUDY OF THE DEMOCRATIC REPUBLIC OF CONGO RURAL COMMUNITY

The existing problems in the Democratic Republic of Congo are due to several factors that have led the country to its current situation. The turbulent changes produced during the last three decades as well as the constant conflicts between its different regions have set aside the necessary reforms the country needed. Taking into account the Belgian Colonialism and the way it ruled the country, to understand the dramatic situation of the Democratic Republic of Congo nowadays is not difficult. These variate factors need to be focused on different perspectives to discover how the considered to be the richest in resources country around the world has so great needs in the 21st century.

5.1 Problem Nature in the Democratic Republic of Congo

To start with, to go back to the 15th century is required. From the 15th to 17th centuries, there existed two major states in the southern savanna region. One of them, the Congo Kingdom was located in the west whereas the Luba-Lunda States in the east. The political institutions were ruled by a strong kingship supported by a loyal military force. The competition for the kingship was not the only existing conflict in this period, but the slave trade was another source of instability. As the 16th century advanced, the Atlantic slave trade meant a great vested interest among local leaders and debilitated the ability the kingdom used to have to defeat its enemies. At the end of the century, the Imbangala group, originally from Central Angola entailed a severe famine and drought in the east of the country. The differences between Luba and Lunda people magnified and fights for the control of slaves and ivory were very common. The tropical rainforest region, located in the north of the country, progressed in a completely different way. Vegetation meant a great problem to create a state. Therefore, small communities organized themselves until trade and social interactions got to homogenize. Even so, the savanna region was far more organized.

Moving forward to the 19th century, Belgium realized how beneficial for its development this massive region could be. Natural resources in the country are enormous. In fact, it is

considered to have the richest natural and mineral resources in the world. The British journalist and explorer Henry Morton Stanley explored the region from 1874 to 1877 and King Leopold II was so impressed about what he detailed that in 1878 launched the Committee for Studies of the Upper Congo to use the Congo River as the European road to Center Africa. This resulted in the beginning of the Belgian colonialism. Although at the beginning it was an amicable settlement between Belgium and local entities, it rapidly changed. The West Africa Conference established the "Congo Free State" in 1885 as the private property of the Belgian King. At first, it involved a humanitarian mission with the objectives of concluding the slavery period and bringing religion to local people. As usual in the period, the Belgian administrative and political institutions were imposed in the Congo Free State. The conflict was there, modern state's structures over an indigenous population trying to "civilize" the region. To sum up, only some citizens were given the "Native authority" and the law was exclusively competent from Belgian institutions.

The Conference of Berlin in 1885 did not fix the limits of the country as they are today. It was not until 1910 when Germany agreed to delimit the country the way we know it. The actual ruler in the territory was not Leopold II, but the military and the governmental administration in Africa. The nationality was aliened to the Congolese as well as the majority of his rights. It took long for the governors to control the area and expand the administration. The main objectives in the country were to use labor for mines and plantations as well as to collect taxes from its workers. By 1933, the administrative structure was completely defined over the entire territory. The system was designed in a way that not only they tried to extract the maximum amount of natural resources, but the maximum amount of labor from people. This way, there were few paid workers and a lot of forced labor in which violence was frequent. Many private companies obtained large areas to take advantage of the rubber. A typical measure was requiring the local population to give natural rubber as a tax. Once a railroad was built between the capital, Kinshasa, and the port of Matadi, mining became another important activity.

The industry was focused on improving the rate of exporting of the Congo Free State and local people were forbidden to have industry property. The distribution of exports changed over the years. In 1959, copper was around 60 % of total export revenue. Palm-oil and coffee 8 % and diamonds 7 %.

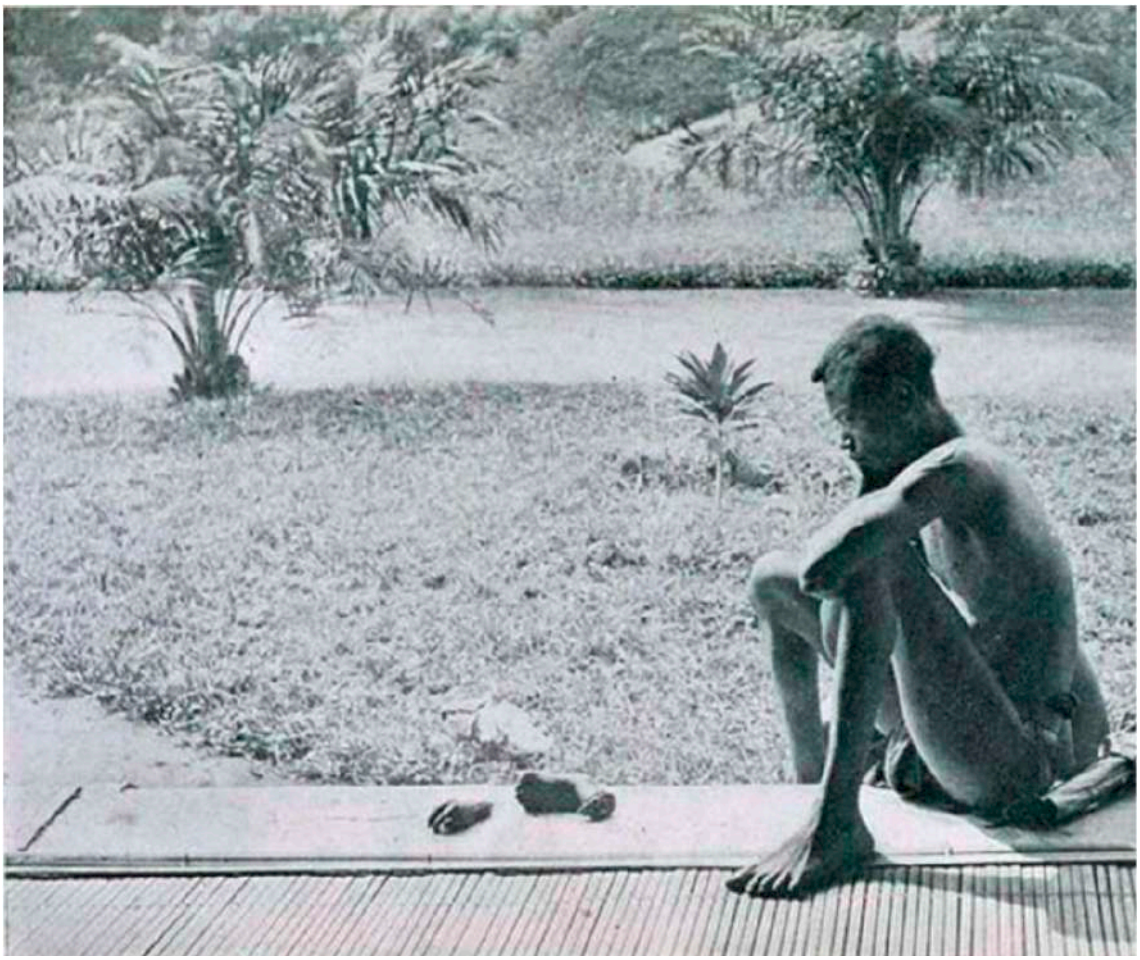

Figure 13: Congolese worker with the severed hand and foot of his five-year-old daughter as he had not met his rubber quota [26]

The social disruption did not only complicate the establishment of local administration but also gave rise to an increasing hate relationship with Occident. Important matters such as health and education were left to missionaries and this is an important characteristic of Belgian colonialism: it did not try to produce a social improvement. Until 1960, missionaries were the only ones in charge of education. Leopold II was who decided to rule the country in this way since in 1908 in the Colonial Letter which played the role of the constitution. It prohibited the association in political parties and people from organizing unless it was with a religious or cultural purpose. The Belgian authorities had the conception of a unique Congolese State, but they needed from local authorities to bring their message. Institutional multiplicity remained even after the occupation.

When the Belgian Colonialism was almost over in the region in the '50s, investments in health and education started to grow rapidly. The first universities of the country appeared

and the government expenditure doubled. In 1958, the first political parties were founded and despite existing around 100, they represented much more different regions than different ideas. Since that moment, there were multiple attacks to the Belgian administrators and two years later, in 1960, the Belgian Government promulgated the "Fundamental Law" and meant the Constitution of the country after independence in that year.

Logically, few people were prepared enough to reassume the political function once the colonialism concluded. The remaining institutions after the occupation were still considered as part of Belgium. The white minority still maintained the power using institutions as a very lucrative business as well as governing the tribe leaders to obtain labor force to create more railroads and to keep running the rubber industry. Only Congolese with native authority had the right to own land which meant that private property was a right that only the white minority had. Only Belgian could occupy administrative positions and manage mining and other industries. The non-existence of an anti-colonialism movement is something atypical, but some reasons easily explain it. The low rate of schooled people, the diversity of ethnic identifications and political exclusion made it completely impossible. After independence, the fragmentation of the society brought an enormous number of political parties that could be divided into unitarist and federationalists.

As far as rural areas are concerned, some roads were constructed but it was not enough to approach the advance these areas needed and remained isolated from the modern world. The agricultural sector did not improve much and technology was not implement at a modern country rate. The control over all production factors led to growing mining companies ruled by Belgians.

On June 30 of 1960, the Congo became independent from Belgium. A few days later, on the 11th of July, the richest region of the country, Katanga province, declared itself independent. The current President of the Congo, Patrice Lumumba, argued they were supported by Belgium trying to rule this profitable region again. Lumumba appealed to the United Nations the day after asking for a peacekeeping mission. However, the Prime Minister, Joseph Kavasubu, totally opposed to the use of force. Then, Lumumba asked the Soviet Union to send a part of its army to solve the problem. This is the moment when

the country got involved in the Cold War. Not only Katanga split the country, but it broke up into four regions: Katanga, Orientale Province, Leopoldville and Kasai. Lumumba tried to reunite the country helped by a part of the army, but months later he was executed. In 1963, *UN* forces got to defeat the Katanga´s insurrection. There was another attempt to divide the country in 1964 when Lumumba's supporters announced the east of the country became the People's Republic of the Congo. It happened months later Cyrille Adoula dissolved the parliament and it was one of the many rural uprisings. The rebellion did not have a political wing to support it and the order was restored with the help of European mercenaries. The Prime Minister at the moment was Moise Tshombe, the same leader that less than two years before led the independence of Katanga region and was defeated by United Nations' forces.

In 1965, Mobutu took advantage of the fights between the current President, Kavasubu, and the Prime Minister, Tshombe, and he decided to assume the Presidency. There was a logical period of instability when the military divided into Mobutu's supporters and Tshombe's. Finally, Mobutu got to calm the situation and focus on governing the country. In 1971, he renamed the country as Zaire and ruled the country until 1990. The economy did not progress and the anti-Mobutu sentiment rapidly grew. There were some attacks from Angola conducted by the opposition, but they were neutralized with the help of allied countries like Morocco or France.

The situation dramatically changed when the Cold War ended. The international supporters of Mobutu's regime demanded democratic reforms. He permitted the opposition to organize, but the brutal repression of protests in 1990 changed the international situation of Zaire. France cut off the monetary aid as well as the World Bank. One year later, a coalition group was born. It was called the High Council of the Republic and Étienne Tshisekedi was selected as Prime Minister. Mobutu rejected to reduce his power and got the loyalty of the army by giving them the right to sack different regions of the country. Finally, in 1994 Mobutu agreed to sign the Transitional Constitutional Act and Kengo wa Dongo was named Prime Minister.

The Rwandan civil war and the later genocide in 1990 - 1994 was an opportunity for Mobutu to improve the relationships with his pre-Cold-War partners: France and Belgium. It was a conflict between Hutu and Tutsi groups than resulted in a genocide that

killed from 500,000 to 1,000,000 Tutsi people in July 1994, around 70% of them. Zaire offered logistics to the French and Belgian armies while they supported the Hutu side. Once the war ended, Mobutu promised these two countries and also the US privileged access to Congolese resources. At the same time, Mobutu carried out an offensive in Zaire´s territory against Tutsi people living in the east of the country. As a reply, the Rwandan Governed joined forces with local Tutsi and the Alliance of Democratic Forces for the Liberation of Congo-Zaire was born with the help of Laurent Kabila, Mobutu´s opponent in Zaire. Finally, in 1996 this alliance got its first results due to the capture of Bukavu and Goma. One year later, in 1997, they took Mbuji-Mayi and Lubumbashi in April and the capital of the country, in May. Mobutu died in exile not long after.

Kabila brought back the name of the Democratic Republic of the Congo. Among his first measures, he did not allow the instauration of opposition, he tried to accelerate the economy and started a new constitution. In August 1998, Kabila was betrayed by some former allies and some provinces were taken. The civil war lasted five years and some neighboring countries were involved. Kabila was helped by Namibian, Zimbabwean and Angolan governments. In 1999, there was an attempt to stop the conflict by the Lusaka Peace Accord, but the conflict quickly resumed. Another point in the war was the ethnic conflict between the Lendu and the Hema located in the eastern of the country. Laurent-Désire Kabila was killed in 2001 and his son, Joseph Kabila became the President until January 2019. In April 2003 the war was completely over, but United Nations decided to maintain its forces in the territory.

Although the conflict seemed to have finished, the situation was terrifying. More than 3 million people killed, starvation, diseases, homelessness and, obviously, the economy ruined. Kabila's Government did not get to control the country at all and promulgated a new constitution in 2006. In the eastern part of the country, conflicts remained until January 2008 when a peace agreement was designed by the government and around 20 rebel groups. However, soon after the conflict resumed in the east. In 2011, presidential and parliamentarian elections took place. Although many international organizations considered many irregularities, on 23rd December the results shown Kabila as President again. The next elections were planned for 2016, but different regulators procrastinate them until December 2018. Kabila did not stand in the elections. There were multiple strange occurrences along with the presidential race. There were some areas where voting

was postponed until March due to the Ebola virus, but these areas only account for 3 % of the country. Results were public in January and Felix Tshisekedi became President of the Democratic Republic of the Congo. The transfer of power was the first peaceful one in this country.

As has been aforementioned, the historic development of the country failed to match up to a well-balanced prosperous economy. The ethnic diversity has resulted in a source of multiple conflicts and betrays. Taking into account the Belgian Colonialism and the later paternalism, Congolese economy became a Belgian farm where progress was forgotten. The propagation of diseases and famines has been a constant along centuries, as well as corruption.

If these factors are considered, the fragmentation of future projects is the best option and another point in favor of cooperatives creation. If funds are direct to the affected area instead of going through many intermediaries, money is less likely to be lost. The grid is not expected to grow exponentially and electricity is a need that has to be spread as soon as possible. Therefore, off-grid is a way to solve the situation meanwhile the *GDP* grows and the government gets the chance to improve facilities as well as the country improves its international image to overseas companies to invest in the *DRC*. Off-grid systems are not a closed solution, but a convertible one. Once the national grid expands, these mini grids would be integrated into it and would become another facility in the national electric system [27].

5.2 Extent of the Problem in the Democratic Republic of Congo

The situation in the Democratic Republic of the Congo is dramatic. The urban electricity access rate is around 49 % whereas in rural areas is null [8]. There are around 13 million households without access to electricity which means 84 % of the population [28]. They are spread in both urban and rural areas and this is why off-grid solutions are likely to become a great alternative. Considering the different regions of the country, few regions surpass 50 % of the electricity access rate: Kinshasa and the territories of Kipushi, Beni, Moanda and Sakania. Only 10 administrative regions are exceeding 20 %, but the 12

remaining ones are below 5 %. In 2017, the access rate in urban settings is 49 % whereas in rural ones 0 %. According the last data published by the *IEA* in 2019, the access rate in the country has followed the below evolution:

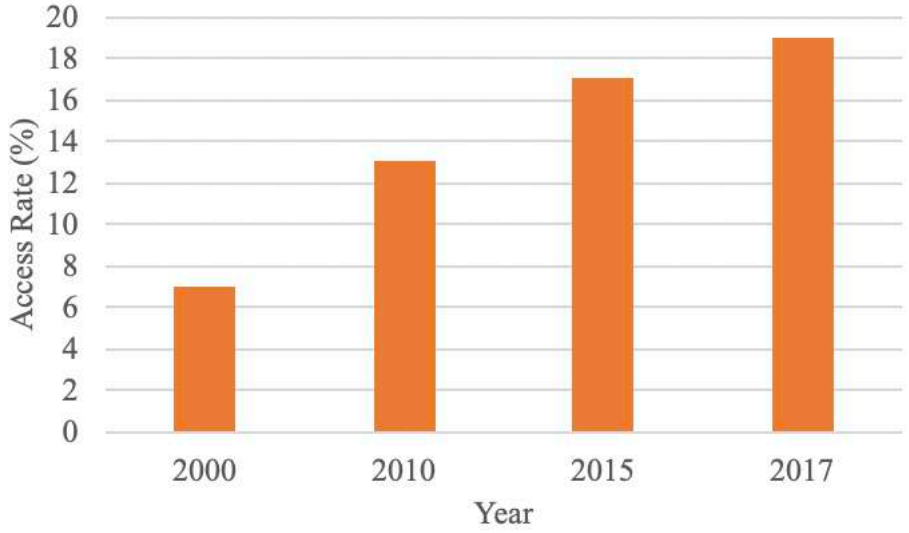

Figure 14: Rate of access to electricity in DRC [8]

Clean cooking faces bleak prospects too. The access to clean cooking in urban areas was 9 % and <5 % in rural ones. The evolution has been dramatically slow and a great advance is still necessary.

Although the rate of renewable energy is not the main concern in the country at the moment, the numbers are quite impressive. The main renewable resource is solid biofuels, but there are big hydro projects in the country such as the Inga I and Inga II, located in the Inga Falls area. The total hydro power capacity installed in the country is approximately 2,704 *MW* [29]. The share of solar power is expected to increase in the following years and this would mean a great advance for the country and the rate of development of its population.

War and terrorism are two main motives why national and international investors are not willing to take the risk. This country is ranked the 155th out of 163 countries in the Global State of Peace Index 2019 [30].

As it has been mentioned before, how easy it is for an entrepreneur to start its project or to a company to expand its business in a country is highly associated to the course of its economy. The Democratic Republic of Congo is ranked the 183rd out of 190 countries described in the Ease of Doing Business Ranking [14]. Another point to consider is to analyze the undeniable links between economic freedom, individual liberty and prosperity in nations around the world. In the last version of the Index of Economic Freedom, the Democratic Republic of Congo's position is 162nd out of 180 considered countries [31].

The National Electricity Company (*SNEL*) has only 500,000 registered connections in an 86-million-people country. The illegal connections are very common and if the low tariff ($0.07 *kWh* – half an American or European one), it results in tremendous losses for *SNEL* [32]. It is possible to argue that this low price is due to the underdevelopment of the country, but it is necessary to consider that most of the equipment installed is imported from developed countries, so total costs are still really high.

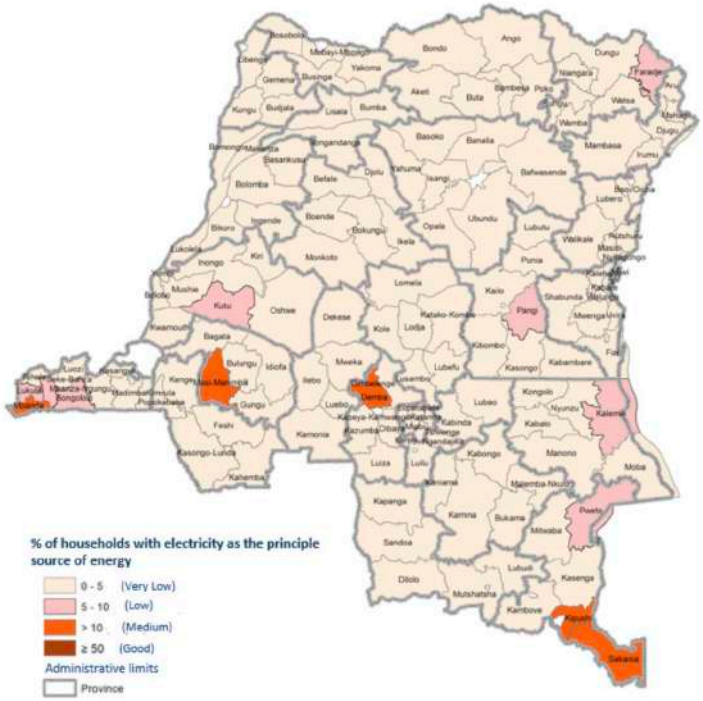

Figure 15: Percentage of households with electricity as the principle source of energy [33]

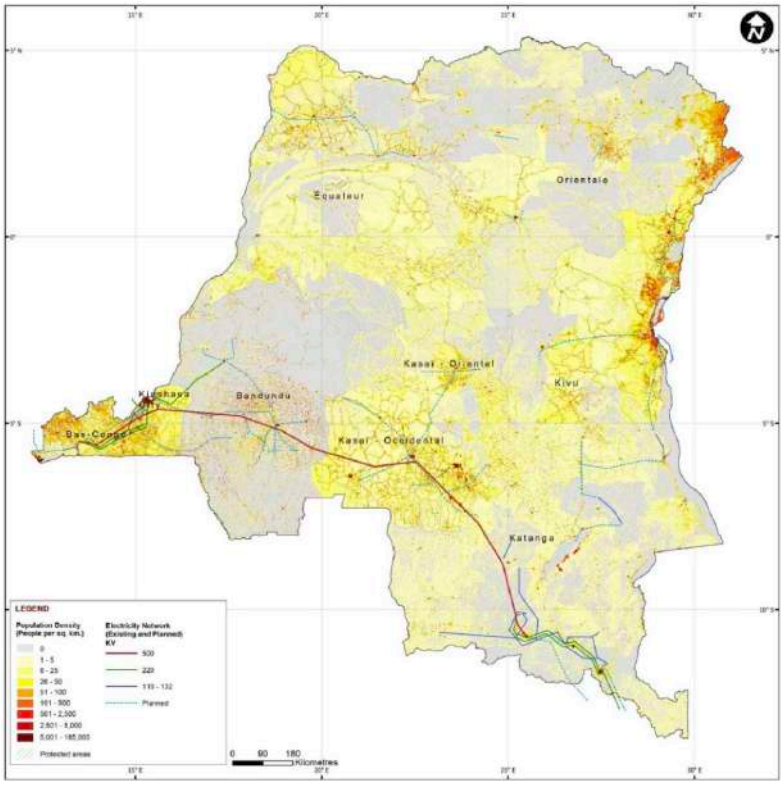

Figure 16:Population density, existing and planned grid [33]

There exists a national grid divided into three different sectors to cover eleven provinces. The total length of high-voltage transmission lines is 5,547.2 *km* (*SNEL*, 2000) and it is the second biggest country in surface (Argelia) in Africa. This point results in many citizens to be completely out of the existing or projected electrical system. According to the African Development Bank analysis, only 19 million people live within 15 *km* of the existing grid which means 22 % of the total population and 31 million live within 15 *km* of the existing and planned grid. Therefore, 50 million people (58 % of the *DRC* population) live completely isolated [33].

Most of the current projects are grid-based. This results in many people to be left aside because their residences are far from the current or projected grid as it has been mentioned. The majority of these projects are hydro power and are attracting a great part of investments. Two great hydro projects like Inga I (351 *MW* in 1971) and Inga II (1,424 *MW* in 1982) stand out over the rest of them, accounting for $377 million investment to rehabilitate them. Also, there is another Inga project, Inga III, that has already captured $68 million to achieve a total installed capacity of 1,344 *MW* [34]. The greatest project in this area is called The Grand Inga Project and will account for an installed capacity of

44,000 *MW* and the estimated gadget is $80 billion [29]. To create an authority that regulates all these massive projects, there is a $106.5 million technical assistance grant [33]. The Inga Falls are located in Matadi, in the province of Central Congo that is near to the capital and largest city of the country, Kinshasa. As it is possible to see in Figure 16, this is the area of the country with the highest population density and also with the most complex grid.

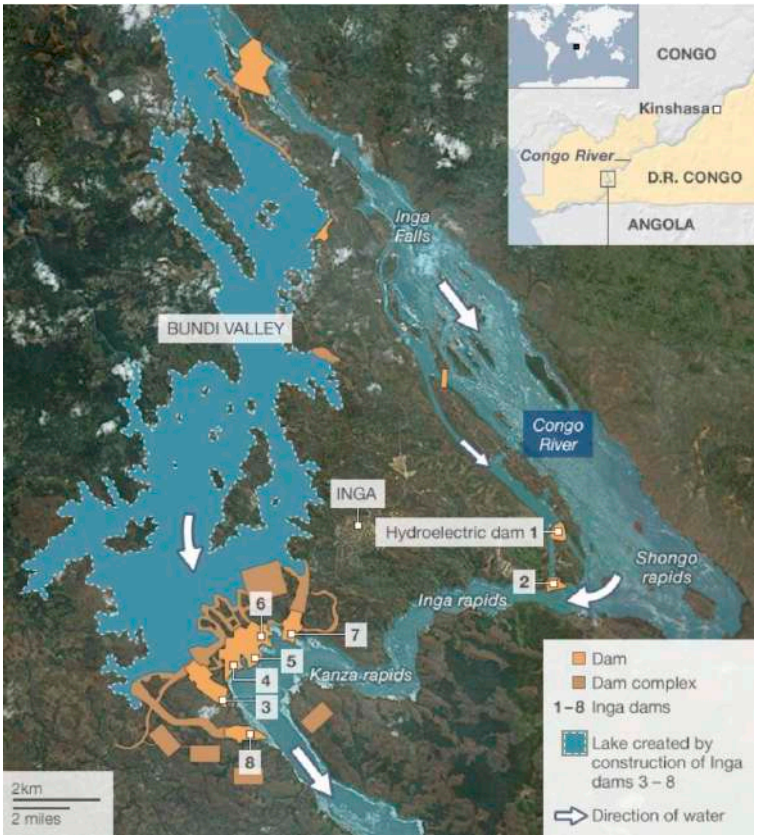

Figure 17: Map of the Inga Projects [35]

The national grid means a great advance for the country, but now it is obvious that there are many that cannot reach it and are left aside. To clarify this idea even more and to not rely only on information, the Congolese grid has been modeled using a Facebook-made idea [36]. The main objective is to estimate where the medium voltage power lines are. These lines are not big enough to be identified in the satellite imagery. Therefore, to show them it is necessary to rely on indirect indicators. This indicator uses information from satellites and consists of nighttime radiance. This information is collected by the *VIIRS* day-night band sensor that is part of the Suomi National Polar-orbiting Partnership (*SUOMI-NPP*) satellite that belongs to the *NASA* [37]. These "night lights" are a good estimator of the average consume and show which communities generate enough light to

be detected from the space. In order to increase the trustworthiness of this indicator, all images are collected at 2 a.m. local time to have an uniform picture of the situation.

There are two assumptions to infer electrification using this method:

- Settlements on the grid generate detectable lighting.
- Settlements off the grid do not generate detectable lighting.

This assumption regarding the Congolese grid is quite precise because as it has been mentioned, the number of off-grid installations is still quite small.

The coordinates are obtained from monthly coverage images taken for a period of five years [38]. The *NASA* composites an image monthly by considering the most cloud-free and moonless ones. Using a filter, they are able to subtract the background level and identify pixels slightly less light coming from reflected light to remove them. This way they also keep only those continuous pixels to get rid of exceptional wildfires or temporary mobile light.

Around 6,000 coordinates have been used to plot the following maps. To achieve it, they have been ordered and linked using Python and, concretely, Jupyter and the libraries Plotly and Pandas. The code to create this map is included in the APPENDIX A: PYTHON CODE.

Figure 18: National electrical grid in *DRC* (African view)

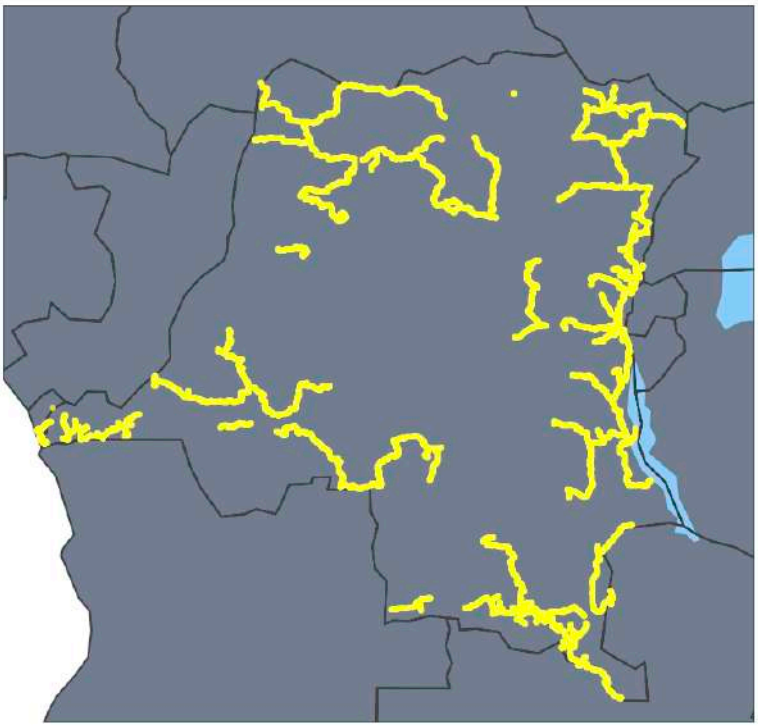

Figure 19: National electrical grid in *DRC* (Congolese view)

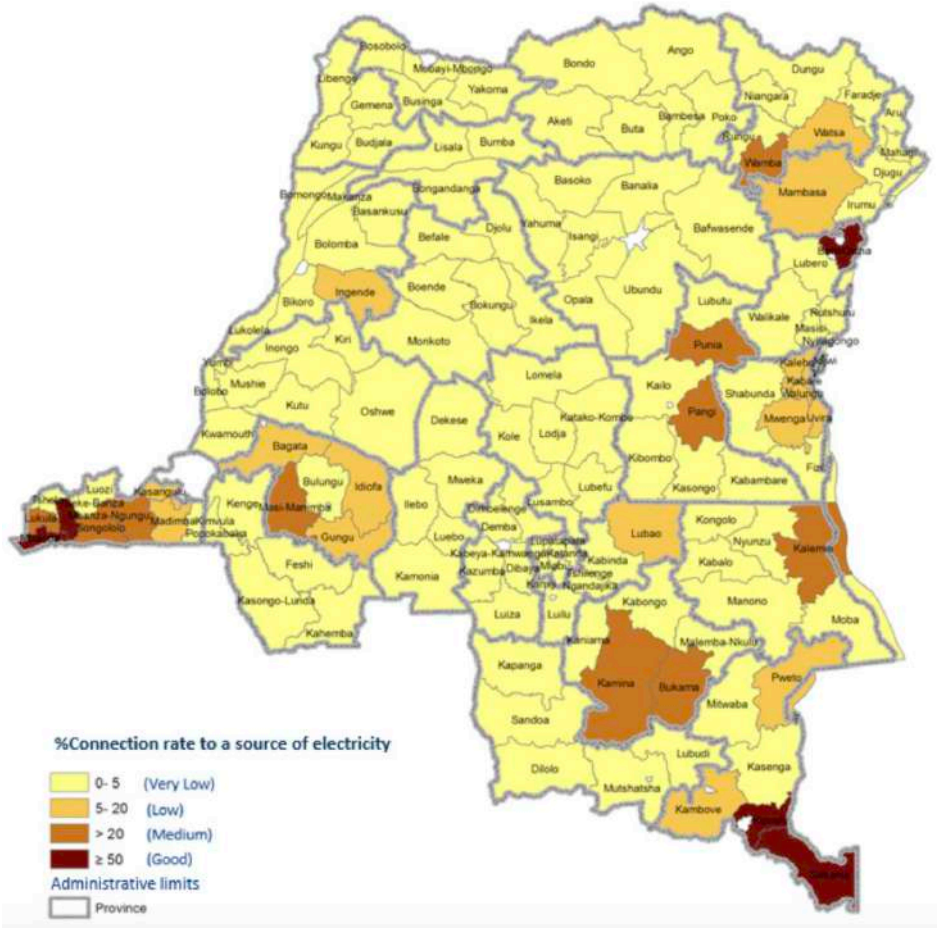

Figure 20: Connection rate to a source of electricity [33]

The result in Figure 19 is quite satisfactory due to it is total relation to Figure 20, where the use of electricity as primary source is shown around the country. These maps show how necessary is the background of this project. Rural villages are completely isolated and, unless they get to impulse this kind of projects, they will have to wait for many years and even decades until the grid arrives (if it does). By using this methodology, they will get access relatively soon and once the grid arrives where they live, it is possible to connect it and to become a new actor in the national energetic economy. In the meanwhile, the system can grow at the path of the community. This framework will be put into practice in the next chapter.

CHAPTER 6: DRC PROJECT

Once the existing problems related to access to electricity in the Democratic Republic of Congo has been stated, the framework mentioned before is implemented in this example. This fictitious community has been designed according to the average household size and the daily income in the country. The chosen devices have been selected from the American and the Spanish markets, since it is difficult to find accurate costs in the Democratic Republic of Congo on the internet or catalogues.

6.1 Load Analysis

To set the basis of the project, the voltage and frequency of the installation must be the same than in the rest of the country to make possible the future connection to the national grid. The typical voltage and frequency in the *DRC* are 220 *V* and 50 *Hz*, respectively [39]. Every household appliance is powered by *AC*. The following table includes the different appliances every household in the village will include. They have been selected in order to ease the lives of the customers as well as to maintain a budget according to their economic circumstances. The average household size in this project is equivalent to the average in the country: 5.5 people.

Table 2: Description of the consumption

ESTIMATED CALCULATION OF THE AVERAGE USAGE PER DAY OF EACH FAMILY							
Customers	Number of members	Light Bulbs	Fridge	Ceramic Cooktop	Water Heater	Water Pump	Outlets
Average usage a day (hr)	-	4	24	1	1	4	2
Family 1	3	6	1	1	1	-	3
Family 2	6	13	1	1	1	-	6
Family 3	7	15	1	1	2	-	7
Family 4	4	8	1	1	1	-	4
Family 5	5	10	1	1	1	-	5
Family 6	5	10	1	1	1	-	5
Family 7	7	15	1	1	2	-	7
Family 8	6	13	1	1	1	-	6
Family 9	5	10	1	1	1	-	5
Family 10	4	8	1	1	1	-	4
Family 11	6	13	1	1	1	-	6
Family 12	8	17	1	1	2	-	8
Family 13	5	10	1	1	1	-	5
Family 14	7	15	1	1	2	-	7
Family 15	6	13	1	1	1	-	6
Family 16	4	9	1	1	1	-	4
Family 17	6	13	1	1	1	-	6
Family 18	5	11	1	1	1	-	5
Family 19	6	11	1	1	1	-	6
Family 20	5	10	1	1	1	-	5
TOTAL	110	230	15	15	19	3	110

Every household includes a fridge and a small burner to cook. The number of light bulbs has been designed according to the average distribution of a household that includes:

- Kitchen: Includes one light bulb.
- One bedroom per child and one for the parents: One light bulb per bedroom and another one for every child to study.
- Living room: One light bulb.
- One bathroom if the number of members is less than 5 or two if they are 5 or more: One light bulb per bathroom.

The number of outlets in every household has been chosen for every person to have one to charge their phones at the same time if needed. Mobile phones are one of the priorities of these people according to several surveys and publications. The installation includes 3 water pumps to help to obtain water even in the months when its extraction is really difficult.

Table 3: Power consumption of appliances [40]

POWER VALUES	[W]
Light bulb	16
Fridge	300
Small burner	1100
Water pump	400
Outlets	18

The total load of the system is 27.86 kW. Considering every gadget in each household and the number of hours it consumes a day, the total consumption of the community a day is 147.980 kWh. So, the total dc load is:

$$Total\ dc\ load\ \left(\frac{Wh}{day}\right) = dc\ load\left(\frac{Wh}{day}\right) + \frac{ac\ load\ (\frac{Wh}{day})}{inverter\ efficiency}$$

As every consumption at homes is ac and the average inverter efficiency is 93 %, the real power the farm has to provide is:

$$Total\ dc\ load\left(\frac{kWh}{day}\right) = \frac{147.98\ kWh/day}{0.93} = 159.118\ kWh/day$$

To better designed the installation, it is necessary to obtain the load equivalent in Ah per day:

$$Total\ load\ \left(\frac{Ah}{day}\right) = \frac{total\ dc\ load\ (\frac{Wh}{day})}{system\ voltage\ (V)} = \frac{159{,}118}{48} = 3{,}314.96\ Ah/day$$

The efficiency of modules is around 17.7 %. Therefore, the load has to be considered around 5 times greater than it actually is:

$$Actual\ load = \frac{1}{0.18} * 159.12 \frac{kWh}{day} = 884\ kWh/day$$

6.2 Solar Module Choice

The number of solar panels varies depending on the location where they are installed. The higher the insolation, the fewer panels are usually required. To calculate the average insolation in the Southeast of the Democratic Republic of Congo, three different locations have been selected. On the one hand, two cities in the region of Kasai Oriental: Kabinda and Mbuji-Mayi. On the other hand, Kamina in the region of Katanga.

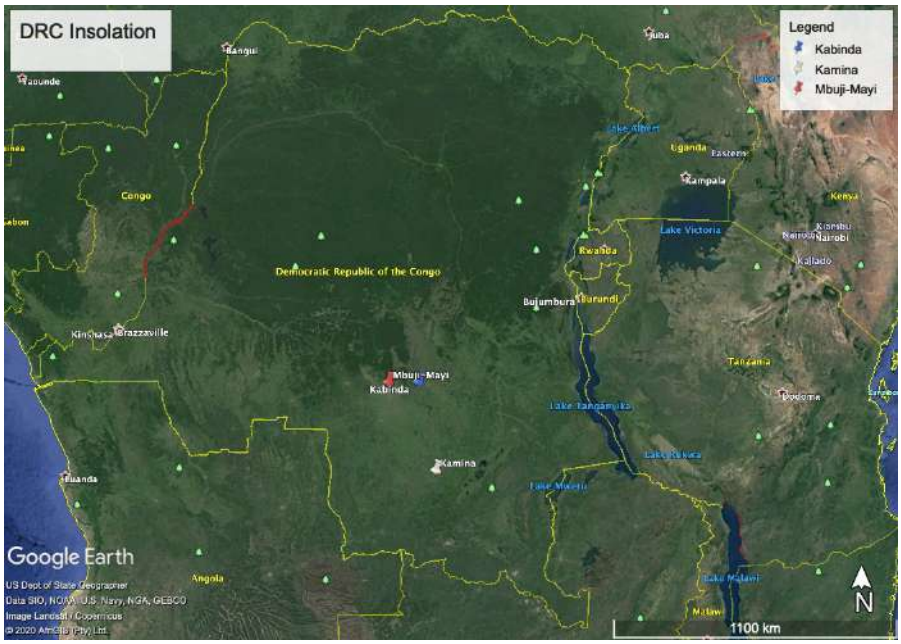

Figure 21: Insolation points - National view

Figure 22: Insolation points (augmented)

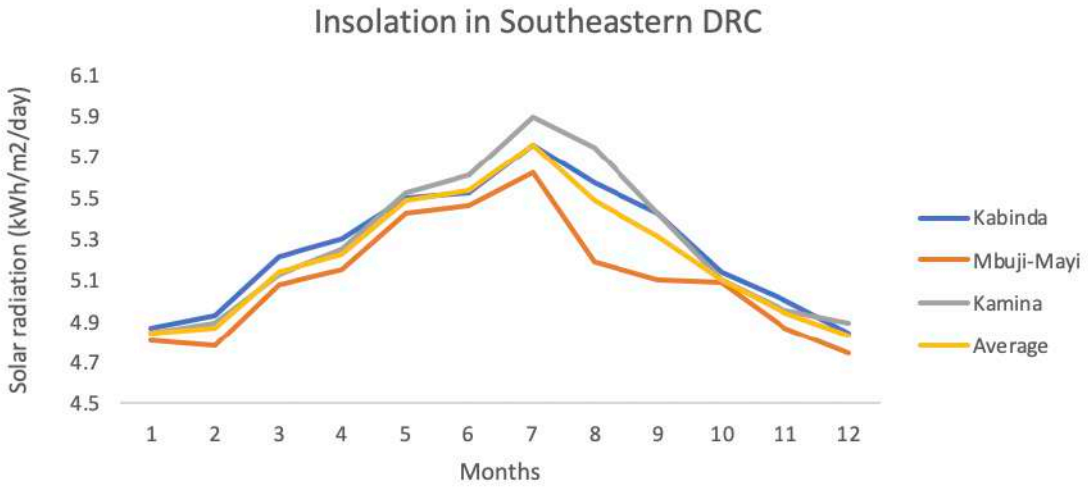

Figure 23: Insolation in the *DRC* [41]

The average insolation in the Southeast of the Democratic Republic of Congo has been calculated considering three different databases from three cities in the region [41]. The farm has to be designed to supply enough energy during the month when the average insolation in the region is the lowest, this means that the customers will have enough

energy during the whole year. This is called the worst month criteria. This month is December and the average insolation is 4.83 $kWh/m^2/day$.

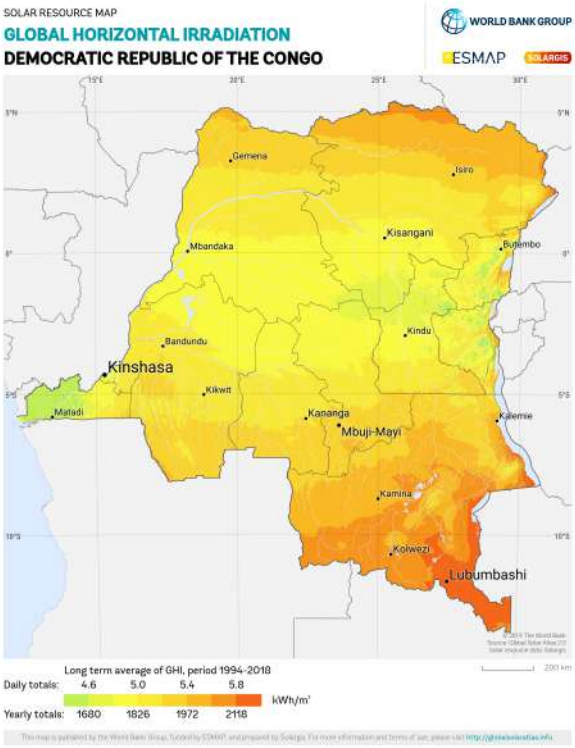

Figure 24: Map of insolation in DRC [42]

Observing Figure 24, it is possible to check that the value obtained for the average insolation using the worst month criteria is similar to the gathered data for that region by the World Bank.

Therefore, the required panel surface is:

$$Panel\ surface = \frac{total\ load}{average\ insolation} = \frac{884\ kWh/day}{4.83\ \frac{kWh}{m^2}/day} = 183.023\ m^2$$

To get rid of risks, it is recommended to use a safety coefficient that provides some extra surface. This coefficient will be 1.1 and that means the actual panel surface to consider is 200 m^2. As it was mentioned in the previous chapters, this installation is

standalone as well as modular. This means that the current number of solar panels may increase according to the necessities of the customers.

The solar module chosen is the following: Astronergy - CHSM6612P/HV-345 [43].

Table 4: Solar panel characteristics [43]

Feature	Value
Type	MPPT
Panel cells	72
Vmpp (V)	37.38
Panel watts (W)	345
Module efficiency	17.7%
Cost ($)	229
Dimensions (mm)	1,960 x 992 x 40 mm
Impp (A)	229

The number of panels can be defined as the required area over the area of each module:

$$Number\ of\ panels = \frac{required\ area}{module\ area} = \frac{200\ m^2}{1.96\ m\ x\ 0.992\ m} = 103\ panels$$

In order to have some extra power, the number of panels will be 110 to solve any rapid increase in the consumption and they will be set as 10 lines of 11 modules connected in series each one. This set up will have the following voltage and current:

$$Voltage = 11 * 37.38\ V = 411.2\ V$$
$$Current = 10 * 9.23\ A = 92.3\ A$$

6.3 Inverter Choice

A key point to design the required inverter is its efficiency. The losses in this device have to be taken into account since they are quite high. A conservative default assumption for a regular inverter efficiency is about 85 % [44]. This device is the ultimate one before the *AC* installation (home), so the *AC* load has to be corrected by this factor.

Inverters are usually specified by several parameters such as the dc input voltage and the ac output voltage, the continuous power handling capability and the amount of surge power capability for brief periods. The input voltage means a tradeoff between high currents in order to have low voltage that results in high wire losses (Joule Effect) or high voltage in order to have low currents but increasing the number of batteries wired in series to supply the load.

The maximum *AC* power in *W* in the household with the greatest number of members with every appliance connected is "Family 14":

$$\begin{aligned}\text{Maximum AC power} &= \text{number of light bulbs} * \text{light bulb power} + \text{fridge} * \text{fridge power} \\ &+ \frac{1}{10} water\ pump * water\ pump\ power + number\ of\ outlets \\ &* outlet\ power + small\ burner * small\ burner\ power \\ &= 15 * 16 + 1 * 300 + 7 * 18 + \frac{1}{10} * 1 * 400 + 1 * 1100 = 1{,}806\ W\end{aligned}$$

Since the requirements of the customers are projected to increase, this maximum *AC* power will be fixed at 3,000 *W* to maintain the modular aspect of the farm at every household. As this power is greater than 2,400 *W*, but lower than 4,800 *W*, the system *DC* voltage will be 48 *V* [40]. This voltage means that the system will draw 62.5 *A*, which is lower than the 100 *A* recommendation and allows plenty of growth and even more for smaller households [40].

The inverter chosen is the following: Changi – CJ 3,000q [44].

Table 5: Inverter characteristics [44]

Feature	Value
Input voltage type	DC
Input voltage (V)	48
Output Voltage (V)	220
Output Voltage	AC
Efficiency (%)	93
Cost ($)	145.62

6.4 Regulator Choice

The charge/load controller *MPPT* plays the role of regulator. This controller has three main missions: One of them is to maintain the system operating at its most efficient point. The second one is shutting of the charging current when the batteries are fully charged. The third one is to disconnect the accumulators from the *DC* load when there is a low-voltage condition. It consists of a solid-state circuitry placed between the generator (solar panels) and the batteries.

The entering voltage and power that the regulator has to deal with depend on the aggregation of the lines of panels. To look for a value, the lines of modules will not be joined to reduce the number of regulators and, also, to find a regulator with an *MPP* as high as 8 *kW i*s not easy and that is the one that would be required if lines were joined into groups of two. Therefore, the total voltage and current will be:

$$Voltage: 11 * 37.38\ V = 411.2\ V$$
$$Current: 9.23\ A$$

So, the minimum power the regulator needs to tolerate is:

$$Minimun\ maximum\ peak\ power = 411.2\ V * 9.23\ A = 3{,}795.38\ kW$$

Since there are 10 lines of modules, the required number of regulators is 10.

The chosen regulator is the following: Must Solar – PC18-8015F [45].

Table 6: Regulator characteristics [45]

Feature	Value
Panel Type	Poly
Vmpp (*Vdc*)	48
Impp (*A*)	80
Regulator Power (*W*)	5,000
Efficiency (*MPPT*)	98% (99%)
Data Temperature (*K*)	313

6.5 Batteries

The batteries are not a fundamental section of the installation because its implementation depends on the economic situation of the customer. Batteries mean an important increase in the total costs of the photovoltaic farm. As every device in this project, it must have an extra capacity and capability to keep working if the load increases a little. It is a margin for the lifespan of the first installation to be longer and does not have to be continuously changing devices to increase the total power produced.

$$Battery\ storage = \frac{installed\ Ah * time\ without\ source\ of\ energy}{depth\ of\ discharge}$$

Although the total load in *Ah per day* was estimated around 3,315 *Ah/day*, there is something that must be taken into account: this device is the most expensive one in the installation. To save some money, the total load us assume to not be connected at nighttime. Besides, on a cloudy day, the solar panel would still produce around 25 % the amount they produce on a sunny day [46].

Therefore, the total load in Ah to calculate the battery storage will be 2,000 *Ah/day*.

The total time without source of energy to calculate the required storage will be 6 hours.

Considering the previous formula [40], the designed load in *Ah* the battery must have is:

$$Load = 2{,}000\frac{Ah}{day} * 6\ hours = 2{,}000\frac{Ah}{day} * \frac{1}{4} day = 500\ Ah$$

There are some possible configurations of the bank of batteries depending on their connection: series or parallel. The required voltage is 48 *V* that is the voltage the regulator provides and the total load is not affected by the depth of discharge of the batteries since the chosen model has a depth of discharge up to 100 %. Therefore, there are different configurations of the bank of batteries that could work with those 48 *V* and 500 *Ah*, depending on the batteries' connection: series or parallel. Since the aim of this project has been stated since the beginning and is to be as inexpensive as possible for these needy people can afford it, the following configuration is the cheapest way for the batteries' connections for the considered models.

Although another option is to buy an only enormous battery and do not create a bank of them, it is quite inadvisable for several reasons. First, to divide the installation into many medium-size devices makes possible that the customer could afford to change one of them if it stopped working or that specific battery did not work as expected. Second, since the modular characteristic of the installation allows the customer to extent the system if the load increases, it is much easier for him to buy another medium-size device that to buy one great battery that he could not afford.
To illustrate the different configurations, this figure shows how the batteries can be connected:

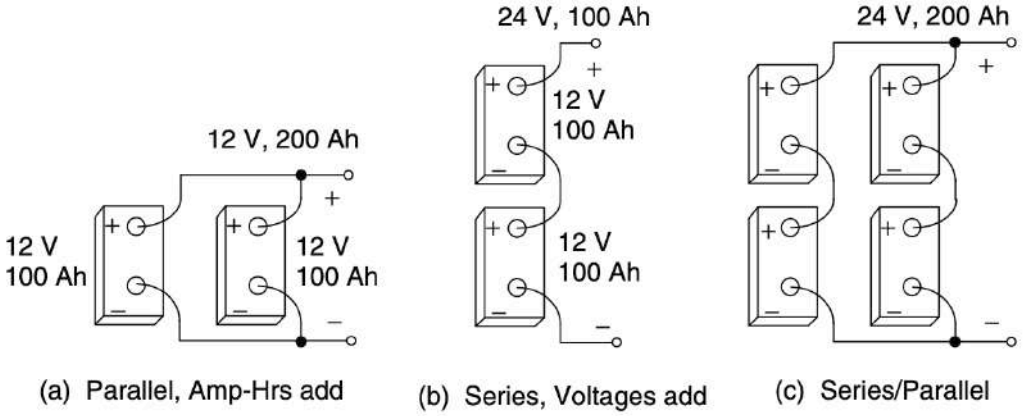

Figure 25: Different batteries configurations [40]

The chosen battery is the following: Simpliphi – 9580101 [47].

The characteristics of the selected model are:

Table 7: Battery characteristics [47]

Feature	Value
Chemistry	LFP
Voltage (*Vdc*)	51.2
Amp-hours	75
Depth of Discharge	Up to 100%
Efficiency (*MPPT*)	98%
Cost ($)	2950

The required number of batteries is 8 and the configuration is:

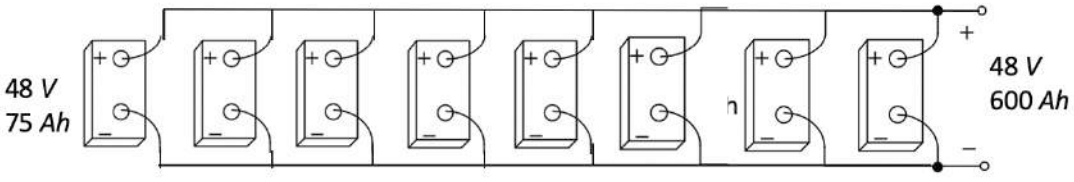

Figure 26: Batteries configuration

By this configuration, the total voltage of the batteries is 48 *V* and the *Ah*:

$$Total\ Ah = 75\ Ah * 8\ batteries = 600\ Ah$$

This load is greater than the actual one, so there is a margin for the customer to grow and to solve unexpected events.

6.6 Estimated Costs

Once the devices have been designed and chosen among the available models in the market, an approximate budget is prepared:

Table 8: Estimated costs of the installation

Component	Units	Cost per unit ($)	Total cost ($)
Solar Module	110	242.00	26,620.00
Regulator	10	269.00	2,690.00
Batteries	8	2,950.00	23,600.00
Inverter	20	145.62	2,912.40
Subtotal costs			55,822.40
Other components	Total *Wdc*	Cost per *Wdc* ($)	Total cost ($)
Structural components	78,485.00	0.1	7,848.50
Total cost of the installation			63,670.90

The structural components' costs have been estimated to obtain realistic total costs [48]. As it was mentioned in Chapter 4, the customs taxes are expected to be eliminated for this kind of project to import technological devices to improve the quality of life of needy people. This is why this tax was not considered.

6.7 Payment

The multiple ways to specify the particular details about payments in every particular case were described in Chapter 4. In this section, a system of payments to make the installation affordable is described. No benefactor will be considered, although if it were possible, it would be great to pay the upfront payment. This project will be conducted as a perpetual lease.

The total costs of the installation have been estimated at around $63,670.9. To include an extra margin for contingencies, it will be round to $65,000. This way, it will put apart $1,329.1 for any unexpected event. The total community is made of 110 people. Therefore, every person owes $590.91. If the number of households is considered, every household owes $3,250.

The area where the system would be installed is rural. There are 55 million people in the Democratic Republic of Congo living in extreme poverty. Obviously, the poorest areas in the country are rural. The upper limit for extreme poverty is $1.90. These citizens are below this limit. The average annual income in the country in 2013 was $394.25 [49]. Although this is a little out-of-time, it is assumed that the increase in salaries in the country will be equivalent to the increase in rural areas which are the poorest. Therefore, that income will be considered the average income in rural areas nowadays to make estimations. Therefore, the daily income in these areas is $1.08 a day [49].

Table 9: People working in the community

Number of members	Members working	Frequency
3	2	1
4	2	3
5	3	6
6	4	6
7	4	3
8	5	1
Total of members currently working		67

Not everybody in this cooperative works. There are many children since the average size of a household in the country is 5.5 people. So, to suppose that everybody has a salary is not realistic to make calculations. The number of members of the community currently working is 67 according to the following table.

Initially, there is an upfront payment that works as a hedge for the project. This payment is actually a fixed cost that will be paid by all the connections (household) since they are connected. Each household has to pay $250 since this fixed cost of the installation accounts for $5,000 and there are 20 connections. This fixed cost is the main reason why the users are much more secured by joining as cooperatives than producing energy on their own. Also, they have bigger power to fight unexpected circumstances such as replacement of equipment once the warranty expires. After this upfront payment is satisfied, the *PAYG* method starts and will last 16 years according to the selected monthly payments.

Each household will have to pay a monthly service fee according to the number of members connected. All households will pay a basic fee of $12 a month. If the number of members is greater than 4, that household will pay $16. If it is greater than six members, they will pay $20. This method is trying to be fair, so smaller families do not have to pay for others.

Contingencies are considered to work as an insurance in case that any device stops working and the company does not have to pay for it for any reason. Also, it may be used to pay for some extra modules to increase the size of the system. In case this money was not necessary, it could be used to start renovating the devices as well as the installation once the lease concludes.

Table 10: Estimated budget for the *PV* farm

Operation	($)
Total Cost of Installation	65000
Upfront Payment	-5000
Loan	60000
1st Year Total Payment	-3840
Amount due	56160
2nd Year Total Payment	-3840
Amount due	52320
14 Remaining Years	-53760
Contingencies	1440
Balance	0

The activation of the system will be through the line (an assumption is that this community has an operative line). An *SMS* with the activation code will be sent to the customer once the payment is received.

The resulting system makes possible to be optimistic. Considering the required specifications of the TIERS created by United Nations and explained in Chapter 2, the detailed installation would move this community up to Tier 2. According to the criteria, it could reach even a greater Tier, but the specification of expenditure is less than 5 % of total income cannot be accomplished. By the implementation of this system, they would get access to electricity much before than they otherwise due by waiting for the national grid to arrive. It means a great advance and the one and for all inclusion into the modern world.

CHAPTER 7: CONCLUSIONS

The present situation of electricity access in rural Africa makes possible to be optimistic according to the last published data. However, it is necessary to find effective ways to help the most in-need people in the continent. Although the rate of access has improved, the focus has centered on the easiest situations to solve. Massive hydro projects are being carried out according to comprehensive advice by international organizations and governments from developed countries. This kind of installations are grid-based, so big cities that account for great populations will benefit and, perhaps, the *SDG7´*s goal of total access by 2030 might be achieved in many highly-populated areas. However, smaller towns and remote villages are ignored. They latter need specific, customized solutions that make technology affordable as well as functional. The critical factor that must be considered in the formulation of a framework for rural Africa is the village inhabitants' income level. The average village person lives in extreme poverty, so how much the inhabitants can afford must be determine before a specific design for implementation. Benefactors may support the upfront payment, but no project can de based solely on their philanthropy. A customer who plans to electrify his household must recognize how valuable the project is and, through a monthly subscription, pay his debt off. The installments have to be designed so this in-need customer can continue his life and does not have to change all his habits just to simply pay his debt.

Another feature that every installation must have is modularity to allow a way its expansion in terms of both capacity and capability. This kind of project is not temporary, but a long-term solution. Therefore, all equipment must include some margin of unused capacity to address expected increase in consumption, either in the number of customers or in the demand of the existing customers. It seems unreasonable to expect these communities to be able to afford to continually redesign the initial installation. Another important consideration is to prepare the implemented plant to be eventually directly or indirectly connected to the future national grid so it can become a new player in the national electric system. To sum up, the reliance on renewable resources such as solar can provide the basis to maintain rural areas electricity to meet the required standards of sustainability. As such, it makes sense for sub-Saharan governments to exempt renewable energy projects from all taxes, including trade and sales taxes to reduce the impediments

to undertake such initiatives. Government initiatives of this type can provide appropriate incentives to deepen the penetrations of renewable resources in the future and contribute to the global trend of decarbonization without the need of giant expenditures to expand the energy infrastructure that requires a far longer long-term development to provide rural communities energy access.

Electricity access provides many additional benefits, such as clean cooking. The most recent figure on the number of people in the world without access to clean fuels to cook is 2.9 billion, which is nearly-three times the number of people without access to electricity. Those who have access to a reliable electricity source can start to cook using electrical heaters, thereby provided access to one of the cleanest ways of cooking. Such benefits imply a great advance in the health of the affected population since the cessation of the use of solid fuels, responsible for multiple kinds of pulmonary diseases such as lung cancer or pneumonia, can prevent such diseases. Therefore, progress on access to electricity opens up many additional improvement opportunities. In addition to clean cooking, healthcare uses electricity for the operation of basic facilities for lighting, information and communications technology (*ICT*), ventilation and temperature control. Such services are fundamental for nigh-time medical care provision, diagnosis, preservation of vaccines and operation of ultrasound and heart rate monitors to reduce infant mortality. Clearly, the proposed framework in this thesis is inadequate to run a hospital, but is a critically important first step to bring the modern world to these rural locations and a way to bring about progress in improvement of the rural population living standards.

Electricity access many other developments such as clean cooking. The rate of population without access to clean fuels to cook is estimated at around 2.90 billion which means three times the people without access to electricity. Those who got access to a reliable electricity source would start to cook using electrical burners, so they would get access to one of the cleanest ways of cooking out of the blue. These would mean a great advance since the usage of solid fuels is responsible for multiple kinds of pulmonary diseases such as lung cancer or pneumonia. Therefore, any particular progress in the rate of access to electricity would mean an improvement in this issue as well. Among the benefits of accessing electricity, there are many that are vital. Besides clean cooking, healthcare needs electricity for the operation of basic facilities such as lighting, information and

communications technology (*ICT*), ventilation, temperature control, etcetera. It is fundamental for nigh-time service and diagnosis, to ensure the cold chain and preserve those primordial vaccines to mitigate the severe illnesses that are affecting the continent and to operate ultrasound and heart rate monitors to reduce infant mortality. Obviously, the proposed framework in this report is not enough to run a hospital, but the first step to bring the modern world to these remote locations and a way to accelerate the process.

Education can also benefit too if a reliable source of electricity is available. Students can prolong their study sessions and lights in schools can improve the quality of classes. The use of audiovisual material and access to the internet, to name only two services, is life-changing for both students and teachers. An attendant side effect of energy access is the retention of teachers in rural areas or the possibility to import urban teachers, who may be willing to move to rural areas.

There are multiple barriers that a community solar project faces and many of them were described in this report. The access to funds is one of the main concerns and without a loan to begin the acquisition of devices, the project cannot be carried out. Another point to worry about is how isolated this kind of customer is. The roads to communicate these remote villages to greater towns may not exist. So, it might be even more difficult to find the right company to work with or to make their necessities visible to the rest of the country.

As a region, sub-Saharan Africa is growing, but changes do not arrive in local communities and, even less, in rural ones. So, this microgrid framework is a solution for the region in the meanwhile and a way to ensure the development of isolated areas. This report is a way to solve the daily situations that these in-need people have to deal with. To fight the absence of modern conditions until a long-term solution such as the national grid arrives.

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APPENDIX A: PYTHON CODE

Python code to create maps in Figure 18 and Figure 19.

```
import plotly
import chart_studio.plotly as py
import plotly.graph_objs as go
from plotly.offline import init_notebook_mode
init_notebook_mode(connected=True)

import pandas as pd
df = pd.read_csv('electrical_grid_democratic_republic_of_congo_15.csv') #read the
coordinates
del df['Electrical Distribution Grid'] # get rid of an unnecessary column

fig = go.Figure(data=go.Scattergeo(
        lon = df['lon'],
        lat = df['lat'],
        mode = 'markers', #use points
        #points' size
        marker = dict(
           size = 3,
           opacity = 0.8,
        ),
        marker_color = 'yellow', #points color
        connectgaps = True, #connect points

        ))

fig.update_layout(
        title = 'Power Grid Democratic Republic of Congo',
        geo_scope = 'africa',
        geo = dict(
        landcolor = "slategray", #map color
        lakecolor = "lightskyblue", #lake color
        #zoom
        lonaxis = dict( range = [ df.lon.min(), df.lon.max() ] ),
        lataxis = dict( range = [ df.lat.min(), df.lat.max() ] ),
        ),
    )
fig.show()
```

APPENDIX B: LIST OF ACRONYMS

AC	Alternating current
Ah	Ampere-hour
AIDS	Acquired immune deficiency syndrome
CO	Carbon monoxide
COVID	Coronavirus disease
DC	Direct current
DRC	Democratic Republic of Congo
GDP	Gross domestic product
GERD	Great Ethiopian Renaissance Dam
GSM	Global system for mobile communications
ICT	Information and communications technology
IEA	The International Energy Agency
Impp	Maximum power point intensity
km	Kilometer
kW	Kilowatt
kWh	Kilowatt-hour
LMICs	Low-and-middle-income countries
MPPT	Maximum power point tracking
MW	Megawatt
NASA	National Aeronautics and Space Administration
NGO	Non-governmental organization
PAYG	Pay as you go
PM 2.5	Fine particulate matter
PV	Photovoltaics
SDG	Sustainable development goal
SE4ALL	Sustainable Energy for All
SIM	Subscriber identity module
SMS	Short message service
SNEL	National Electricity Company
UIUC	University of Illinois at Urbana-Champaign
UN	United Nations

VIIRS	Visible Infrared Imaging Radiometer Suite
Vmpp	Maximum power point voltage
W	Watt
Wh	Watt-hour
WHO	The World Health Organization

APPENDIX C: ANALISYS OF THE SUSTAINABLE DEVELOPMENT GOALS

The seventeen Sustainable Development Goals are some urgent needs that have to be solved in a global partnership by all United Nations Member States as soon as possible. These countries signed the 2030 Agenda for Sustainable Development in 2015 where these requirements should be solved worldwide by 2030.

The rate of electrification is one of the simplest indicators of development. United Nations Sustainable Development Goal 7 (*SDG7*) focuses on the assurance of access to affordable, reliable, sustainable and modern energy to all. The poorest countries are increasing their efforts to meet the targets by 2030.

To analyze numbers, two main institutions are providing them: The World Bank and The International Energy Agency (*IEA*). Their databases have been constructed in a different way which results in a little disparity of results and then put together. On the one hand, The World Bank estimation has been developed by standardized household surveys conducted in most countries every two to three years. This system analyzes the reality of communities including off-grid access or self-supply. On the other hand, The *IEA* develops its own Energy Access Database which combines government-reported values for electrification based on utility connections.

The most recent data regarding access to electricity worldwide was gathered in 2017 by the Sustainable Energy for All (*SE4ALL)* Global Tracking Framework with the World Bank, the *IEA*, and the Energy Sector Management Assistance Program. Going through numbers and comparing 2010 data to 2017's, the evolution is evident. From an 83 % global electrification rate in 2010 to 89 % in 2018. This results in still 840 million people lacking access to electricity [11]. It means an increase of 0.8 % a year and the fortunate individuals account for 920 million. These improvements are mainly allocated in Asian countries with the largest population of affected people. As a result, 91 % of Central and Southern Asia population had access to electricity in 2017. Some particular cases have stood out like India, Bangladesh or Myanmar. Despite the advances, the share of people in Asia without access to electricity is smaller but considering the population of this continent, it is also an enormous quantity. The problem focuses on Sub-Saharan Africa

and some countries in Asia. The lowest percentage of electrification is allocated in Africa with percentages that fall below 20 %. A clear example is Chad where 8.8 % of people had access.

As it has been mentioned before, to meet these requirements, it is estimated that the Sub-Saharan governments will have to spend around 15 % of *GDP* a year on this matter [7]. These accelerated changes promoted by their governments attracting private equity let look optimistically to the future where some indicators seem to be hopeful. Child mortality rates are declining as well as life-expectancy does not stop increasing and the middle-class is rising worldwide.

Another great problem to solve is clean cooking. The rate of population without access to clean fuels to cook has never stopped increasing since the population growth is outpacing the increase in access. Around 2.90 billion people were estimated to cook using polluting fuels in 2017. This is a section of the Sustainable Development Goal Number 7 and it is quite associated with electricity, so any particular advance in the rate of access to electricity would mean an improvement in this issue as well. Not clean cooking practices are those which utilize polluting fuels such as wood, charcoal or kerosene. On the other hand, natural gas, liquified petroleum gas, biogas or electricity are considered clean cooking. Around 2.90 billion people were estimated to live using non-clean cooking fuels in 2017 [11]. According to the University of Oxford, the usage of solid fuels for cooking is responsible for multiple kinds of pulmonary diseases such as lung cancer or pneumonia. In 2010, the percentage of the population using this sort of fuel to cook was around 80 % in Africa [17]. Electricity would mean an enormous advance in clean cooking and less diseases. This is one of the main goals that a reliable electric system brings and a microgrid could also allow the possibility to purify water as well as its extraction from wells in places where its extraction was not feasible. In the DRC Project, four water pumps are included in the budget as a way to show the importance of this kind of element in this kind of isolated installations.

The proposed framework in this project is a way to provide an implementable and sustainable mechanism to involve the village communities to improve their lives in a very meaningful and scalable way through the establishment of a community solar system on a microgrid and which can be financed effectively.