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POLICY FRAMEWORK FOR THE PROMOTION OF DIGITAL TECHNOLOGY IN MINI-GRID SECTOR IN SUB-SAHARAN AFRICA. CASE OF BLOCKCHAIN TECHNOLOGY

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POLICY FRAMEWORK FOR THE PROMOTION OF DIGITAL TECHNOLOGY IN MINI-GRID SECTOR IN SUB-SAHARAN AFRICA. CASE OF BLOCKCHAIN TECHNOLOGY

A thesis submitted to the Pan African University Institute of Water and Energy Sciences (including Climate Change) in partial fulfilment of the requirements for the degree of Master of Science in Energy (Policy option).

By

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DEDICATION

I dedicate this work to my parents without whom none of my success would be possible.

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BIOGRAPHICAL SKETCH

Mirana Njakatiana Andriarisoa is from Madagascar, holding a Master I in Economics from the University of Antananarivo and was pursuing Master in Energy policy at the Pan African University for Water and Energy Sciences in Algeria. She has been very active during her journey at PAUWES where she was the leader of the Pan African University Climate Change and Gender Club representing the club in different national and international conferences such as the United Nations Youth Climate Summit in New-York in 2019. She is an Ambassador at the African Youth Climate Hub as well. Highly interested in the role of digital technology in the energy sector, Mirana is also one of the focal points of the PAUWES Digitalization Lab. Her aspiration is to promote green energy for rural electrification in Madagascar and in Sub Saharan Africa at large in order to contribute in building the Africa we want.

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ABBREVIATIONS AND ACRONYMS

ACM	Association for Computing Machinery
AI	Artificial Intelligence
DES	Distributed Energy System
DRE	Distributed Renewable Energy
DSM	Demand Side Management
DSO	Distribution System Operators
EAC	East African Community
EMTS	Energy Management Trading System
EPEA	Energy and Petroleum Energy Authority
ESMAP	Energy Sector Management Assistance Program
FIT	Feed-In Tariff
GSMA	Global System for Mobile Communications Association
KNES	Kenya National Electrification Strategy
LCOE	Levelized Cost of Energy
ICT	Information and Communications Technology
IEA	International Energy Agency
IoE	Internet of Energy
IoT	Internet of Things
IRENA	International Renewable Energy Agency
ITU	International Telecommunication Union
P2P	Peer-to-peer
PPA	Power Purchase Agreement
RED+	Renewable Energy Decentralized +
SADEC	Southern Africa Development Community
SG	Smart Grid
SHS	Solar Home System
SWOT	Strength Weakness Opportunities and Threats Analysis
SSA	Sub Saharan Africa
TAM	Tariff Application Model
VAT	Value Added Tax
4IR	Fourth Industrial Revolution

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ABSTRACT

The seventh United Nations Development Goals consists in ensuring access to affordable, reliable, sustainable and modern energy for all. However, currently, only 44% of the population in Sub-Saharan Africa has access to electricity and 573 million inhabitants in the region are living without this basic need, most importantly those living in rural area. In order to address those challenges, decentralized energy systems harnessed from local available energy resources has been identified as one of the most promising approach. However, the low purchasing power of the population in rural areas makes difficult the investment in mini-grid sector. Therefore, the present research aims at analysing in what extent the study and improvement in the policy and regulation around digital technology and mini-grid sector can promote the implementation of peer-to-peer energy trading enhanced by blockchain in Sub-Saharan Africa? The thesis addressed four specific objectives, first to review the current situation on digital technology, blockchain and Peer-to-peer energy trading in Sub-Saharan Africa with conducting a SWOT analysis of their implementation status in the region. Secondly, result of diagnostic assessment of policy and regulation framework in relation to blockchain and peer-to-peer market in SSA is presented, then conceptual modelling for policy and regulations around blockchain and P2P energy trading in SSA is proposed. The work presents the validation of the solution proposed through a practical study in Kenya which is more advanced in terms of digital technology and presents favorable context to launch this idea in Africa. The thesis presents also recommendations and future outlook for further research.

1. INTRODUCTION

1.1. Background of the study and problem statement

Ensuring access to affordable, reliable, sustainable and modern energy for all is stated as the 7th United Nations Sustainable Development Goals which is intended to be reached in 2030 (United Nations, 2015). In line with that, the African Union Agenda 2063 claims a prosperous Africa based on inclusive growth and Sustainable development (African Union Commission, 2015) and promoting the energy sector is one of the pillars of achieving that goal. In recent years, some considerable progress has been noticed in the sector of energy. According to the SDG 7 tracker 2020, the global number of populations without access to electricity decreased from 1.2 billion in 2010 to about 789 million in 2018. The global electrification has been accelerated in the recent years since in average, 136 million people get electrified annually between 2016 and 2018 whereas it was 127 million between 2010 to 2016. Hence, the global electricity access rate reached 90% in 2018 (IEA et al., 2020). However, high disparity is observed among the different region in the world. Although pronounced progress was noticed in some countries like Bangladesh, India, Kenya, and Myanmar, the region of Sub-Saharan Africa is still very far behind in terms of access to modern energy since near 70% of the global population without access to electricity in the world are located in Sub Saharan Africa. Actually, 548 million people, which is 47% of the population in the region lack access to electricity in 2018. Burundi, Chad, Malawi, Democratic Republic of Congo and Niger were the countries having the lowest electrification rates. In average, an annual increase of 26 million people gains access to electricity in Sub Saharan Africa since 2010 to 2018. However, with considering the population growth, the number of people lacking access remains almost stable.

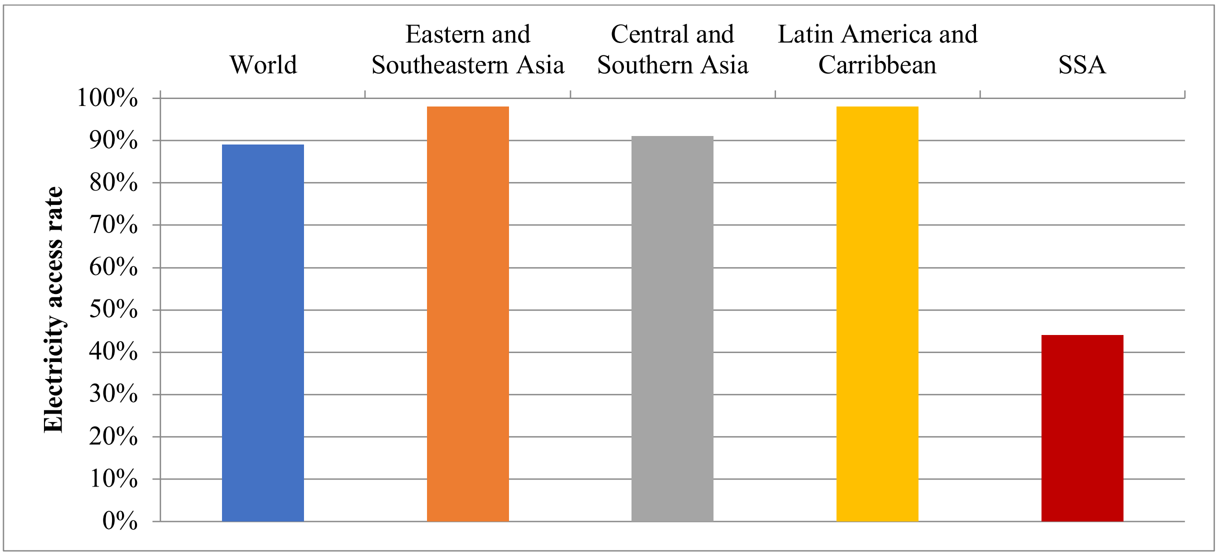


Figure 1: Regional electricity access rate comparison between developing regions (IEA et al., 2019)

Furthermore, high disparity also occurs between urban and rural situation. 85% (668 million people) of the population without access to electricity are from rural area (IEA et al., 2020). Globally, the increase of electrification is more rapid in rural areas than in urban. However, in Sub-Saharan Africa, greater attention had been made for urban area and the incremental rural electrification was only two thirds of the urban rate. The lack of investment in rural electrification is mainly due to two reasons: first, the lack of financial resources allocated to the sector and second is the technical feasibility since many African villages are in remote area, far from the national grid, and also, they are highly dispersed which make difficult the investment (Trotter, 2016).

In order to address this challenge, decentralized energy systems harnessed from local available energy resources has been identified as one of the most promising approach. Therefore, many researchers demonstrated that the mini-grid system is one of the most effective solutions since it can play an important role in meeting the households' electricity demand, and lead to productive use of electricity. It is then expected that renewable energy mini-grid will play an important role in improving electrification and a study by the International Energy Agency asserted that between 2016 and 2030, 60% of new access connection will be powered by renewable energy sources and approximately 40% of it will be through mini-grid (IEA, 2017b). For Sub-Saharan Africa region, by 2040, mini-grid is expected to serve up to 140 million rural people (IEA, 2014).

However, the implementation of mini-grid systems in the region is facing many challenges such as the lack of sustainability of the system due to the low purchasing power of the population who are mainly farmers and have issues in paying the electricity services (EEP Africa, 2018). In order to respond to that issue, the emergence of new digital technologies like artificial intelligence (AI), Internet of things (IoT) and particularly blockchains can have a very promising considerable impact in energy access finance since it can lead to the creation of new innovative marketplaces more transparent, secured and tamper resistant (Ndung'u & Signé, 2020). Besides, the development of those various smart energy has allowed the promotion of effective management of the energy demand. At the heart of this innovative energy management system is the Peer-to-peer energy sharing concept which is a decentralized electricity trade between prosumers and consumers (Alladi, 2019). The International Renewable Energy Agency emphasized that trading based on P2P models makes renewable energy more accessible, empowers consumers and allow them to make better use of their energy resources (IRENA, 2020). In the recent years, the P2P trading platforms has been developed considerably in the world and many projects has already been implemented such as the Brooklyn Microgrid in the United States, the Centrica plc in the United Kingdom, the Lumenaza in Germany and the SOLshare in Bangladesh (IRENA, 2020). Those projects have brought considerable benefits for the energy management of the communities. Particularly for Solshare which was created in 2014, their P2P energy trading system has brought affordable solar electricity to many households in Bangladesh. They demonstrated that the excess of energy generated by 10 households having solar-home-systems can ensure energy supply to 3 other households without electricity while empowering the communities. Therefore, promoting peer-to-peer energy trading can be very promising for electrification in Sub-Saharan Africa.

Nevertheless, the implementation of these new technologies in Sub-Saharan is very limited despite their great potential that can be exploited. One of the major barriers of its implementation is the lack of adequate policy and regulation framework (Klein, 2019).

1.2. Significance of the study

Over the past few decades, technology and innovation have been affecting all sectors of the economy. For the energy sector, the use of data generated by network sensors has grown so fast and has allowed system monitoring and improves the supply to better match the customer behaviour. That led to new business models for the energy sector, particularly for off-grid alternatives (McKibben, 2017). A report from the World Economic Forum back in 2017 asserted as well that the grid is becoming more and more digitized with the development of smart meters, connected devices and grid sensors which allow the customer to have a real-time information on energy supply and demand across the system as well as improve the network management efficiency and optimize the capital allocation. That would lead to a huge benefit and the same report projected that adoption of new “grid edge” technology could produce more than 2.4 trillion USD of value creation for society and the industry over the next 10 years (WEF, 2017).

Although these grid edge technologies were initially occurring mostly in developed countries, African countries are currently getting more and more interest in it due particularly to its rapid falling costs and the fact that it can be a sustainable solution for electrification access.

Policies are a prerequisite for other actions to follow. However, digital technologies are not yet adequately integrated in the energy policy of Sub Saharan African countries. Since the technology is changing, it requires dynamic thinking (Blimpo & Cosgrove-Davies, 2019). The latest SDG 7 tracker report stated the importance of updating the policy framework in order to embrace and support innovation such as off-grid solutions and innovative business model (IEA et al., 2020).

Therefore, the findings of this study will help policy makers in Africa to acknowledge the importance of digital technology for the energy sector and to include that point in their policy and government energy strategies.

1.3. Research question

Peer-to-peer energy trading model based on blockchain is revolutionizing the energy sector and it presents a great potential for developing the electricity sector in Africa. Establishing clear and consistent regulations is one of the key factors to enable deployment of that innovative technology (IRENA, 2020). Therefore, the present research is intended to analyse:

In what extent the study and improvement in the policy and regulation around digital technology and mini-grid sector can promote the implementation of peer-to-peer energy trading enhanced by blockchain in Sub-Saharan Africa?

The research question is subdivided into the following sub research question:

1- How is the current situation on digital technology and particularly blockchain in energy sector in Sub-Saharan Africa?
2- How is the current state of the policy and regulation related to digital technology and blockchain in the energy sector in Sub-Saharan Africa?
3- How should be the policy and regulation framework necessary for the implementation of peer-to-peer energy trading using blockchain in SSA?
4- How will be the proposed framework in a concrete case study of a company using P2P energy trading in Africa?

1.4. General objective

The general objective of the work is to assess the current situation of the digital technology situation in Sub Saharan Africa and to propose a policy and regulation framework required for the introduction and promotion of smart peer-to-peer energy trading enhanced by blockchain technology in the mini-grid sector in SSA.

1.5. Specific objectives

In the frame of this study, four specific objectives have been identified, which are:

- To conduct an overall assessment of the current situation in digital technology and Blockchain in energy sector in Sub-Saharan Africa,
- To review and conduct a diagnostic assessment of the current policy and regulation related to digital technology in energy and blockchain in SSA countries
- To propose a conceptual modelling of the policy and regulation framework necessary for the implementation of peer-to-peer energy trading using blockchain in SSA
- To validate the solution through a case study: the case of Rehub company - Kenya

2. GENERAL CONCEPTS

2.1. Renewable energy mini-grid

Renewable mini-grid is a system using technology of harnessing energy from different sources like hydro, solar, wind, biomass or hybrid sources. A system is considered as mini-grid when its capacity ranges from less than 1kW to up to 10 MW (IRENA, 2016) A mini-grid may be autonomous, but it may be interconnected to the main grid as well. Mini-grids are particularly very suitable for rural electrification, and it can be interconnected to a larger grid in the future when it becomes available.

Off-grid renewable energy has increased largely in the last recent years and has served globally more than 130 millions of populations in 2016 and it is predominated by the solar sources. Particularly, Africa has emerged a dynamic, fast-moving hub for off-grid renewables. Rapid increase of off-grid solutions has particularly been noticed in the region since 2012 as it is shown in the figure below. While off-grid had served only 2 million people in 2011, it reached to over 53 million in 2016 (IRENA, 2018a).

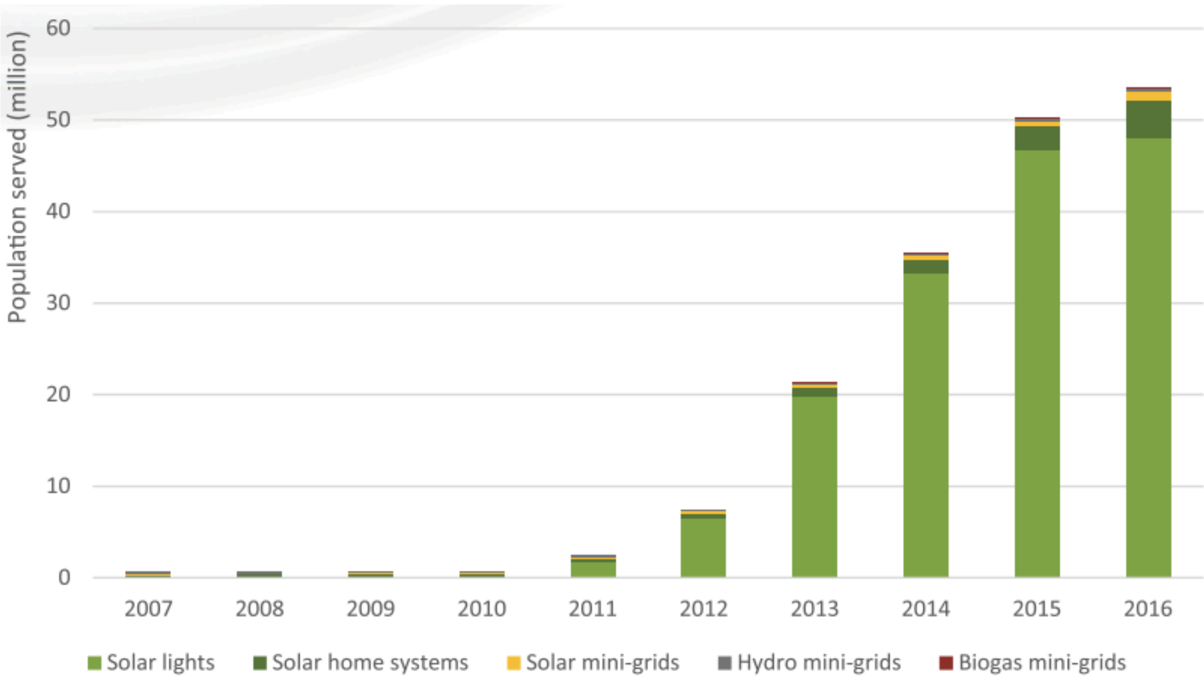


Figure 2: Evolution of the number of populations served by off-grid renewable energy solution in Africa (IRENA, 2018a)

2.2. Energy system structure: centralized, decentralized and distributed

Over the recent few years, a considerable growth in small-scale distributed energy has been noticed particularly in the household level. It embraces innovative generation system, energy storage, inverters, electric vehicles and control loads. It is necessary first to define briefly the three different energy system structures: centralized, decentralized and distributed.

The traditional energy system is the centralized one which can be defined as large scale energy production units delivering energy through a large distribution network which is most of the time far from the end-user. However, decentralized energy systems consist in a small-scale energy generation delivering energy to local customers. These production units can be either a stand-alone or connected to local other producers and users in order to share the surplus which is called locally decentralized energy network. The distributed energy systems which are mostly from renewables have similarities with the decentralized one. It is a small-scale energy generation unit at or close to the point of use where the users are the prosumers which can be individuals, small businesses or local community. The production in a distributed renewable energy (DRE) can be a stand-alone or connected to a local network to share the surplus of energy, where we talk about locally distributed energy networks. It can be connected to nearby similar networks as well (Vezzoli et al., 2018).

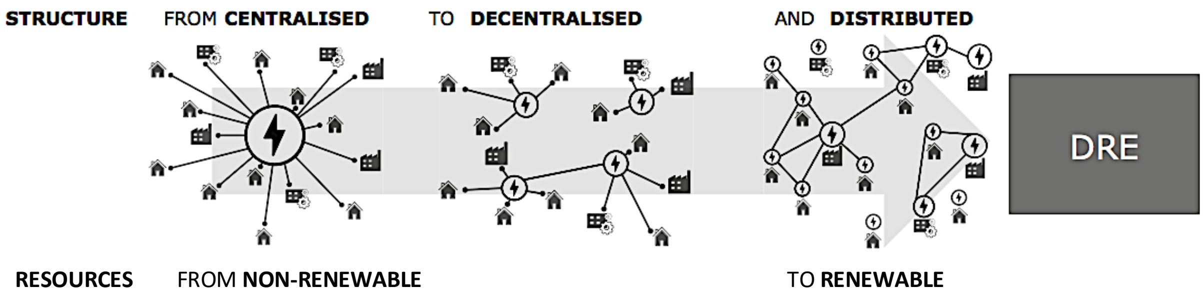


Figure 3: Shift from non-renewable and centralized to renewable and distributed energy system (Vezzoli et al., 2018)

The existence of prosumers is at the heart of the modern decentralized energy system. The raise of energy prosumerism is mainly the result of the recent advances in electricity generation and storage technologies as well as smart metering. That is favoured by the declined cost of small renewable energy system and appropriate regulation. The solar energy from households PV is at the heart of the prosumerism system. For instance, Morgen Peck and David Wagman estimated in their research that the global market of rooftop solar photovoltaic (PV) panels would grow by 11% over the next six years, and residential storage systems will increase from 95 MW in 2016 to 3700 MW by 2025 (Peck & Wagman, 2017).

In the traditional energy system, there are basically the utilities who produce electricity and the users or consumers who buy and use the electricity distributed. However, recently, in the modern decentralized energy distribution system, a new concept was born: the prosumers. The term “Prosumers” was originally coined by Alvin Toffler in his book The Third Wave, as a mixture of the word “producer” and “consumer”, intended for the active role that consumers can play in the production process (Toffler, 1980) . In the context of energy market, Yael Parag and Benjamin K. Sovacool gave a simple definition of prosumers as agents that both consume and produce energy (Parag & Sovacool, 2016). Their article entitled “energy market design for the prosumer era” gives a clear understanding of the mechanism of prosumerism. The table below gives a summarized comparison between conventional grid consumers and smart prosumers.

Table 1. Comparing conventional grid consumer and smart prosumers (Parag & Sovacool, 2016)

Dimension	Conventional grid consumer	Smart prosumers
Resilience and self-healing	Operators respond to prevent further damage, focus is on reaction and protection of assets following system faults	Consumers or their devices can automatically detect and respond to actual and emerging transmission and distribution problems; focus is on prevention
Information and consumer involvement	Consumers are uninformed and non-participative in the power system	Consumers are informed, involved and active.
Quality of energy services	Produced in bulk, typically through centralized supply	More modular and tailored to specific end uses, which can vary in quality
Diversification	Relies on large centralized generating units with little opportunities for energy storage	Encourages large numbers of distributed generation deployed to complement decentralized storage options, such as electric vehicles, with more focus on access and interconnection to renewables and V2G systems

Competitive markets	Limited wholesale markets still working to find the best operating models, not well suited to handling congestion or integrating with each other	More efficient wholesale market operations in place with integrated reliability coordinators and minimal transmission congestion and constraints
Optimization and efficiency	Limited integration of partial operational data and time-based maintenance	Greatly expanded sensing and measurement of grid conditions; technologies deeply integrated with asset management processes and condition-based maintenance

The same research identified three main potential prosumer market models which are: the prosumer to grid, the organized prosumer groups and the Peer-to-peer energy trading. The chart below gives a brief summary of those 3 models.

Table 2: Summary of the three prosumer market models (Parag & Sovacool, 2016)

Role	Function	Profit optimization orientation	Relationship with conventional agents	Main challenges
Peer-to-peer				
Facilitate the arrangement of transactions between two or more agents	Distribute presuming services between agents	Individual agent	Prosumers compete with utilities over clients	- Cost of building and maintaining a highly distributed and diverse distribution network; - Liability and accountability assurance for delivery of safe and high-quality energy services.
Prosumer-to-grid				
Aggregate of capture the value of presuming energy services. Agents may sell	Provide high quality energy services by optimizing the integrating of numerous	Individual agent, grid The local / main grid	Prosumers act mostly as partners that provide various services to the grid. At times, they can become a competitor for	Integrating and optimizing large amounts of data provided by numerous presuming agents

presumption services in local microgrid or to the main grid.	individual prosumers into the system.		generation	
Organized prosumer groups				
Serve the interests of a group of prosumers	Provide high-quality energy services by optimizing the integration of limited numbers of organized prosumer groups into the system	-Agent groups, grid -The local/ main grid	Prosumers act mostly as partners that provide various services to the grid. At times, they can become a competitor for generation.	-Integrating and optimizing large amounts of data provided by presuming groups. -Complexity and high transaction costs of managing, arranging, optimizing and balancing agent relations within the group.

All these prosumer market models are distributed energy market relying on smart grid. Ghatikar et al. developed in 2016 a modelling in distributed energy systems integration and demand optimization for autonomous operations and electric grid transactions (Ghatikar et al., 2016). The paper explains a cost-effective solution to the distributed energy systems integration and communication challenges by exploring communication technologies and information model system integration and interoperability. This solution suggests the use of dynamic-pricing notifications as well as autonomous operations within various domains of the smart grid energy system. That leads to optimization models for resource planning.

Those three prosumer market models are all interesting and are implemented depending on the context of the region. However, the present research will focus mainly on Peer-to-peer energy trading.

2.3. Peer-to-peer energy trading

In recent years, the development of various smart energy services and demand response management has allowed the promotion of effective management of the energy demand.

Particularly, various signal processing technics such as Artificial intelligence and Machine learning has allowed the participation of customers in the electricity management. The development of peer-to-peer energy trading is one of the innovative energy management system.

According to the International Renewable Energy Agency, « Peer-to-peer (P2P) electricity trading is a business model, based on an interconnected platform, that serves as an online marketplace where consumers and producers meet to trade electricity directly, without the need for an intermediary”. Its key enabling factors are: distributed renewable energy resources, digitalization and conducive regulatory framework (IRENA, 2020).

2.3.1. Mechanism of P2P energy trading

After the feed-in-tariff, Peer-to-peer energy trading is the next generation energy management technique for smart grid. Peer-to-peer energy trading is a bottom-up energy market structure where the prosumers are connected directly with each other. It is a decentralized, autonomous and flexible energy trading network. In energy trading, compared to existing FiT (Feed-in Tariff) schemes, the direct involvement of the users with one another and with the grid makes P2P systems unique (Tushar et al., 2018).

Chenghua Zhang et al. performed a study on peer-to-peer energy trading in Microgrid in which they demonstrated that not only do direct transaction practice leads to promotion of use of renewable energy and reduction of transmission loss, but also it can generate revenues for producers and prosumers and save money for end users (Zhang et al., 2018). P2P energy trading also constitutes an incentive for investment in renewable energy and ensures the balance of supply and demand.

Below is a simple schematic representation of an exemplary microgrid market scenario of residential consumers and prosumers using photovoltaic system.

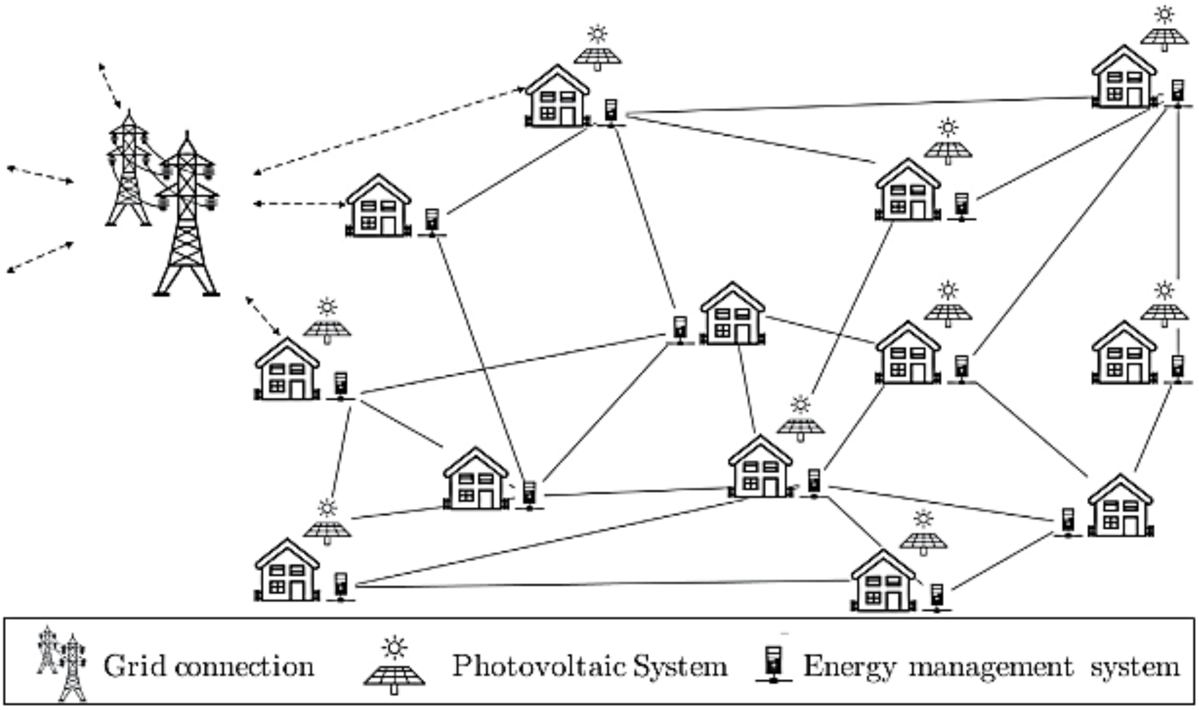


Figure 4 : Schematic representation of a P2P microgrid market (Mengelkamp et al., 2017)

2.3.2. The network elements in P2P energy trading: the virtual and physical layers

A peer-to-peer energy network is a distributed network architecture in which the participants share a part of their own energy resources with one another. Tushar et al. shows that a P2P network can be divided into two layers: a virtual layer and a physical layer (Tushar et al., 2020).

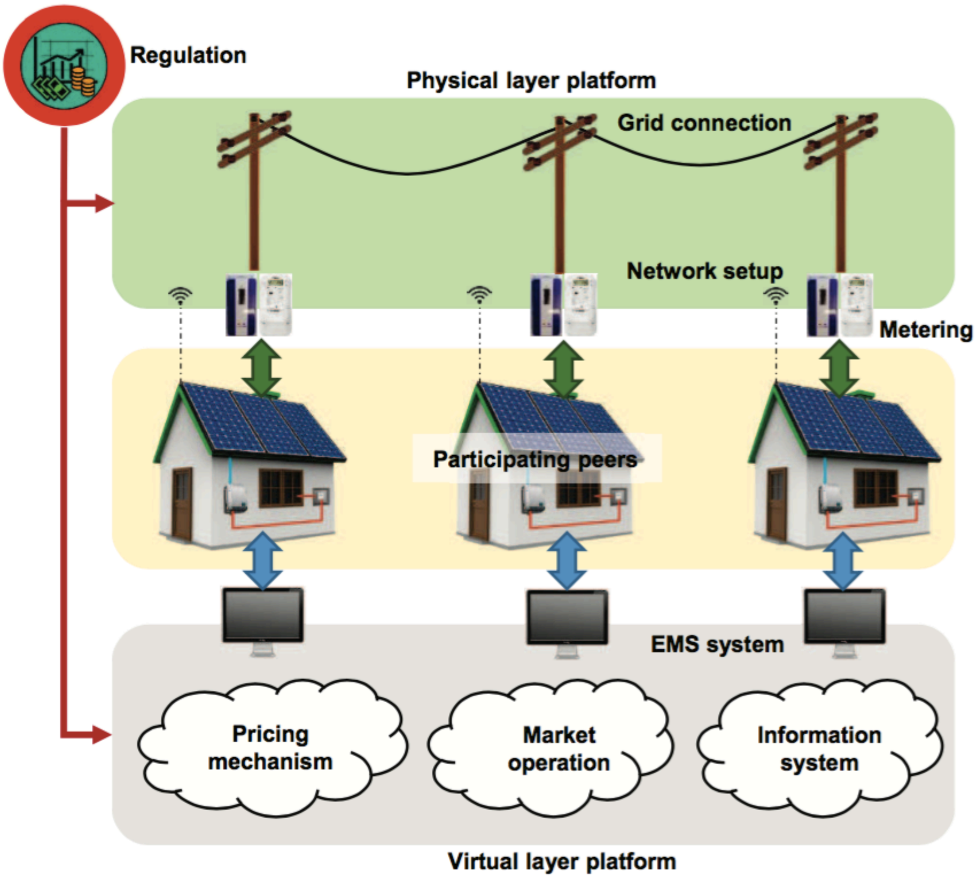


Figure 5: An illustration of the virtual and physical layers in the P2P network (Tushar et al., 2020)

- The virtual layer of a P2P energy network

The virtual layers are comprised of the information system, the market operation, the pricing mechanism and the energy management system. Basically, the virtual layer ensures a secured connection for the prosumers and consumers to decide on their energy trading parameters where all participants have equal access and the transfer of all kind of information takes place there. The market mechanism consisting in the buying and selling orders is also managed in this layer and upon successful matching of the orders, financial transactions are carried out.

- The physical layer

On the other hand, the physical layer is mainly the physical network that shares the electricity from the producers or sellers to the buyers after the financial transaction are settle in the virtual layer. This physical network can be either the traditional distributed-grid network managed by the independent system operator, or a new separate microgrid linked to the traditional grid.

The table below summarizes the different elements in each layer.

Table 3: The different elements in the P2P energy network (Tushar et al., 2020)

Elements	**Details**
	VIRTUAL LAYER
Information system	A high-performing and secured information system which ensures: - Communication between all market participants - Integration and equal access of the participants within a market platform - Monitoring of the market operation - Network security and reliability through putting restriction on participants' decision Blockchain based smart contract and consortium blockchain are examples of such information system.
Market operation	The market operation is facilitated by the information system. Its objective is to ensure an efficient energy trading process within the participants by matching the sell and buy orders in near real-time granularity. It consists of: - Market allocation - Payment rules - Clear bidding format
Pricing mechanism	It is considered as part of the market operation and is supposed to efficiently balancing between the energy supply and demand. The price reflects the amount of surplus of energy within the network. The more energy surplus is available in the network, the lower is the price. The pricing mechanism used in P2P energy trading is different from the traditional electricity market in which there is a heavy proportion of electricity surcharges and taxes. However, since the marginal cost of renewable energy production is very low, the prosumers are able to get more profits when setting the prices of their energies.
Energy management	The P2P trading has a particular bidding mechanism where the EMS of a prosumer ensure the supply of energy. The EMS has access to real-time

system	supply and demand information of the prosumer via the transactive smart meter which permit to have the generation and consumption profile of the prosumer and hence determines the bidding strategy. The EMS of the prosumer determines when to buy energy in the microgrid, depending on its energy generation and demand as well as the price.
PHYSICAL LAYER	
Grid connection	P2P trading can be implemented for both grid-connected and islanded microgrid system. For the grid-connected system, smart meters are installed in the connection points to the main grid and it allows to evaluate the performance of the P2P network such as the energy and cost saving. For islanded microgrids, it is important to make sure that the participants are able to generate enough energy to ensure security and reliability.
Metering	In order to be part of the P2P network, each prosumer should have an adequate metering infrastructure. In addition to the traditional meter, a transactive meter is required. It is necessary to determine whether to participate in the P2P market based on the information regarding the market condition: price, total demand, total supply and network conditions. Besides, it can communicate with other prosumers through an appropriate communication protocol.
Communication infrastructure	It is required to allow the exchange of information within the network. There is multiple types of communication architecture. The choice of communication architecture follows the performance requirements established by the IEEE 1547.3-2007 regarding the integration of DER which include latency, throughput, reliability, and security.
OTHER ELEMENTS	
Market participants	A sufficient number of participants is necessary to have a P2P network and some of the participants should be able to produce energy. The purpose of P2P energy trading as well as the form of energy traded has to be clearly defined.
Regulation	The regulation and policy govern the success of P2P trading. It is the rule set by the country's government regarding the market design which can

	be allowed, the question of taxes and fees, the relation between the P2P market within the existing market and the supply system. The government has the power to support or discourage the P2P energy markets depending on the objectives that the country intends to achieve and the context of the country.

2.4. Blockchain technology

Blockchain is a decentralized database system consisting in linking together records in secure blocks of information. Its name was introduced in 2008 by a persons or group of persons having as pseudonym: Satoshi Nakamoto. It is originally from the two words “block” and “chain” where transactions are grouped in blocks as a data package and also chained sequentially with each block linked to the previous one (Nakamoto, 2008).

It provides an open and decentralized database for any transaction involving value either money, goods, property, works or others by using math and cryptography. In 2015, the doyen of Silicon Valley’s capitalists Marc Andreessen (Fung, 2014) claimed that the blockchain distributed consensus model is the most important invention since the discovery of internet.

Blockchain technologies have many advantages. First, it is accessible as anyone using internet can have access and use blockchain based transactions. It is also transparent since all the transactions or digital events are executed and shared among participating parties. The records of every single transaction are authentic since it is verified by the entire community. Information can never be erased once it is entered in the system. Moreover, it will help to reduce significantly financial frauds since each transaction is recorded on a public and distributed ledger which is accessible to anyone having internet connection.

Another advantage of blockchain is also its simplicity, rapidity and low cost. In usual business, there are usually third parties involved in transactions which are mainly assured by banks in the case of money transfer or payment. With blockchains, this third party is no longer necessary, therefore it avoids the delay in time and also it could reduce dramatically the cost of transactions and, if adopted widely reshape the economy (Iansiti & Lakhani, 2017).

If blockchain technologies are promoted, digital record and signature would be applied in every process, every task, and every payment. All contracts would be inserted in digital code and stored in transparent and shared database where they cannot be removed, tampered or revised. With blockchains, individuals and organizations would easily and freely transact and interact with one another. Blockchain technologies are applied in many scenarios, for instance financial services, sharing economy, credit investigation, internet of things etc.

Bitcoin is intrinsically tied to blockchain technology. In early 2000, the Nobel prize economist winner Milton Friedman stated that: "The one thing that's missing, but that will soon be invented, is a reliable e-cash" (Dearing, 2017). Eight years later the Bitcoin was invented by an unknown person or group of people using the pseudonym Satoshi Nakamoto. In his white paper, he defined bitcoin as "a Peer-to-Peer Electronic cash system" which allows online payment to be sent directly from one party to another without passing through any financial institution (Nakamoto, 2008). Bitcoin is a cryptocurrency, a decentralized digital currency which is not issued by central bank or any administration. With peer-to-peer bitcoin network, it can be sent from user to another without any intermediaries. On June 2019, 17,754,100 Bitcoins has been in circulation and the supply limit is 21,000,000. Bitcoins are created through a process called mining when people verifying transactions get some percentage of bitcoins as rewards. Apart from bitcoins, there are many other cryptocurrencies. The most common cryptocurrency global brands nowadays include Bitcoin, Litecoin, XRP, Dash, Lisk and Monero, Namecoin and Peercoin.

3. LITERATURE REVIEW

3.1. Features of digital technologies and blockchain in the energy sector

3.1.1. Application areas of digital technologies in the mini-grid sector

Digital technology is important for mini-grid sector. As shown in the figure 6, the application of digital technology can provide various ranges of added value for mini-grid. The IASS study divided it into two levels of application where the first concerns technical functionalities and system balancing including generation and storage, distribution and control and demand side management. The second level is about the application of digital technology in the mini-grid value chain including finance, planning and design, operation and maintenance, customer management and productive use of energy from mini-grids. Peer-to-peer energy sharing is among the features related to customer management.

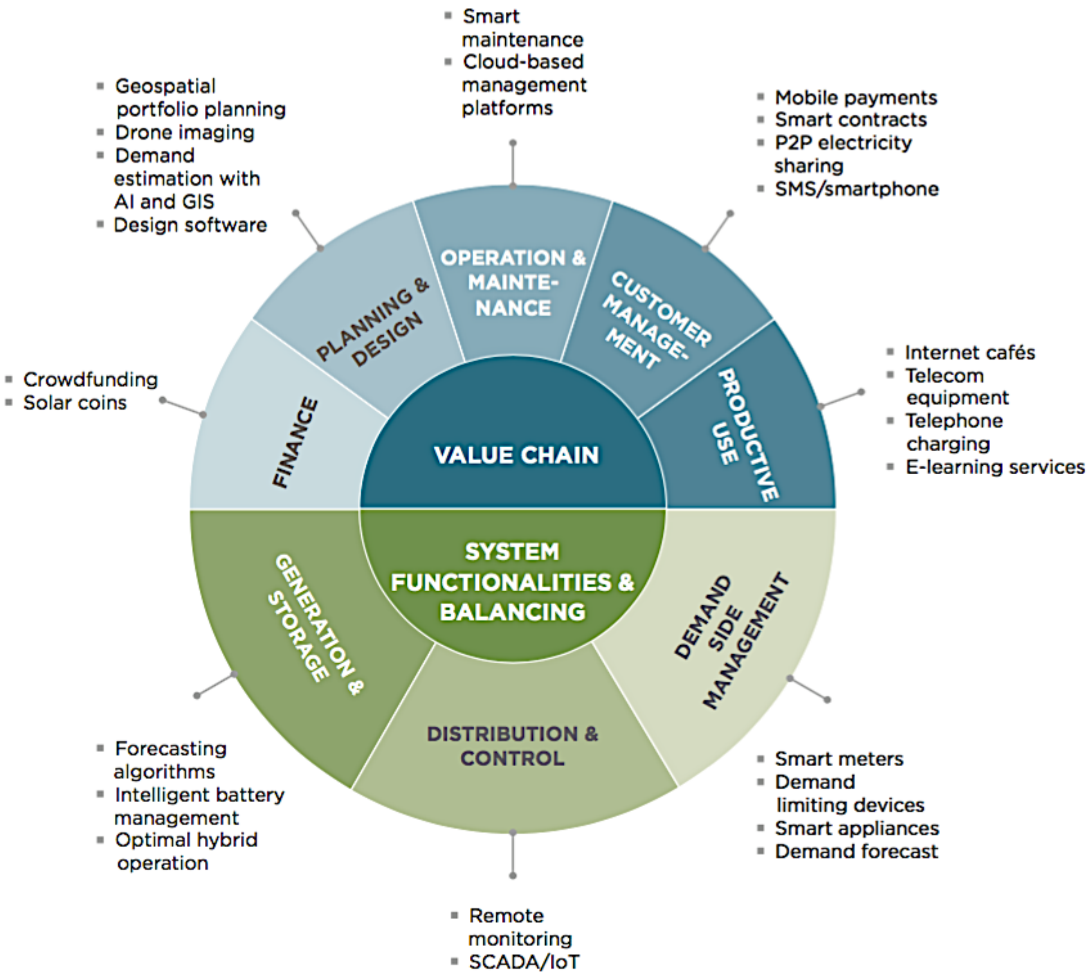


Figure 6: Application areas of digital technologies in the mini-grid sector (Fritzsche et al., 2019)

On other side, the International Energy Agency in their report on Digitalization and Energy released in 2017 emphasized the impact of digitalization on energy demand in the three different categories: transport, buildings and industry as well as the impact of digitalization on oil and gas, coal, and power supply. The report highlighted as well that digitalization is transforming the way the electricity system functions and talks about smart demand response, distributed generation and the concept of prosumers (IEA, 2017a).

3.1.2. Blockchain market opportunities in the renewable energy sector

Due mainly to continuous increase of demand and the intermittency of renewable energy sources, an efficient management of energy demand and supply is a big challenge for mini grid systems. That is why innovation in the energy sector are highly necessary and Blockchain is one of the most promising solution to solve those issues. In the recent years, different applications of blockchain have been continuously developed and three different stages of evolution can be noticed in the field of smart grids:

- Blockchain 1.0 which is based on digital currency systems like Bitcoin.
- Blockchain 2.0 includes smart contract as well as other digital assets that support applications within the currency system and the blockchain.
- Blockchain 3.0 incorporates infrastructures such as mobile communications and internet. The development of blockchains can lead to an improvement of the efficiency of doing business with facilitating the documentations, payments and energy exchange allowing consumer to develop their market. Furthermore, the absence of a third party make the cost of energy much lower than the usual utility system (Wu & Tran, 2018).

The fourth industrial revolution with the development of IoT, AI, Big data along with Blockchain technology has brought considerable impacts to the energy sector and has permitted the development of the mechanisms of smart grids. Alladi et al. has recapitulated the applications of blockchain in smart grid sector which are: P2P energy trading, the energy trade between electric vehicles, Security and privacy-preserving techniques, Power generation and distribution, Secure equipment maintenance. Those different applications are summarized in the chart below:

Table 4: Blockchain applications in the smart grid (Alladi et al., 2019)

Application	Problem Addressed	Preferred Blockchain Architecture	Sample Block Content	Technologies Used
P2P energy trading	Decentralized electricity trade between prosumers and consumers, promotion of renewable energy harvesting	Consortium blockchain	Transaction ID, consumer meter ID, amount of energy requested and energy granted, a digital signature of the seller and the processing node	Smart contracts, virtual currency, credit-based e-wallet
Energy trade between EVs	Buying and selling of surplus energy between EVs, privacy-preserving of EVs	Consortium blockchain	Transaction ID, EV's meter ID, charged energy, a digital signature of the charging station and the processing node	Smart contracts, energy coins
Security and privacy-preserving techniques	To protect the application usage pattern and the privacy information of users	Private blockchain	Transaction ID, the energy transferred, a digital signature of the seller and the LAGs	Bloom Filter, data aggregation, authentication techniques
Power generation and distribution	Protection from cyber attacks, incorporation of abnormality control measures	Consortium blockchain	Time of measurement, measurement of frequency, voltage and current, switch states	Smart contract, dApps, remote control of distortion using power electronics devices
Secure equipment maintenance	Platform for interaction between vendor and client for equipment diagnosis and privacy preservation	Consortium blockchain	Device ID, mode of maintenance, service files and credits, transaction value	Smart contracts, user interaction using smart phone app

Other researches such as the PwC Global Fintech Report in 2016 and the IRENA innovation landscape brief on blockchain have also explained the opportunities presented by blockchain for the energy sector (PricewaterhouseCoopers, 2016) and (IRENA, 2019). The different key applications integrating renewables can be summarized in the diagram below where Peer-to-peer energy trading is the most common application.

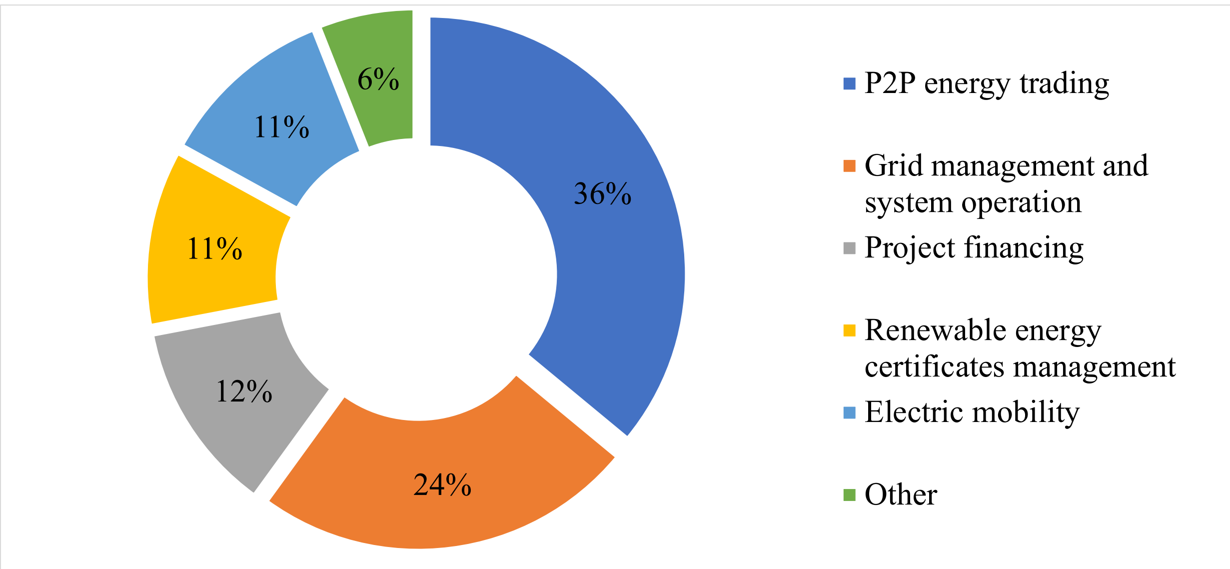


Figure 7: Blockchain-based key energy application in the renewable energy sector (IRENA, 2019)

Peer-to-peer energy trading is the most common use of blockchain in the energy sector globally since it occupies 36% of the use of blockchain. However, peer-to-peer energy trading is just at a very early stage in Africa either in research study or in project implementation. That is why the present research would focus on blockchain use in P2P energy trading and the use of blockchain for P2P energy trading will be detailed in one section below.

Then, concerning grid management and system operators, blockchain technology also enable an easier control of electricity networks due to the smart contracts which signal to the system when there is a need to start specific transactions. Blockchain technology can directly control network flows and provide flexibility operations. Predefined rules which ensure an automatic management of the power and storage flows is needed to be defined in the platform to generate the automatic management of the grid supply and demand. Therefore, when there is excess of electricity generated, this excess can be directed automatically to storage according to the smart contract, then the energy stored could be deployed for use whenever the electricity generation is deficient. When optimized over a wider network, blockchain allows a lower cost of energy supply. It can reduce the complexity of network operation as well, especially for distribution system operator and transmission service operator by supervising and tracking the transaction. As an example, a Belgium's Transmission System Operator, Elia, is working on the uses of blockchain technology to improve demand response area, particularly for registration, measurement and verification, as well as financial settlement (Bronski, 2018).There is also the Electron which is working with the National Grid, EDF, Shell and other industry to figure out how Blockchain can contribute in reducing cost in the grid and cut carbon emissions while ensuring reliability (Electron, 2018).

Apart from that, blockchain can also contribute to project financing. Blockchain presents the features for lower transaction costs, efficient processing, and secured transaction due to smart contracts and its payment capabilities (IRENA, 2019). Therefore, it provides an attractive platform for financing mechanisms and marketplaces to bring together energy demand and supply. Some companies such as the Sun Exchange and Impact PPA are promoting renewable energy finance using blockchain.

Blockchain can also be used for crowd-funding for renewable energy mini grid investment, for charity or aid purpose. It can enhance transparent and simple crowdfunding system aiming at contributing to start-up evolution and to help interesting and important projects to come to fruition. As an example, Bankymoon and USIZO have partnered for a crowdfunding platform created by Lorien Gamaroff where people from around the world can directly fund the energy needs of any African schools and hospitals through using bitcoins (Higgins, 2016).

In addition, blockchain can also be used to manage renewable energy certificates which are a way to reduce CO2 emission, based on actual generation rather than the usual way to base the award on estimation and forecast. With blockchain, double counting and double disclosure of guarantees of renewable energy origins can be avoided. It also allows for the distributed renewable energy producers to be awarded in real time due to sensors and smart contract which record and propagate real-time generation data through the network (IRENA, 2019). As an example, the SolarCoin is a cryptocurrency for solar energy aiming at providing rewards to solar power producers around the world to reduce CO2 emission. There is also the TerraGreen coin particular for biomass waste energy to support clean energy revolution.

Moreover, blockchain also plays an important role in the development of electromobility, structuring the platform coordinating electric vehicles charging (Kirpes & Becker, 2018). For instance, the company WeCharg developed the Charg Coin project which is designed specifically for Electric vehicles to offer crowdsources energy distribution among EVs through sharing stations in the Internet of Energy (IoE) (Charg, 2017).

All those assets presented by blockchain can be studied in order to exploit their potential for Sub-Saharan Africa. Nevertheless, considering the context of low electricity access in rural Africa, exploiting the blockchain for peer-to-peer energy trading would be the most relevant.

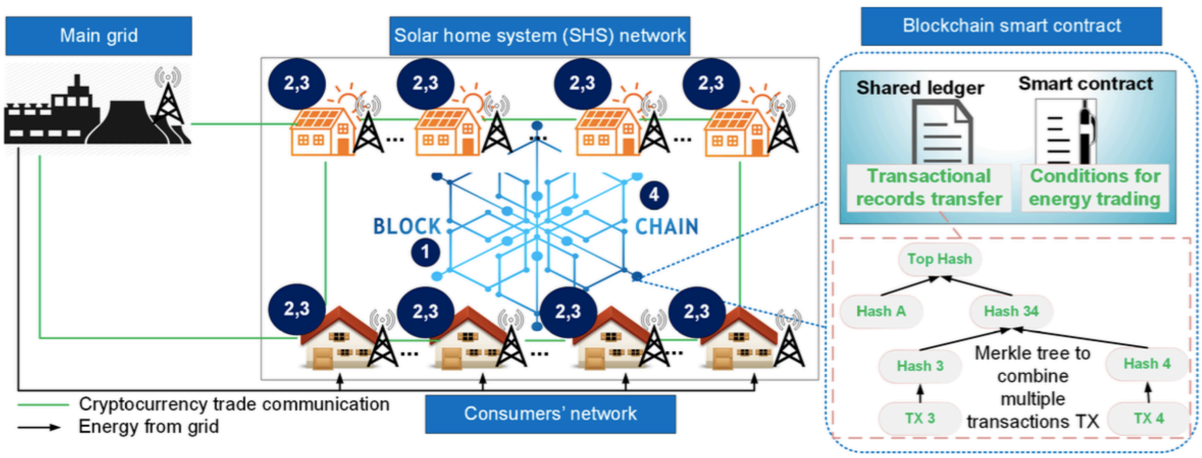
3.1.3. Blockchain framework for P2P energy trading

The general focus of approach of blockchain is to provide a replicable data structure, sharable among the participants allowing secured, transparent, and decentralized energy trading in the P2P network. The popular method for that are smart contract, Elecbay, consortium blockchain, Hyperledger and Ethereum (Alladi et al., 2019).

Samuel et al. have stated that Blockchain is particularly suitable for rural settlers especial for electrification in SSA where the households owning a SHS can generate electricity and trade their surplus among participants in the same community (Samuel et al., 2020) . When the

SHSs generate enough energy, which can meet consumers' demand, they get incentives instantly. Basically, energy trading is operated in the blockchain network through digital tokens and tokens can be redeemed for a remote cryptocurrency (Samuel et al., 2020).

Blockchain technology improves the pricing mechanism of a P2P energy trading by removing any third parties. When a prosumer announces a trading requirement to buy or to sell energy, a certain amount of trading tokens from this prosumer are passed around all the participants who validate them simultaneously and decide whether to deal with the token-sender or not. Then finally a prosumer who are able to deal with that sender will receive those tokens. When the token-sender receives all the responses, he selects peers to trade. Finally, the information of the trading process is stored in a new block and added to the blockchain of the microgrid. These whole transactions are operated automatically by the smart contract. When the prosumer who sent the token (the buyer) received the amount of energy from the prosumer who dealt with it (the seller), the equivalent amount of money is transferred from his account to that seller and the transaction is completed (Samuel et al., 2020).



1: Financial mode; 2, 3: Metering mode and Trading platform; 4: Industrial standard.

Figure 8: Blockchain framework (Samuel et al., 2020)

The roles and features of each element in the blockchain structure are detailed below:

- **Prosumers:** they are the consumers who have a SHS, hence can generate electricity. The SHS comprises basically of one or several PVs, charge controllers, solar cells and a battery (Samuel et al., 2020). The prosumers sell the surplus of their energy generated to the micro-grid within the community. However, when their energy demand is higher than what they generate, they buy energy from the local distributed energy market. While

SHSs are more suitable for small-scale deployment, other renewable energy sources like wind turbine is more suitable for large-scale (Kotilainen, 2020).

- **Energy consumers:** they are entities which only consume electricity. They can pay their electricity bills through cash or debit cards generally at the beginning of each month or quarterly depending on the negotiation. The price of electricity is the same for all consumers. Depending on the contract, the consumers who have dual meters may pay less for night consumption. Those who have capped rate pay for the eventual amount exceeding the consumption threshold. The blockchain technology is used to optimize the vetting processing time during electricity bill payment (Samuel et al., 2020).
- **Smart contract:** The blockchain's smart contract is a contract that uses a computer language in the place of legal language to provide terms and conditions which liaise the participants and also concord the digital currencies or assets transfer between participants. It can be executed automatically by a computing system and avoid the cost of contract signing, enforcement and regulation (Hou et al., 2018) and (Samuel, et al., 2020). Similarly, Singh and his team in their research on blockchain smart contract formalization defines smart contracts as a piece of software enabled by blockchain, allowing decentralized application without the necessity of a third-party (Singh et al., 2020).
- **Financial Mode:** Lack of trust between participants and inadequate financing are among the major barriers in financing distributed and decentralized energy system. Long-time contract rules are costly for the energy brokers. Blockchain has the potential to create trust and address those issues by unanimously processing and validating participants' contract rules, which hence promote financial efficiency of distributed and decentralized SHS (Hou et al., 2018) and (Mollah et al., 2020).
- **Metering mode:** Smart meters are installed in each household of the prosumers and consumers participating in the energy trading. Contrary to traditional meters, smart meters are more advanced and can collect in details the energy consumption and production, status and diagnostic data usually used for billing process, user appliance control, monitoring and troubleshooting (Samuel et al., 2020). However, several issues like substandard measuring devices, information losses during transmission, lack of focus by data entry staffs may occurs and they can cause inaccurate metering. That is why blockchain is important in smart metering as it has the potential to provide a digital precision of the smart meters' data and management. An accurate measurement is possible with blockchain, it allows recording of access restriction and time of access and enforce proper digital mapping (Kogure et al., 2017).

- **Trading platform:** By allowing prosumers to sell their energy surplus to their neighbouring consumers and other prosumers, blockchain help to minimize energy wastage and ensures that energy is fully utilized. When the prosumers have deficient energy, they can also buy from the other prosumers (Wang et al., 2019) and (Samuel et al., 2020).
- **Industrial standard:** The degree of adoption of decentralized SHS is high. Due to transparency in blockchain mechanism, it enables P2P trading markets without the need of trust endorsement of a third party. Hence, it promotes standardization of industrial activities (Hou et al., 2018).
-

3.1.4. Analysis of successful cases of P2P energy trading projects

3.1.4.1. Some major companies in P2P energy trading

Grid+ is a company based in Texas which provides simplified financial security. It is a supplier of distributed electric power (Consensys, 2018). The company is proving the concept of using blockchain technology to revolutionize traditional methodologies. This company uses an already established blockchain infrastructure to facilitate efficient electric power trading within the market. The cryptocurrency used by Grid plus is Ethereum which will automate its energy billing system and provide transparency by enabling consumers to access their energy usage data in real-time via an in-home smart agent-device. Grid+ is experiencing exponential growth from 1,000 households to 255,000 households in just over a year. GridPlus has demonstrated an early progress in product development. However, peer-to-peer energy trading in the United States encounters challenges due to regulation restriction. In 2019, GridPlus started extended its project to Singapore which is a highly suitable early market because it is liberalized, stable and has well defined regulations. Besides, the government is very favourable of not only the technology but also the regulation, providing incentives to innovation.

Power ledger is an Australian renewable energy and environmental commodities trading company which allow its participants to invest in renewable and transact energy. They have created a software which enables peer-to-peer energy trading from solar photovoltaic on rooftop. Through the use of blockchain technology they empower households to sell to the neighbourhood their excess power. They also aim at creating new markets for energy from renewable sources. Participants can use or sell the power produced through their own device and the revenue can be automatically allocated to their personal wallet address proportionally to their shareholding ratio. Working with Thai Digital Energy Development (TDED), Power ledger utilized blockchain technology to manage several clean energy projects. Power ledger also have a partnership with Malaysia's Sustainable Energy Development Authority to help increase the country's renewable energy generation to be 20% of total generated. Power Ledger has saved an average of USD 424 on annual electricity bills for its energy consumers and helped solar home system owners double the savings they normally get from their solar plants (Kabessa, 2017). However, the Australian P2P energy trading is also facing challenge regarding regulation, since regulations to enable and assess the P2P power trading market did not exist yet. Also, considering the current Australian regulation, it is challenging to implement a low-cost P2P administration (ARENA, 2017)

LO3 Energy is a blockchain based community energy platform headquartered in New York. It has developed an energy platform which enhances the integration of distributed energy resources (DERS) in Brooklyn. The platform promotes the use of renewables like solar and wind, and including battery storage with supply networks on the grid. The company is teaming up with other partners such as Siemens, Centrica and Braemar Energy Ventures. Last July, the Shell Ventures and Sumitomo also joined the business. They are also undertaking similar projects in Colombia, Australia, UK and Japan (Gordon, 2019).

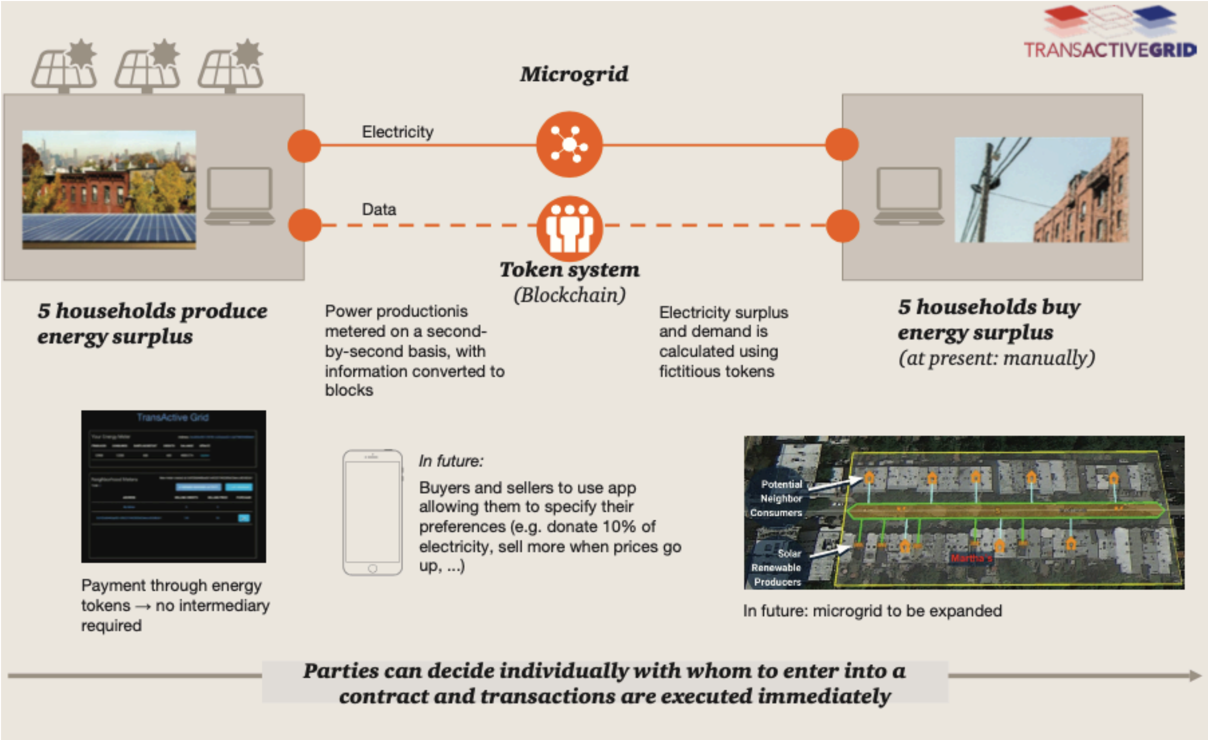


Figure 9: Brooklyn Grid project (PricewaterhouseCoopers, 2016)

The Brooklyn microgrid project has demonstrated that a private blockchain protocol can successfully operate a microgrid energy market. The microgrid setup, the grid connection and the information system are fully operational. Then the market and pricing mechanism are partly implemented but still need to be tested and adequately adapted for allocation efficiency. Finally, the implemented Energy management trading systems are also operational but require further development. Besides, public acceptance and customer participation are very promising for the case of Brooklyn microgrid project. However, the legal environment did not allow peer-to-peer electricity transactions between participants. Therefore, there is a need to adapt the regulation in order to fully develop that system (Mengelkamp et al., 2017).

ME SOLshare company created in 2014 is based in Bangladesh and operated the first ever P2P energy exchange platform. It has developed a peer-to-peer platform which allows peer-to-peer trading between the prosumers (Solshare, 2020). The benefit of solar energy is showcased by over 6 million households purchasing this form of solar energy system. SOL share stated that all systems in Bangladesh are standard due to heavy regulations and the standard systems produce 30% excess electricity. With this logic having 10 solar producing households can supply the electrical needs of 3 households without electricity. Swarm electrification exploits the excess electricity generated from each solar system. Bangladesh current electricity cost is $1.50 KWh, while Solshare prices generation is at $1.00 with a generation fee of 25%. ME SOLshare showed that using microgrids can help people out of poverty, with every $1 invested in SOLshare technology $4.85 was generated on social return of investment. Solshare expects to operate more than 20,000 nanogrids by the end of 2021, which are expected to supply more than 1,000,000 customers in Bangladesh. The success of Solshare projects lies first on the massive number of solar home systems in Bangladesh. The case of Bangladesh has demonstrated that transactive energy does not have to be complex and the technology enabling it can be cheap. Also, the presence of an advanced developing market with low regulation in Bangladesh represents an ideal environment to harness the technical and commercial potential for microgrids.

Suncontract: SunContract is a blockchain based company that is pioneering the decentralization of the energy sector. It launched the world's first trading platform on April 13th, 2018 in Slovenia. The company has partnered with European nations and many energy sectors and blockchain partnerships to provide an energy trading platform to households. Via an app, users can enter into deals with each other, set prices and share energy amongst one another. While the project is currently being implemented in Slovenia, it will shortly begin in the European Union where they have received support from the government and reputable EU commissioners. The SunContract platform has allowed the users to instantly access and audit of the energy consumption and production. It also ensures transparency and removes the need of intermediaries. In its white paper in 2017, the Suncontract pointed out the issue of subsiding conventional energy in many markets and consumer segments and emphasizes the importance of a conducive policy framework as a prerequisite for clean energy. It highlighted the importance of democratization of energy supply as well (SunContract, 2017). Regarding the legal context, contrary to the US, the European Union states is more favourable to peer-to-peer energy trading.

3.1.4.2. Analysis of the strengths and weaknesses of existing projects

Generally, peer-to-peer energy trading always come with the promises of lower electricity prices and more stable grids. That is the case for instance for Grid+. Nevertheless, in terms of real-word activity, operating a P2P energy trading is still challenging for many cases, especially in the U.S. which has restriction in terms of regulation. On the contrary, the current state of European Union energy law might in principle allow P2P electricity trading, yet the lack of specific provisions lead to challenges in practice. According to Henri Van Soest who conduct a review of the legal context of P2P electricity trading (van Soest, 2019), the electricity system in the US is far behind the European Union in terms of modern approaches to energy regulation. That is why most of P2P energy trading projects are localized in Europe who carried out regulatory efforts to initiate and promote P2P energy trading. In 2018, the European Union mandated that all their member states should facilitate the study and implementation of projects in P2P energy trading by 2021 (Deing, 2019). In many other situations around the world, peer-to-peer energy trading is explicitly forbidden due to strong lobbying power of incumbents and the energy market which is less liberalized.

3.2. The current situation in digital technology and blockchain in Sub Saharan Africa

The rural Sub Saharan Africa is still largely under-electrified. Mini-grids, micro-grids and solar home systems have been promoted in the recent years to provide modern energy services as well as new sources of employment to remote communities, and that is facilitated by digital technologies and payment tools (IEA, 2019).

3.2.1. Africa's ICT development indicator

The African Economic outlook 2020 stated that African countries are digitally under connected (AfDB, 2020). Although Sub Saharan Africa still lag behind in terms of digital revolution, the continent has witnessed considerable growth in ICT access since the 1990s (figure 11). The development in terms of ICT in Africa is predominantly driven by mobile telecommunication and particularly mobile financial services. In fact, in 2018, Africa alone disposes for half of the global mobile money accounts and it will continue growing fast until 2025. Nevertheless, the continent is starting being attracted by Blockchain technology and artificial intelligence.

The chart below shows the countries which are the most advanced in Sub Saharan Africa in terms of digital technology and the next figure is showing the situation of Africa compared to the rest of the world.

Table 5: Internet situation in some SSA countries (Internet World Stats, 2020)

Countries	Population (2020 est.)	Internet users (31 dec 2019)	Penetration (%population)	Internet growth % 2000-2020
Kenya	53,771,296	46,870,422	87.2%	23,335%
Rwanda	12,952,218	5,981,638	46.2 %	119,532%
Ghana	31,052,940	11,737,818	37.8%	39,026%
Nigeria	206,139,589	126,078,999	61.2%	62,939%
South Africa	59,308,690	32,615,165	55%	1,259%
Total Africa	1,340,598,447	526,710,313	39.3%	11,567%
World total	7,796,615,710	4,585,578,718	58.8%	

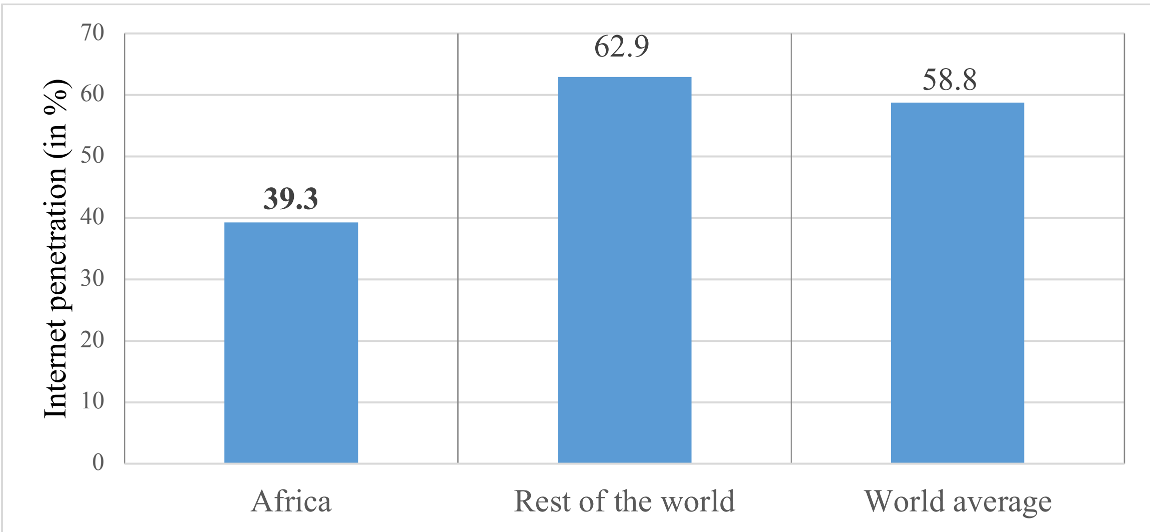


Figure 10: Internet penetration in Africa compared to the rest of the world in the first quarter of 2020 (in %) (Internet World Stats, 2020)

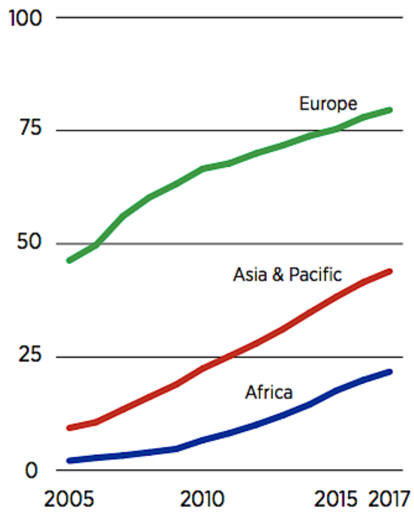


Figure 11: Evolution of internet penetration (in %) in Africa compared to other regions Kapoor et al., 2019)

Apart from internet penetrations, some indicators are also used to measure digital technology development such as the percentage of household having a computer and those having internet access at home (figure 13) which is generally correlated with the region's level of development. Only 17,8% of the African households were having internet at home in 2019 whereas the average in the world is 57%. The same for the case of households owning a computer which is only 10,7% in Africa while 49,7% in the world.

Also, for the case of technology preparedness which is related to the level of education (figure 14), Africa still lags behind compared to other regions.

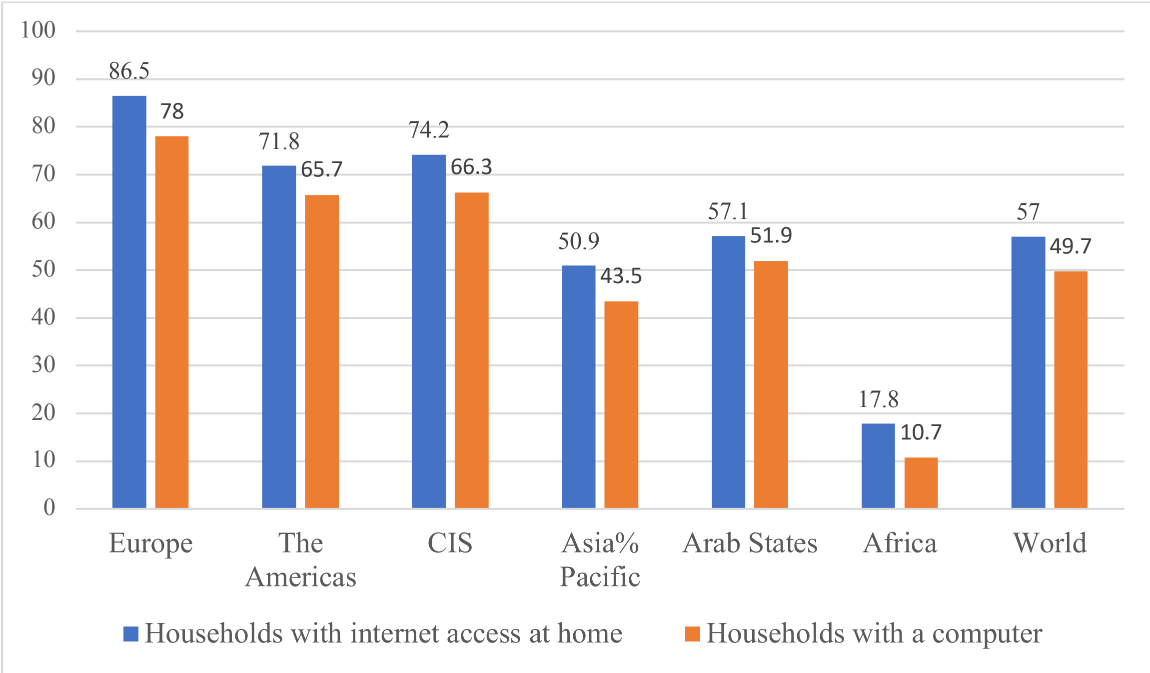


Figure 12: Percentage of households with internet access at home and with a computer in 2019 (ITU, 2019)

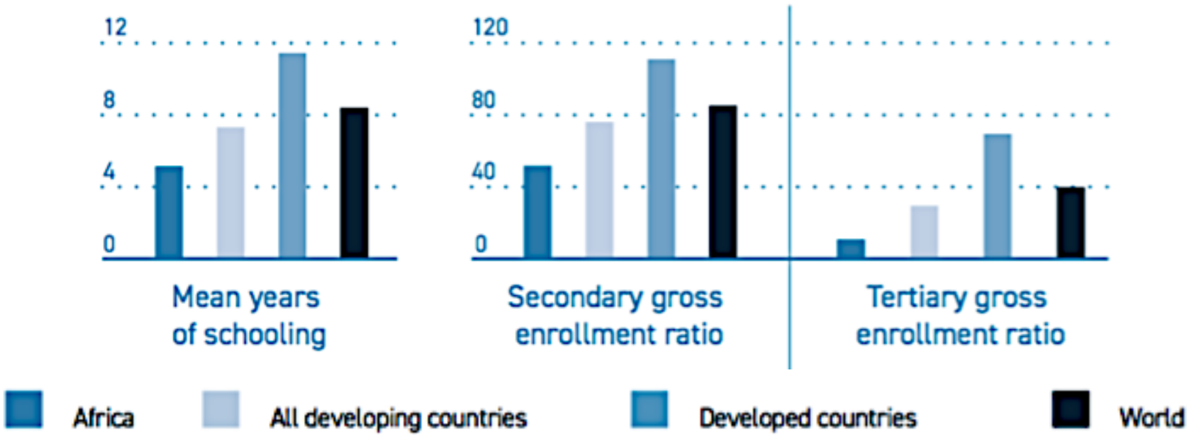


Figure 13: Technology preparedness in 2019 (Ndung'u & Signé, 2020)

3.2.2. Review of existing blockchain projects in SSA

An article written by Pavitra Rao in the Africa Renewal in 2018 stated that the conditions in Africa is favourable for virtual currency and Africa could be the next frontier for cryptocurrency (Rao, 2018). Cryptocurrency is more attractive to countries having high inflation rate since it is an alternative to failing central bank policies due to its decentralization. Bitcoin is the most common cryptocurrency used in the continent. The article stated that Botswana, Ghana, Kenya, Nigeria, South Africa and Zimbabwe are the main Bitcoin countries in Africa. Besides, a research conducted by T. Koffman confirmed also that the blockchain situation in Africa is raising (Koffman, 2019).

Cryptocurrency has also starting popping up for remittance services in the continent for instance the Abra in Malawi and Morocco, BitMari in Zimbabwe, GeoPay In South Africa, and Kobocoin in Nigeria.

In Malawi, up to 10,000 farmers joined the one-year pilot project intended to explore the use of blockchain technology in order to track supply chains for tea sold to the great companies Unilever and the British supermarket Sainsbury's. The project consisted in rewarding with financial incentives like access to credit and preferential loans those producing a fairer and more sustainable brew. In a further extent, a group of ten large food and retail companies (Nestle, Unilever, Tyson Foods, etc.) has joined the IBM project on how blockchain systems can help track food supply chain and improve safety (BNP Paribas, 2019).

There is also the Plaas farmers token, which is a technology used by the agricultural business plaasio founded in Gaborone Botswana in 2017. It is working as a mobile app enabling farmers to manage their stock on blockchain. It is a platform designed for Africans working in agriculture sector for data storage, tracking and validation with price notification via SMS and market improvement via future contracts (PLAAS, 2018).

In Kenya, the BitPesa facility was launched in 2013. It offers virtual remittances to African and international countries, to and from individuals' mobile wallets. According to LocalBitcoins.com, the value of bitcoin trading exceeded already 1.8 million USD as of December 2017 (BitPesa, 2020).

In Tunisia, the government itself has issued the digital currency eDinar, the same for eCFA in Senegal introduced in December 2016 (Rao, 2018).

In South Africa, in 2015, A. Nieman performed a research on virtual currency entitled "A few South African cents' worth on bitcoin". It has developed an assessment of current state of the development of bitcoin use in South Africa. It also analysed the challenges that this new technology is facing. Particularly, in April 2015, South Africa held its first commercial bitcoin conference in Cape Town. There are local innovators like Lorian Gamaroff in the country, who designed a local blockchain smart metering service for energy management and prepaid electricity. In addition, the Cape innovation and Technology Initiative has launched a

Virtual Currency hub and incubator. Since 2012, regular Bitcoin meetups are organized in Capetown and Stellenbosch (Nieman, 2015).

3.2.3. The current use of blockchain in energy sector in SSA

To increase the capacity of energy, several African countries focused on renewable energy. Using a decentralized energy system (DES) is the easiest and most affordable way to get electricity to rural communities within Africa by having independent and flexible sources of energy that satisfy several communities. Having microgrids is the way that rural Africa can solve its electricity problem. Smart grid (SG) systems can mimic the characteristics of an interlocking grid system.

Several African companies have started having interest in exploring blockchain technology in the energy sector. For instance, there is the OneWattSolar based in Nigeria which objective is to contribute in solving the unreliable power grid in Nigeria where many households and businesses are obliged to use diesel power generator which is expensive, noisy and harmful for the environment. OneWattSolar is an innovative funding model. It pays for, installs, owns and operates the Solar Home System with zero up-front investment and no out of pocket expenses from the households. The operational data is put onto Blockchain and tokens are used to pay the electricity which ensures high efficiency and transparency for consumers, developers, investors, and regulators. OneWattSolar currently have almost 7000 customers with an electricity generation capacity of 4018 MWh. The tariff is very low compared to the one of the grid cause it is only 0.1USD cents per kWh (OneWattSolar, 2020).

There is also the South Africa based startup Bankymoon which is developing smart meters with integrated payments using Bitcoin. They are using PAYG to top up the energy meters. Each meter has a unique bitcoin (Bankymoon, 2020).

Another company which is exploring blockchain use in Africa is the Lightency. It is a green tech startup that harnesses the power of deep technologies to ensure better access to affordable and green energy by promoting distributed energy resources in microgrids. Particularly, they are exploring peer-to-peer trading platform to balance the grid and allow user to trade their energy surplus. The Lightency are targeting the following countries: Kenya, Tanzania, Uganda, Burkina Faso, Senegal, Mali and Lybia. They claim that the government policies in those countries are favourable to the peer-to-peer energy trading because under a certain capacity of production, electricity can be traded freely between participants. Also, according to their study, mini-grid market is already developed in those countries, which can promise wider customer for them. It is also because of the ease of doing business and some encouraging indicators such as the high mobile penetration (Lightency, 2020).

3.3. Policy and regulations on digital technology in energy sector

Policy and regulations are important in order to set the strategies on how African energy sector can benefit from the Fourth Industrial Revolution driven by digital technologies such as Internet of Things, Artificial Intelligence, and blockchain.

3.3.1. Importance of regulation and legal environment in a micro grid energy market.

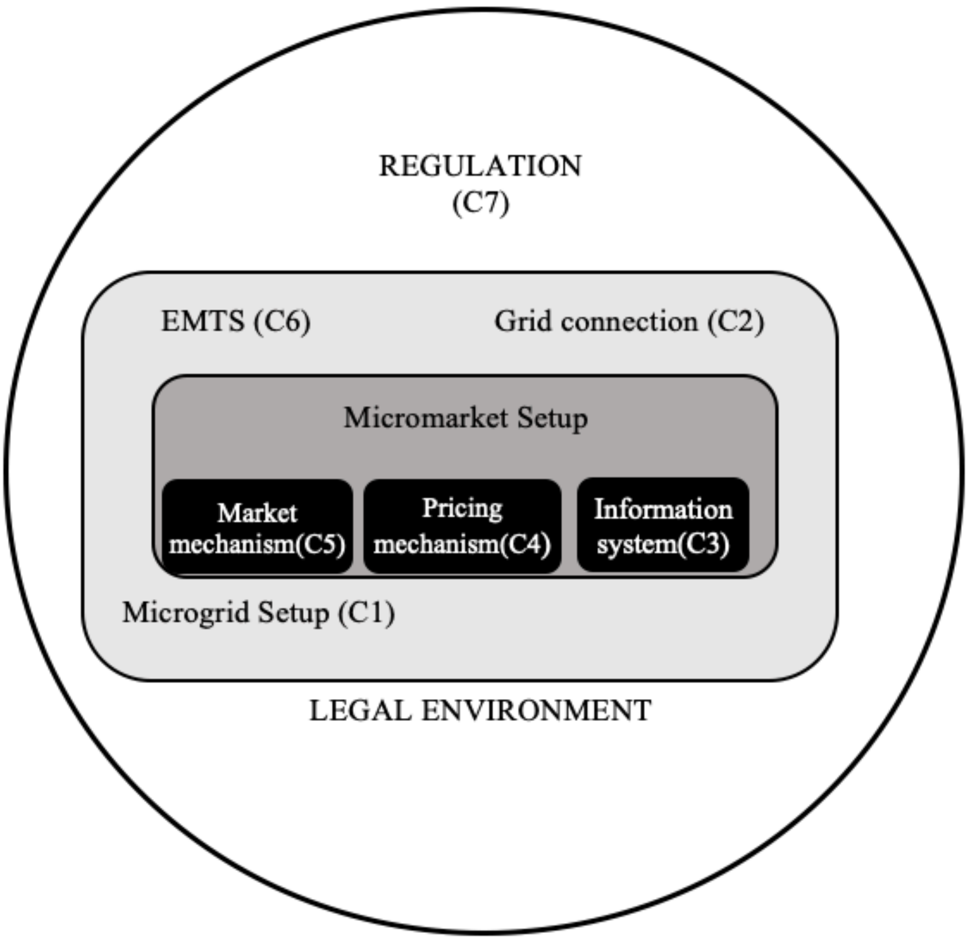


Figure 14: A schematic overview of the seven components of a micro-grid energy market (Mengelkamp et al., 2017)

In 2017, Mengelkamp and her team conducted a study in designing microgrid energy markets and had the Brooklyn Microgrid as a case study (Mengelkamp et al., 2017), they asserted that a microgrid market has seven components which are:

(C1) A micro-grid setup which consists in defining clear objective, the market participants and the form of energy traded;

(C2) Grid connections containing one or several connection points toward the superordinate grid. Each point has a metering;

(C3) A high-performing information system which ensures connection between all market participants. It also provides the market platform and market access and ensures the monitoring of the market operations.

(C4) The market mechanism which comprises the market's allocation and payment rules and ensures a clear and useful bidding.

(C5) The pricing mechanism which implemented through the market and which aims at an efficient allocation of energy supply and demand. This price can vary according to the load. (C6) An Energy management trading system (EMTS) which aims at securing automatically the energy supply for a market participant with implementation of particular bidding strategy. The EMTS can have access to the blockchain account of the market participants to facilitate automatically the energy transaction.

(C7) The last one, but not the least is the regulation which ensures that the microgrid energy system is in line with the current energy policy. As shown in the figure 14, The regulation and legal environment govern all the six previous components of the micro-grid market. The policy and regulatory framework is the fundamental requirement for the implementation of P2P energy trading and the lack of those regulatory is one of the major barriers for implementation of P2P energy sharing across the world (Klein, 2019).

3.3.2. Policy on P2P energy trading and blockchain in energy sector in the world

Effective policy and regulation are necessary to govern the success of P2P energy trading. Those policies consist in deciding the kind of market design which will be allowed, the distribution of taxes and fees and also to determine how will be the status and mechanism of the P2P market in relation to the already existing energy market. Since P2P energy transaction can accelerate renewable energy deployment and limit environmental issues, governments can decide to support P2P energy trading by establishing the right regulatory system, like in the EU countries. On the contrary, governments have also the power to discourage the implementation of such project if it can have considerable negative impacts to the existing energy system (Tushar et al., 2018)

Ahl et al. and Diestelmeir both emphasized that efforts are being made to recognize the importance of regulatory schemes in facilitating the development of P2P energy trading and to deal with the related challenges. Ahl et al. conducted an analytical framework for blockchain-based P2P micro-grids which includes technological, economic, social, environmental, and institutional dimensions. In the institutions, it affects the market policy, grid codes, P2P policy and mechanism for institutional innovation (Ahl et al., 2019). On the other hand, Diesteleimer focused more on the policy implications for EU electricity law of the new roles of consumers. One of the pressing legal questions of the energy transition is how to integrate prosumers in the electricity market since their roles have been limited so far. Due to blockchain technology, the approach "integration in the market" can be changed to "becoming the market". Three main policy implications of blockchain-based electricity transaction were identified, which are: organizing decentralized responsibilities, establishing a legal framework for incentivizing consumers to invest in flexibility technologies, and the last is to strike balance between self-responsibility and protection of consumers (Diestelmeier, 2019).

Apart from that, Morstyn et al. who focused more on P2P question highlighted the role of P2P energy trading markets for distribution system operators to facilitate prosumer coordination. Therefore, they suggested it may be needed to make changes in Distribution System Operators (DSO) regulations to link the DSO rate of return to network capacity investments in order to provide incentives for DSOs. Besides, they suggested to carry out further investigation to understand how regulation can best align DSO, prosumer, social, and power system objectives (Morstyn et al., 2018).

Zhou et al. made a recapitulation of the elements needed to be considered under the policy analysis of P2P energy trading which are: first, the DSO regulation, second the legitimacy and distribution of taxes and fees, third is the ownership and partnership models, prosumer licensing, market roles and the last is the decentralized responsibility, flexibility incentives and customer protection.

Regarding standardization of the use of blockchain in the energy sector, efforts are currently undertaken in order to standardize blockchain technology in its various use cases. For the energy sector, the Institute of Electrical and Electronics Engineer has formed two blockchain groups: the first is the Project 2418:5 to provide a standard framework for blockchain application in energy sector (IEEE SA, 2018). The second is the Project 825 approved in 2016 to develop a guide for interoperability of blockchains for energy transaction applications (IEEE SA, 2016).

For the US, the National Renewable Energy Laboratory released in 2014 the IEEE 1547 and 2030 Standards for Distributed Energy Resources Interconnection and Interoperability with the Electricity Grid (Basso, 2014). The IEEE 1547 has helped shape the way utilities and other businesses have worked together to promote Distributed Energy Resources. Then the IEEE 2030 is helping in better embrace the implementation for ICT.

In the last recent years, recognizing the importance of blockchain and P2P energy trading, several countries have starting working on policy to embrace that new system. As an example, Colombia has had a research project called Transactive energy Colombia Initiative starting from April 2019. It is managed by researcher from UCL and Universidad EIA working with local utility and partners. It consists in setting up a peer-to-peer pilot in Medellin Colombia and the project includes the development of a P2P trading app, the elaboration of policy recommendations for Colombian policymakers as well as a roadmap to for commercial scale-up (UCL, 2019).

Although several studies have discussed the peer-to-peer energy trading policy and blockchain from different perspectives, there is still lack of details on how the new policy reform should be exactly. Also, there has not been any radical change in the P2P energy trading in large scale around the world (Zhou et al., 2020). Moreover, such policy and regulation are not clearly defined yet in the energy policy documents of African countries. That is why the present research is important to give some basic framework for the implementation of P2P energy trading platform in SSA.

3.4. Comparative study on the policy and regulation on blockchain and cryptocurrencies among African countries

3.4.1.1. Analysis of the overall situation on blockchain and cryptocurrency in SSA

Blockchain and cryptocurrency are still at an early stage in Africa. The few available researches in that field in Africa are reflecting that most of African governments are still on stand-by towards that innovative finance. Several documents have been analysed to make the comparative study on blockchain and cryptocurrencies in several SSA countries. The law library of congress has made a compilation of regulation of cryptocurrencies around the world, including 10 Sub Saharan African countries which are Ghana, Kenya, Lesotho, Mozambique, Namibia, South Africa, Swaziland, Uganda, Zambia and Zimbabwe (The Law Library of Congress, 2018). The Pan African Bank Ecobank conducted particularly a research on African crypto regulation and described briefly the situation in 39 Sub Saharan African countries (Ecobank, 2018). It has stated that Africa's regulators and central banks are adopting a "Wait and See" approach. They remain reticent towards authorizing cryptocurrency transactions due to the potential risks that it may create.

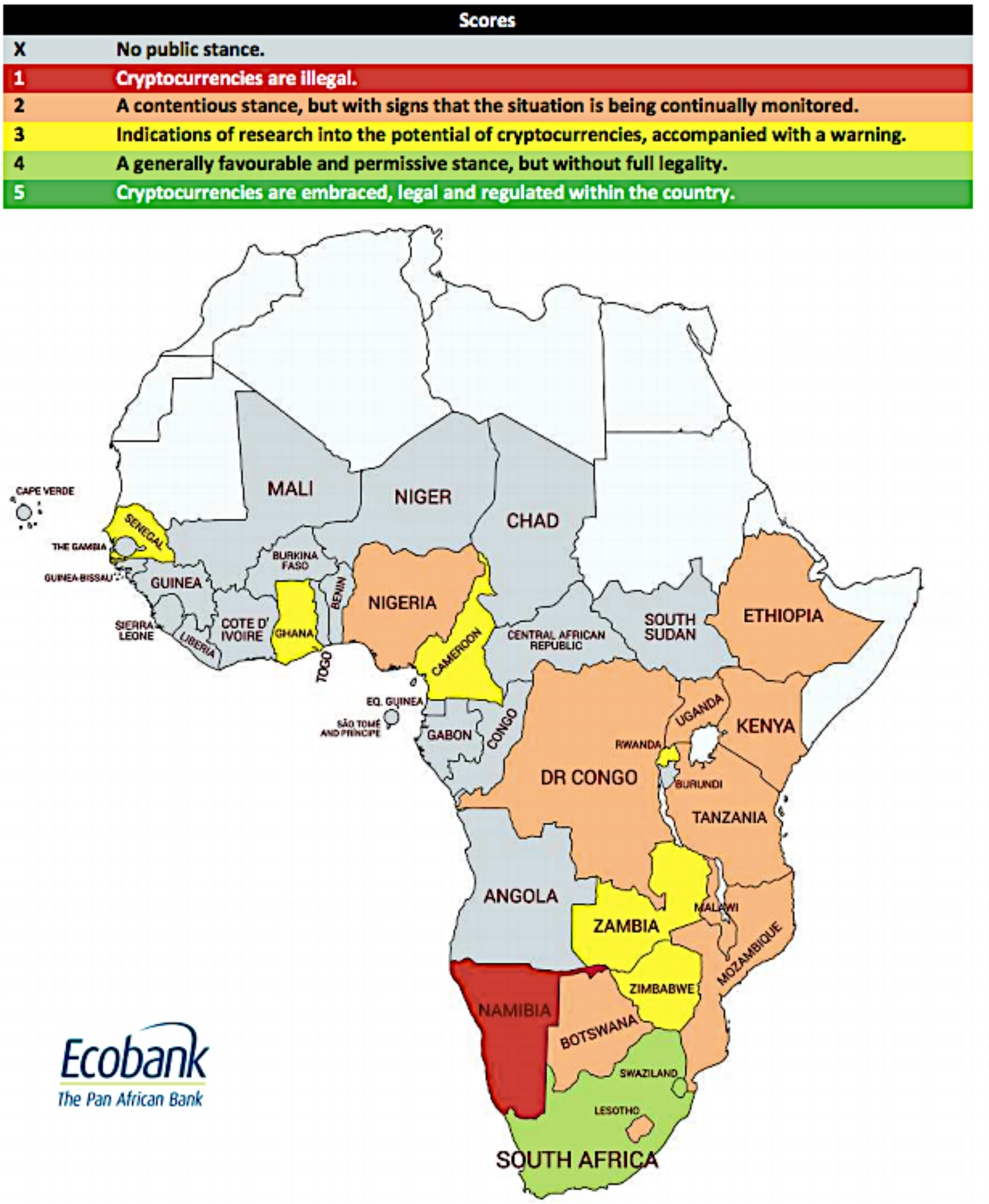


Figure 15: Sub-Saharan African Cryptocurrency Regulation Map (Ecobank, 2018)

While those two previous researches are more about cryptocurrencies, another research carried out by Baker McKenzie has put more focus on Blockchain situation (McKenzie, 2018). Blockchain has considerable potential which can be applied in various domains of development. Nevertheless, this technology is still at an early stage in Africa. Most of Sub Saharan African countries have not started yet to study and analyse well the potential that this technology can have and do not even have any policy and regulation related to that matter. However, some see blockchain as an uncontrollable tool which can threaten the financial status of the country and has set restrictive policy. For instance, blockchain and cryptocurrency are banned or prohibited in Zambia, Zimbabwe, Namibia and Swaziland. On the contrary, other countries have set friendly and progressive policy towards blockchain, such as South-Africa, Mauritius, Senegal and Sierra Leone. Some others are indifferent or do not have any official stance towards the blockchain use such as Kenya, Tanzania, Ethiopia, Madagascar, Uganda, Democratic Republic of Congo, Botswana, Cameroon, Nigeria and Ghana (Fig. 16) (McKenzie, 2018).

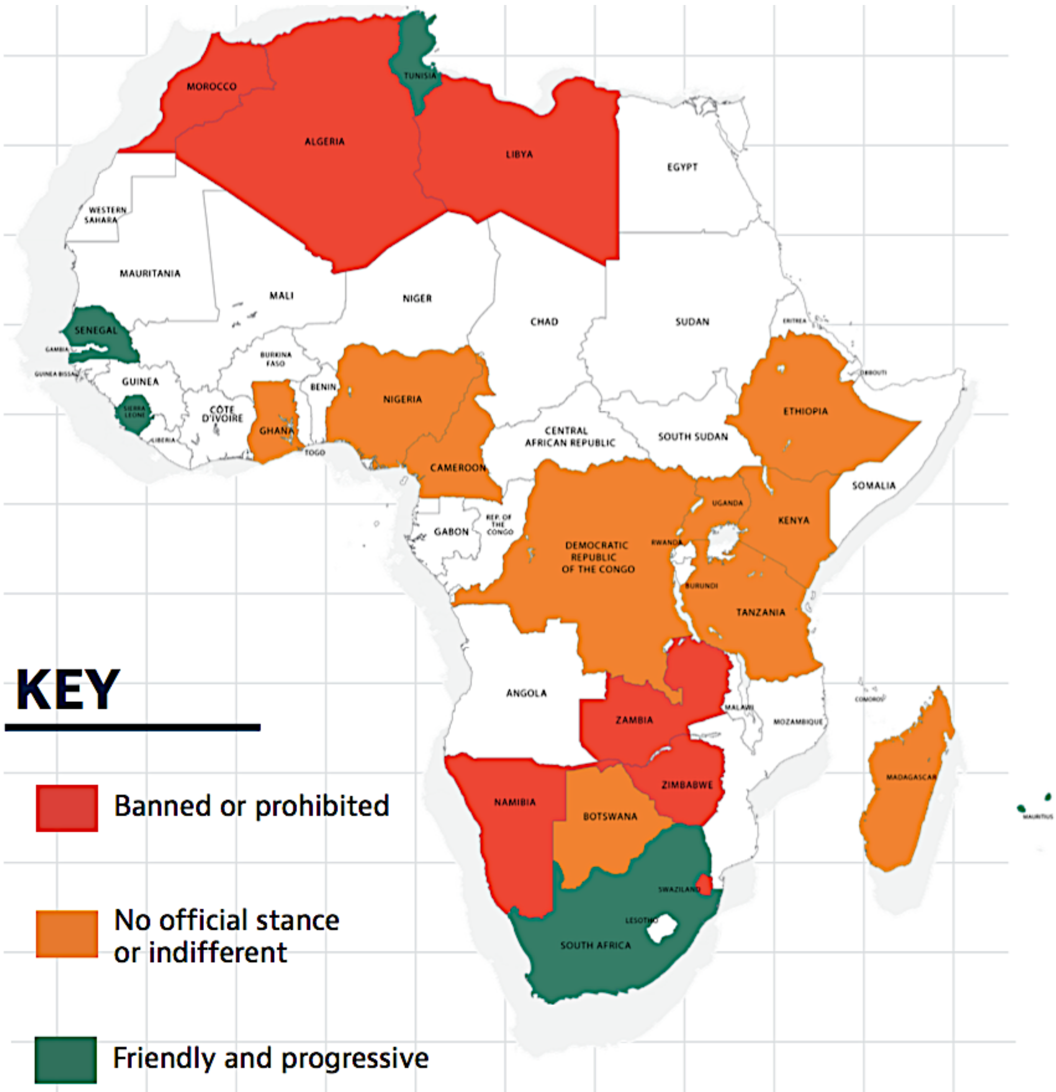


Figure 16: Geographical overview of attitudes towards blockchain (McKenzie, 2018)

The tables in the three sections below summarize the blockchain and cryptocurrency situation in some more relevant Sub African countries (McKenzie, 2018).

3.4.1.2. Countries favourable to blockchain and cryptocurrency

Countries & date of introduction	**Overall position on Fintech**	**Central Bank regulatory position**	**Regulations issued by Central Bank**	**Other regulations**
South Africa	Willingness of the regulators to work with the fintech and banking industry to regulate efficiently cryptocurrencies	No regulation. However, existence of the Project Khokha: exploring the use of distributed ledger technology for interbank payments settlement	The South-African reserve bank had 5 year-long consultation period on the topic of digital asset and planned to deploy the new rules this year	Proposition of amendments to the taxation legislation by the National Treasury and classification of cryptocurrency as financial services in terms of the VAT Act and financial instruments in terms of the ITA
Mauritius	Actively trying to create a Fintech hub in the country	Supportive and aiming to create an Ethereum island	No regulation yet. Creation of the MBCE and the fintech innovation-driven Financial Services Regulatory Committee	Creation of a Regulatory Sandbox to provide licenses to financial innovators despite the lack of legislative framework

Senegal	Favourable. Senegal launched the eCFA, a national virtual currency in 2016, which can be stored on mobile money and e-money wallet	Supportive	The eCFA is regulated by the Central Bank	The "Banque Regionale de Marches" (BRM) and the eCurrency Mint are also regulating the eCFA
Sierra Leone	Strong willingness of the government to establish a Smart Country with high digitalization of diverse services. The first country to utilize blockchain in its national election. Launch of the New Kiva Protocol intended to build the new credit bureau of the future.	No official statement yet from the Bank of Sierra Leone	No regulation yet	No regulation yet

3.4.1.3. Countries with no official stance for blockchain and cryptocurrencies

Countries	Overall position on Fintech	Central Bank regulatory position	Regulations issued by Central Bank	Other regulations
Kenya	Positive reaction from the government but unclear decision from the Central Bank. Support from the Judiciary to the Central Bank's authority to regulate cryptocurrency	Rejection of the use of digital currencies due to their unregulated nature	No regulation yet	No regulation yet but establishment of a task force to explore the use of digital currency and AI
Tanzania	Cryptocurrency mining activities flourishing despite the absence of relevant authorities	Cautious about cryptocurrency which may threaten the launch of the East African common currency	No regulation framework in place	No regulation
Ethiopia	Existence of a blockchain based supply chain application for coffee shipment from farmer to end user, by the cryptocurrency start-up Cardano	No statement	No regulation	No regulation
Madagascar	A project on a blockchain fundraising for conservation projects	No statement	No regulation	No regulation

	by the Ixo Foundation/			
Uganda	Some government agencies such as UNAFRI and NITA are examining the cryptocurrency regulatory framework in order to advise on potential legislative changes	Warning the public about the risk of trading with cryptocurrency and its volatility	No regulation	No regulation
DRC	A pilot project using blockchain to track the supply chain of cobalt and coltan mining by the Dorae Inc.	No statement from the Congolese central bank. However, the project of Dorae Inc has been approved by the government.	No regulation	No regulation
Botswana	Interest in blockchain from the private sector but no interest in blockchain regulation from the relevant authorities	They expressed that they had no interest in studying or regulating cryptocurrencies	No regulation	No regulation
Cameroon	The government has a trial on its own digital currency called Trest and the test was promising but high cost of electricity associated with the process hindered the project	No clear statement	No regulation	No regulation

Ghana	Resolving land ownership issue: Replication of the Government Land Registry system on the blockchain network.	Cryptocurrency is not recognized as a legitimate form of currency	Drafting the Ghanaian Bill for cryptocurrency regulation through "Electronic Money issuers"	No regulation
Nigeria	Nigeria is the world's third largest bitcoin holdings in terms of percentage of GDP	Against the use of cryptocurrency because of the risk of fraudulent schemes	No regulation yet but intention to release its white paper on the use and regulation of cryptocurrency	No regulation yet but ongoing investigation on cryptocurrency by the Nigerian Senate

3.4.1.4. Countries which ban cryptocurrency

Countries	Overall position on Fintech	Central Bank regulatory position	Regulations issued by Central Bank	Other regulations
Zambia	Against the use of cryptocurrencies	A press statement from the Bank of Zambia stated clearly that cryptocurrencies are not legal tender. Warning about the risk of using cryptocurrencies	No regulation	No regulation
Zimbabwe	Individuals and	The Reserve Bank	No regulation	No

	private sector using cryptocurrencies but the Reserve bank of Zimbabwe is discouraging its use. However, the ministry of finance started to encourage its regulation	has banned the trading of all virtual currencies and have notified private banks to close all bank accounts using or trading in virtual currencies		regulation
Namibia	The overall regulators are against the use of cryptocurrencies	Against the distribution and use of cryptocurrencies	Their position paper argues that the use of cryptocurrency is contrary to the existing legislation	No regulation
Swaziland	No restrictions, disclosures or regulatory compliance applicable to transactions using Bitcoin	The central Bank is cautious on the risk for cryptocurrency users	No legislation	No legislation

3.5. Summary: identified gaps of the existing literature and added value of the present research

3.5.1. Huge gap between developed and developing countries

The existing projects on P2P energy trading is mainly located in developed countries (fig. 17), therefore there are not much research in that field for underdeveloped countries. The present research is among the first research in exploring the implementation of P2P energy trading in an underdeveloped world which is SSA.

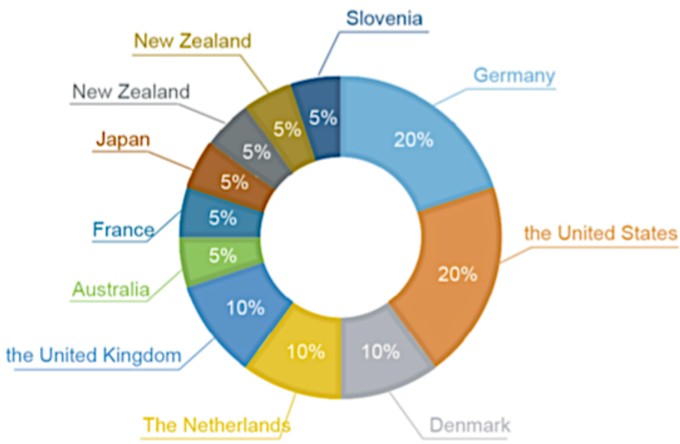


Figure 17: Proportion of projects in P2P by country (Zhou et al., 2020)

3.5.2. Lack of research focusing on policy in P2P energy trading

The already existing researches in P2P energy trading are mainly focused on the technical aspect or the market design and there was not more research in the policy area (fig. 18), although the policy is the foundation of all the operations. Therefore, the present research is very important in order to bring contribution to the policy analysis of P2P energy trading and blockchain uses.

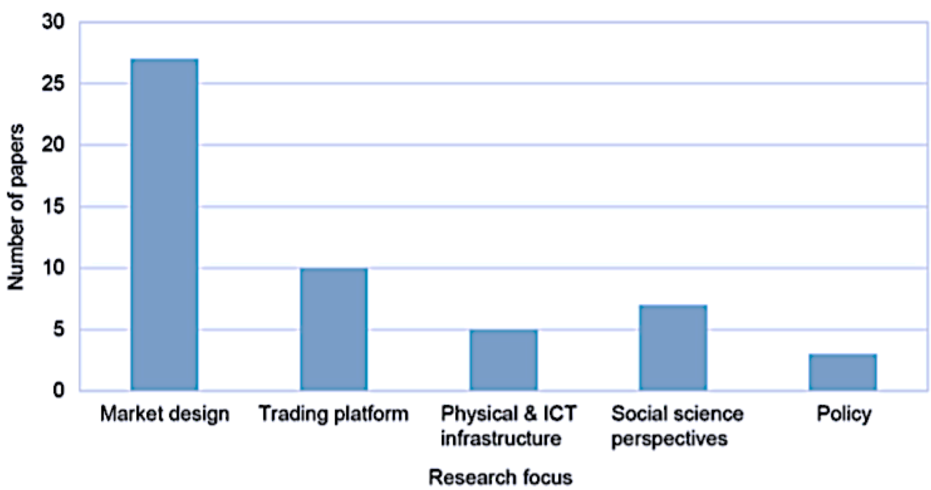


Figure 18: Number of journal papers on P2P energy trading by research focus (Zhou et al., 2020)

3.5.3. Current regulatory focused on conventional energy market

The current energy regulatory schemes all over the world and particularly in Sub Saharan Africa was established based on the traditional energy market system which is centralized, vertical and unidirectional. Therefore, adequate regulatory for the case of revolutionized energy market such as decentralized and distributed energy market are not clear, even unavailable. Besides, several researches have stated that rapid changes are occurring in the sector due to innovative technologies, hence regulatory schemes need to be reformed accordingly (Zhou et al., 2020) . That is why the aims of this research is to set a policy framework for the emerging new system of distributed energy system in which African countries start having interest.

4. METHODOLOGY

4.1. Overall methodological approach

The research method of the thesis followed a linear process which consists of five major steps as it is shown in the schematic below (fig. 19). The first which is a preliminary requirement consists in detailed literature review in order to give understanding of the peer-to-peer energy trading and blockchain as well as its mechanism and also to review and analyse some successful projects in P2P energy trading. The second is an extensive desktop research. Basically, qualitative method was used, based on data from institutions related to the field. Then, the understanding of the mechanism and the knowledge of the Sub-Saharan African situation as well as the data collected had helped to build a conceptual modelling for policy framework for P2P energy trading and blockchain in Sub-Saharan Africa. After building the model, a case study for Kenya, particularly the RED+ company was conducted in order to validate the proposed conceptual modelling of the policy framework. It was based on an interview with operator working in P2P energy trading. That had allowed to understand the technical aspect of blockchain and peer-to-peer energy trading, and gave understanding of the practical situation in the world as well as in Sub-Saharan Africa and to know the challenges in the field.

Figure 19: Simplified schematic overview of the methodological approach

4.2. Methods and instruments for data collection: desktop research and interview

Two main methods were used in order to gather the specific data required for the study: the desktop research and the interview.

The desktop research consisted on gathering secondary data for the assessment of digital technology situation in SSA and the use of advanced ICT technology such as Blockchain, AI and IoT. The data are mainly from grey literature such as reports from the ministries in charge of ICT in each country, ministries of energy, and international organizations specialized in digital technologies like the ITU or International Telecommunications Unions. The data collected included internet penetration as well as awareness and preparedness on the use of blockchain in SSA countries.

Then, conducting an interview was the main method used to gather the practical primary data necessary for the validation of the study. The task consisted in defining very well, first, the purpose of the interview, then identify the profile of a suitable interviewee, designing a questionnaire and finally conduct the interview and analyse the result.

The interview consisted on an online interview with a CEO of a company involved in P2P energy trading and blockàlchain in Africa. The goal of the interview was to have a practical understanding of the reality of P2P energy trading and blockchain in Africa from the point of view of a company which is really working on the field. Since, most of existing research available on the field was about projects in developed countries, the interview has allowed knowing about existing project in in Sub Saharan Africa, to have a practical understanding of their mechanism of peer-to-peer energy trading using blockchain. It has also allowed knowing the challenge that they are facing and the main purpose was to apply the proposed conceptual modelling.

The questionnaire of the interview was basically focused on 8 sections which are:

- Information about the company
- The project on P2P energy transaction operated by the company
- Profile of their customers/prosumers
- Technology and technical aspect
- The electricity price
- Customers analysis
- Policy and regulation
- Stakeholders of the project

Table 6: Overview on the method and instrument

Methods applied	Instruments	Key features	Outcomes

Desktop research	Data extraction sheet	Documentary analysis	Secondary data: - digital technology indicators - blockchain and P2P energy situation in SSA - Policy and regulation on P2P and blockchain
Interview	Interview protocol	Online interview was conducted with the CEO of a company developing a pilot project in P2P energy trading using blockchain	Primary data on: - policy and regulation situation and challenges in Kenya - information about the project

4.3. Rational for the case study

Some SSA countries are quite advanced than the others in terms of promotion of mini-grid sectors and more prepared to welcome those new technologies. One of them is Kenya where 75% of the population has access to electricity (IEA, 2019). Although 13 million people of Kenyans were still living without electricity in 2018, considerable progress in terms of electrification has been noticed in the country since its annualized increase in access is 7% from 2010 to 2018, which is largely higher compared to all the other countries in the region. That progress is largely due the promotion of off-grid system in the country and incentives for the private sector (IEA et al., 2020). Furthermore, Kenya is more advanced in terms of digital technologies. That is why the case study will be focused on Kenya, after working on the general situation in Sub-Saharan Africa. A concrete analysis will be conducted by focusing on the case of Rehub company which has a pilot project in P2P energy trading in Kenya.

4.3.1. Background about Kenya

Kenya, officially the Republic of Kenya is a country in Eastern Africa with the capital Nairobi. Kenya has an area of 580,367 square kilometres. It is bordered by South Soudan in the northwest, Ethiopia to the north, Somalia to the east, Uganda to the west, Tanzania to the south and the Indian Ocean to the southeast. Kenya’s population was estimated at 52,573,973 in 2019. Despite the significant political, structural and economic reforms that have led to sustained economic growth and social development, Kenya still faces the challenges of poverty, inequality, climate change, low private sector investments and the economy’s vulnerability to internal and external shocks. Kenya’s GDP amounts at 95.503 billion in 2019. With its economic growth of 5.7% in 2019, Kenya is one of the fastest growing economies in Sub-Saharan Africa (World Bank, 2020). As of 2020, Kenya is the third largest economy in Sub-Saharan Africa after Nigeria and South Africa.

4.3.2. Selection of the company and Information about Rehub company

Projects in P2P energy trading are still at a very early stage in Africa. Rehub Company is now conducting a pilot project on P2P energy trading in Kenya and it is very suitable for the present study, especially to study their requirements in terms of policy and regulation.

Rehub is a company created in Kenya in 2010 by some Kenyans passionate in renewable energy technology. Its main working area is Kenya but they extended their project to Zambia in 2017 with a grant funding. The main activities of the company are about consultancy projects for renewable energy, decentralized energy and particularly Solar Home System where RED+ is the name of the product. They are engaged in Renewable energy demonstration project as well. The main source of revenue of the company is from solar equipment installation. Currently, the company is having an innovation project in promoting renewable energy decentralized through managing domestic demand.

4.4. Method for elaborating the conceptual modelling of the policy framework

The design of the policy framework was based on Davis Bobrow’s principles of policy design (Bobrow, 2006). It is composed of 10 steps which are:

1) Discipline breakout: Bobrow highlighted that designing policy is not limited in only one discipline, it involves other fields. In the case of the present study, the policy framework involved energy policy, law and legislation, technical consideration and others.
2) Minimum conditions: considering the minimum conditions needed for success is necessary so the study analysed how those minimum conditions can be achieved.
3) Safeguards: it is necessary to build safeguards against major errors
4) Placement (time): he stated that any policy design has to be placed into an ongoing history, and must fit into the existing practices. Blockchain study fits in the current area of fourth industrial revolution where embracing the innovation in ICT is undeniable.

5) Oppositional analysis: analysis of potential opposition to the policy and how can that be resolved. That is why a stakeholder analysis was part of the policy framework.
6) Borrowing: it consists in finding a working program elsewhere that can be borrowed. That is why studying successful cases of P2P energy and blockchain in other continents were carried out before designing the policy framework for Africa.
7) Tinkering: the existing policies always require continuous adaptation, especially for new technologies evolving very fast such as the case of fintech.
8) Backward mapping: policy designer has to start by thinking about the most desired projects to citizens and implementers.
9) Forward mapping: it begins with goals and designing toward reaching that goals.

Judgement: good judgement is necessary at the end of policy design.

5. CONCEPTUAL APPROACH, RESULT AND DISCUSSION

5.1. Analysis of the current situation and implementation state of Digital technologies, Blockchain and peer-to-peer market in SSA

5.1.1. Benefits from promoting blockchain technology and P2P in SSA

To increase the capacity of energy, several African countries focused on renewable energy. Using a decentralized energy system (DES) is the easiest and most affordable way to get electricity to rural communities within Africa by having independent and flexible sources of energy that satisfy several communities.

5.1.1.1. Blockchain features for P2P energy trading in SSA

Introducing blockchain in the mini-grid sector in SSA represents several promising benefits for the sector. Based on the distributed energy systems, the electric mini grid transactions require a trusty system of payment. Sana Noor et al. demonstrated that the emerging blockchain technology can ensure an efficient and robust trading system with low cost through the implementation of optimal energy management strategies (Noor et al., 2018).

The blockchain technologies are introduced in order to facilitate peer-to-peer transactions to enhance the optimization of supply and demand management. Therefore, they suggested that an extended DSM framework and optimized strategy would help consumers reduce their electricity bills, and would allow them to manage their own load by scheduling their electricity consumption. Back in 2010, The ACM shared a view on cloud-computing and developed a testing software project for blockchain. 23 utility companies have participated in the project testing and attested the success of blockchain in their work and it pays off when used for trading (Armbrust et al., 2010).

Noor et al. demonstrated as well that exploring the potential of blockchain would reduce the stress on the grid and avoid building new generation capacity (Noor et al., 2018). The use of blockchain is a great way to avoid passing through national utilities or central electricity agency who often fails in managing efficiently the supply and demand and who are highly affected by corruption issue. Münsing et al. presented similar research that blockchain is a great solution for several problem of optimization (Munsing et al., 2017).

In addition, blockchain use in the distributed energy system would improve reliability by allowing real-time control of the power supply and flow (Mylrea et al., 2017) . That leads to building of a resilient system where the participants trust each other and that would improve considerably the data management. Contrary to the vulnerable traditional system where data is stored in one point, data is stored across all nodes in the DER enhanced by blockchain, which makes it easier to track and audit (Khatoon et al., 2019).

Also, promoting blockchain enabled contracts would allow transparent energy transaction. In 2017, Esther Mengelkamp and her colleagues also shared a study of a micro-grid energy market for the case study of micro-grid Brooklyn where prosumers can sell and buy self-produced energy (Mengelkamp et al., 2017). The Brooklyn microgrid market was the first project in the world that facilitated a peer-to-peer energy transaction using blockchain. Hence, the utilization of blockchain technology will improve trade and communication among prosumers by increasing transparency of transactions along with fortifying security due to a universal decentralized ledger system.

According to all those previous researches demonstrating the benefits of using blockchain technology in the frame of P2P energy trading, it is interesting to analyse how the region of Sub Saharan Africa can apply this innovation in its energy sector especially. Knowing that the rural Sub-Saharan Africa is highly non-electrified, this innovation can contribute considerably to promoting the rural energy access and the present research is aiming at analysing the policy and regulation required to promote the establishment of this practice in the region. The graphic below summarizes the different areas where blockchain can intervene.

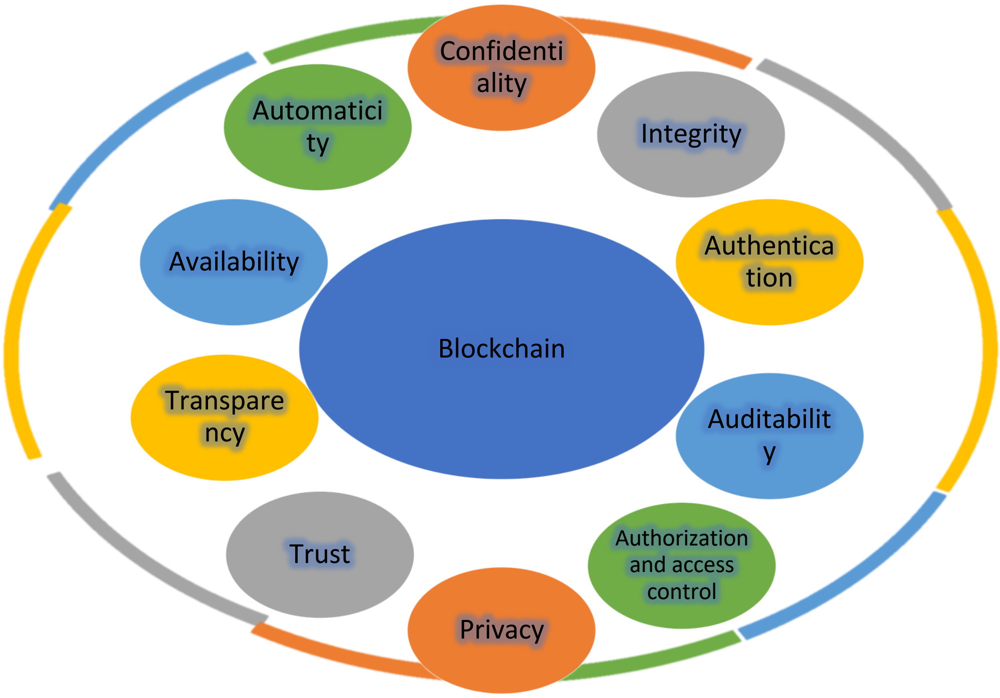


Figure 20: Summary of the different features of blockchain in smart grid

5.1.1.2. Reduction of the cost of energy due to the use of blockchain

Samuel et al. has performed a comparative study in Sub Saharan Africa on the energy cost for the conventional scenarios not using Blockchain and a future scenario integrating blockchain and concluded that the future scenario with blockchain can provide further cost reductions via incentives and P2P energy trading. They stated that the advantage of cryptocurrency trading is that there are clear working capital cost and electricity bill reduction targets. Their analysis shows that while using Blockchain, the Levelized Cost of Energy (LCOE) presents 95% decline in the cost of battery storage and 75% fall in the solar module. Furthermore, the anticipated future LCOE represents less spatial variability among different locations because while the spatial variation was 0.15$/kWh in the current system, it will decrease to 0.049$/KWh when using Blockchain (Samuel et al., 2020).

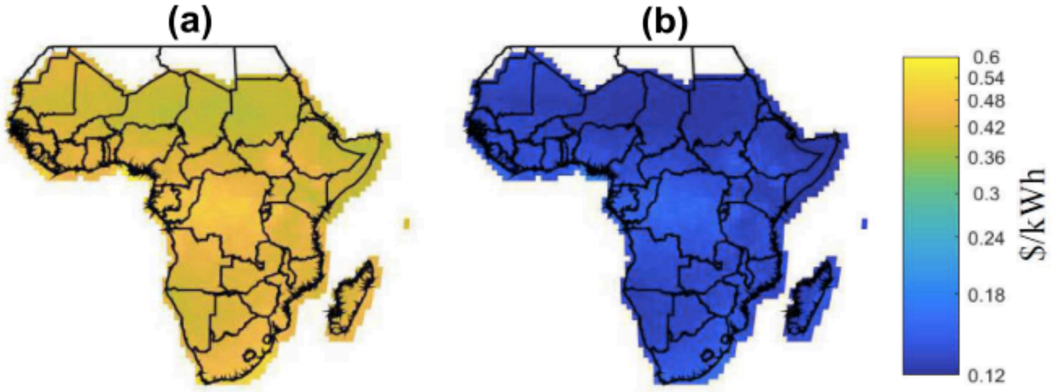


Figure 21: LCOE between the two scenarios: (a): without blockchain and (b) with blockchain (Samuel et al., 2020)

5.1.2. Weakness: Low awareness and preparedness for new ICT technologies, including blockchain in SSA

Njuguna Ndung'u and Landry Signé have made research on Capturing the Fourth Industrial Revolution: a regional and national agenda for African countries. They have stated that "The Fourth Industrial Revolution and digitization will transform Africa into a global powerhouse" (Ndung'u & Signé, 2020). The African economic outlook 2020 stated that Africa lags behind in the digitalization and the technology of fourth industrial revolution (AfDB, 2020). Nevertheless, the continent has met considerable growth in the sector in the last recent years.

Although ICT sector in Africa is largely predominated by mobile digital financial services, in the recent years, artificial intelligence and blockchain has started being attractive to the continent. The report of Ndung'u and Signé on the fourth industrial revolution in Africa has shown a recapitulation of the ICT indicators in Africa. They focused on three points: the technology access, the technology use and the technology preparedness (Ndung'u & Signé, 2020). All indicators show that Africa still lag behind compared to other region.

Particularly for advanced technology qualified among the fourth industrial revolution, Kapoor et al. conducted a survey to several SSA countries to know their awareness and preparedness on the main technologies of the fourth industrial revolution which are the AI and robotics, Internet of things, big data, 3D printing and finally blockchain. The result of the survey demonstrated that most of the African firms has reported moderate to very low levels of business preparedness for the Blockchain, artificial intelligence and internet of things.

Particularly for blockchain, although more than 10% have very low awareness, more than 20% are highly aware of the technology. The issue is on the preparedness where more than 50% claimed of being not prepared for such technology (Kapoor et al., 2019).

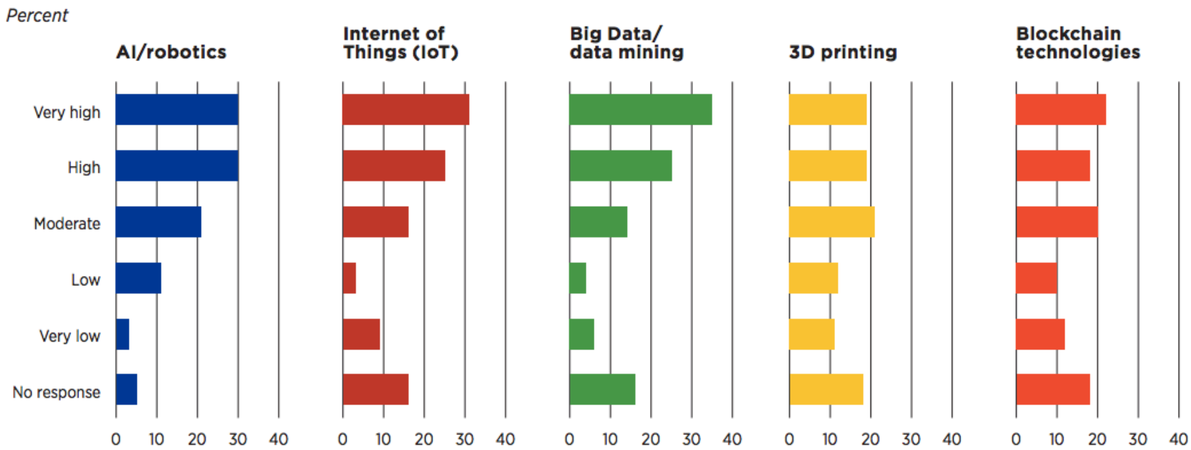


Figure 22: Awareness of 4IR technologies in SSA (Kapoor et al., 2019)

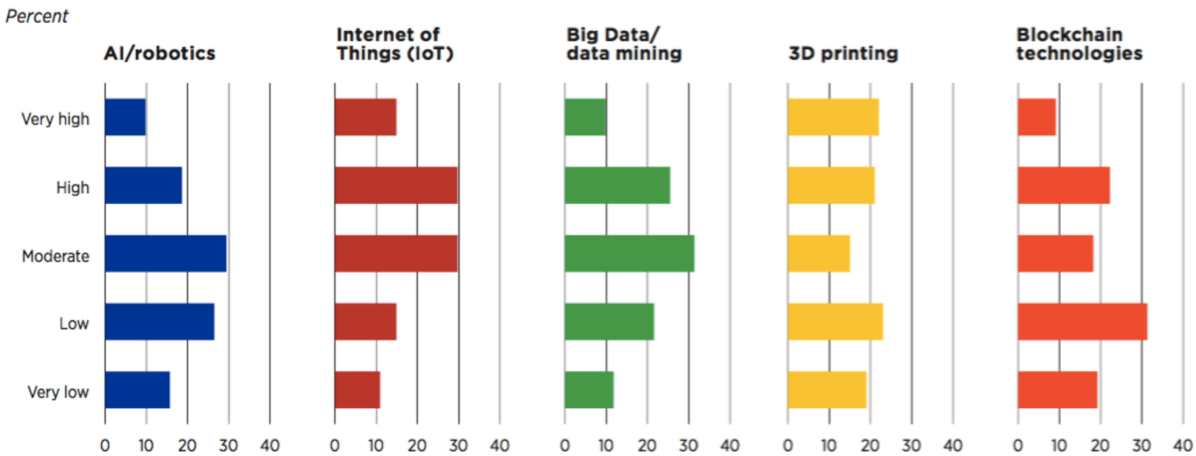


Figure 23: Preparedness for 4IR technologies in SSA (Kapoor et al., 2019)

That low awareness and preparedness of African countries about blockchain technologies would affect the implementation of this technology in the energy sector.

According to the same source, 27% of the African companies which took part in the survey were not using any form of 4IR (figure. 24). For the 4IR currently deployed, the majority is about big data and Internet of things, blockchain occupies only around 17% of the deployment. Moreover, for the planned use of 4IR, 33% were planning to use 4IR whereas 18% do not. Artificial intelligence and advanced robotics are the most solicited.

Therefore, the deployment of blockchain technology in Africa is still low, either currently or in the future.

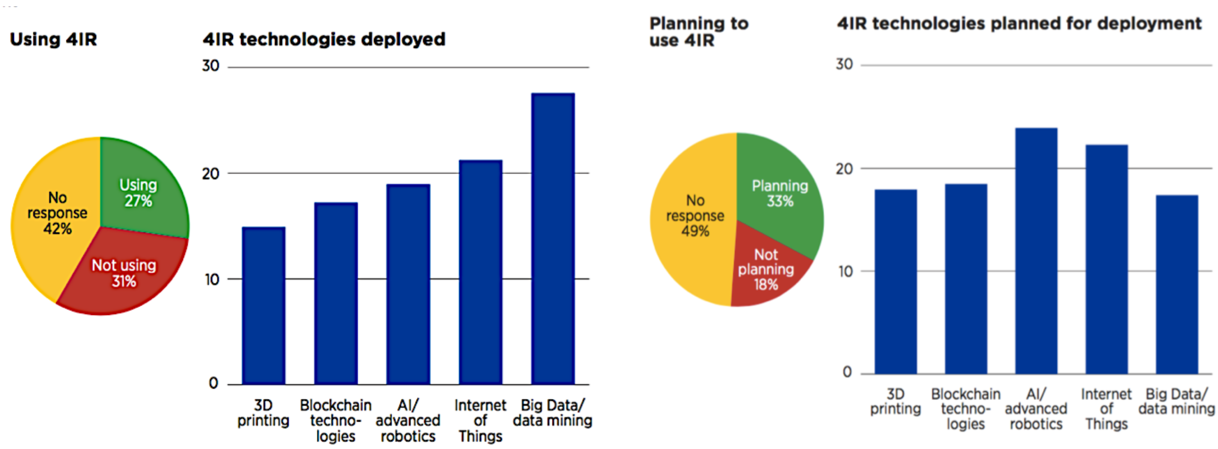


Figure 24: Current and planned use of blockchain, AI, IoT and other new technologies in SSA (Kapoor et al., 2019)

5.1.3. Opportunities in favour of promoting P2P energy trading using blockchain

5.1.3.1.Decreasing cost of stand-alone solar technology

Although on-grid system has always been the main source of energy supply in Africa, the last recent years, decentralized solutions has gained considerable increase in the region compared to the rest of the world. That is due to the decreasing cost of stand-alone solar PV and battery storage technologies combined with new business models using digital and appliance innovations which make decentralized system more competitive. According to the African energy outlook 2019, mini-grid and stand-alone systems offer the least-cost solution to serve over 10% of electricity supply equalling to around 160 TWh in Africa by 2040 (IEA, 2019).

5.1.3.2. Boom of SHS with mobile payment and PayGo mechanism

Innovative digital technologies and finance tools have considerable impact in reducing the number of people without access to electricity in SSA. Currently, Africa has only 50 GW of renewable capacity where 36GW are from hydropower. Nevertheless, the recent years, many African countries have put effort in solar home systems, mini-grid and micro-grid and the digitalization of communication and financial services has played a very critical role in the development of those new systems (IEA, 2019). Particularly, the development of telecommunication and payment infrastructures associated with the large increase of availability of mobile phones and mobile money accounts is one of the most impactful forms of digitalization used in the energy sector (IEA, 2017a).

Particularly for Solar home system, the possibility of an affordable payment plans over several months or years has contributed to the widespread of this technology in Africa. The customer pays only an initial deposit at the beginning, then a reasonable daily payment until the expiration of the payment. Mobile networks have allowed direct communication with customers and remote control of devices which disable the SHS when the customers were not able to pay. With such mechanism, the ReadyPaysolar Systems of the Fenix International Company has enabled 500 000 households in SSA to benefit from their SHS. Like Fenix, the PowerCorner project is also a subsidiary of ENGIE which is the market leader in off-grid solar in Africa. The PowerCorner promote smart mini-grids powered by solar energy with battery storage. It uses digital financial solution like mobile money and Pay As You Go technologies to provide 24/7 energy services to households and local businesses in rural Tanzania and Zambia (Off Grid Energy Independence, 2019). The digital payment could facilitate as well the purchase of more efficient appliances. For instance, for solar TV, 272,485 units of TV were sold in SSA using the Cash and PAYGo mechanism (GOGLA, 2019) .

The evolution of SHS is very considerable in SSA, particularly in Eastern Africa. This will be favourable for the promotion of prosumer models.

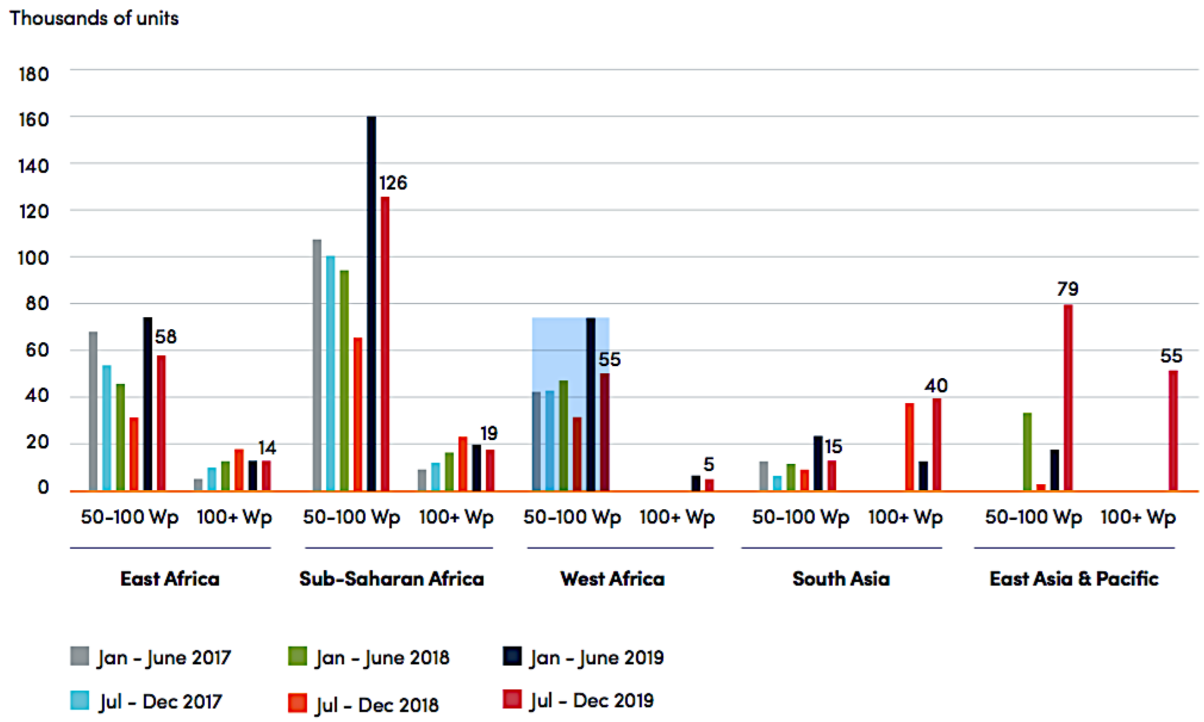


Figure 25: Semi-annual Evolution of Large Solar Home Systems Sold regionally (GOGLA, 2019)

5.1.3.3.Expansion of Investment in mini-grid sector in SSA:

According to the estimation of the World Bank, the amount of investment in mini-grids in SSA amounts so far at 4 billion USD for 1500 mini-grids (ESMAP, 2019) . The majority of those mini-grids were financed and operated by state-owned utility companies. Nevertheless, the private finance has been expanding in the recent years and around 480 mini-grids in Africa today are developed by private sector.

Regarding the global solar market and stand-alone systems, East and West Africa are particularly more advanced. Between 2012 and 2017, 75% of the funds raised by top developers accounts for developers operating in East and West Africa. It amounts at almost 700 million USD (World Bank, 2018).

5.1.4. Challenges for the promotion of P2P energy trading and blockchain in SSA

After reviewing the energy policy documents of several Sub Saharan African countries, it has been noticed that specific policies on mini-grid development does not exist or are still under development in many countries and they are not integrated into national electrification plans.

Particularly for distributed energy system and P2P energy trading, they do not appear in any policy document. However, according to IRENA, a conducive regulatory framework is one of the key success factors for P2P electricity trading platforms (IRENA, 2018b). It is also the case for the blockchain technology where the position of the central banks is either opposing to cryptocurrencies, or not recognizing it and no clear policy and regulations are available in that field.

The legal and regulatory environment is one of the most important challenges for the adoption and implementation of blockchain technology. The first challenge is the resistance from regulators across the continent who are doubting the potential benefits of this new fintech technology and are worried about the risks that it may threaten the finance of the country.

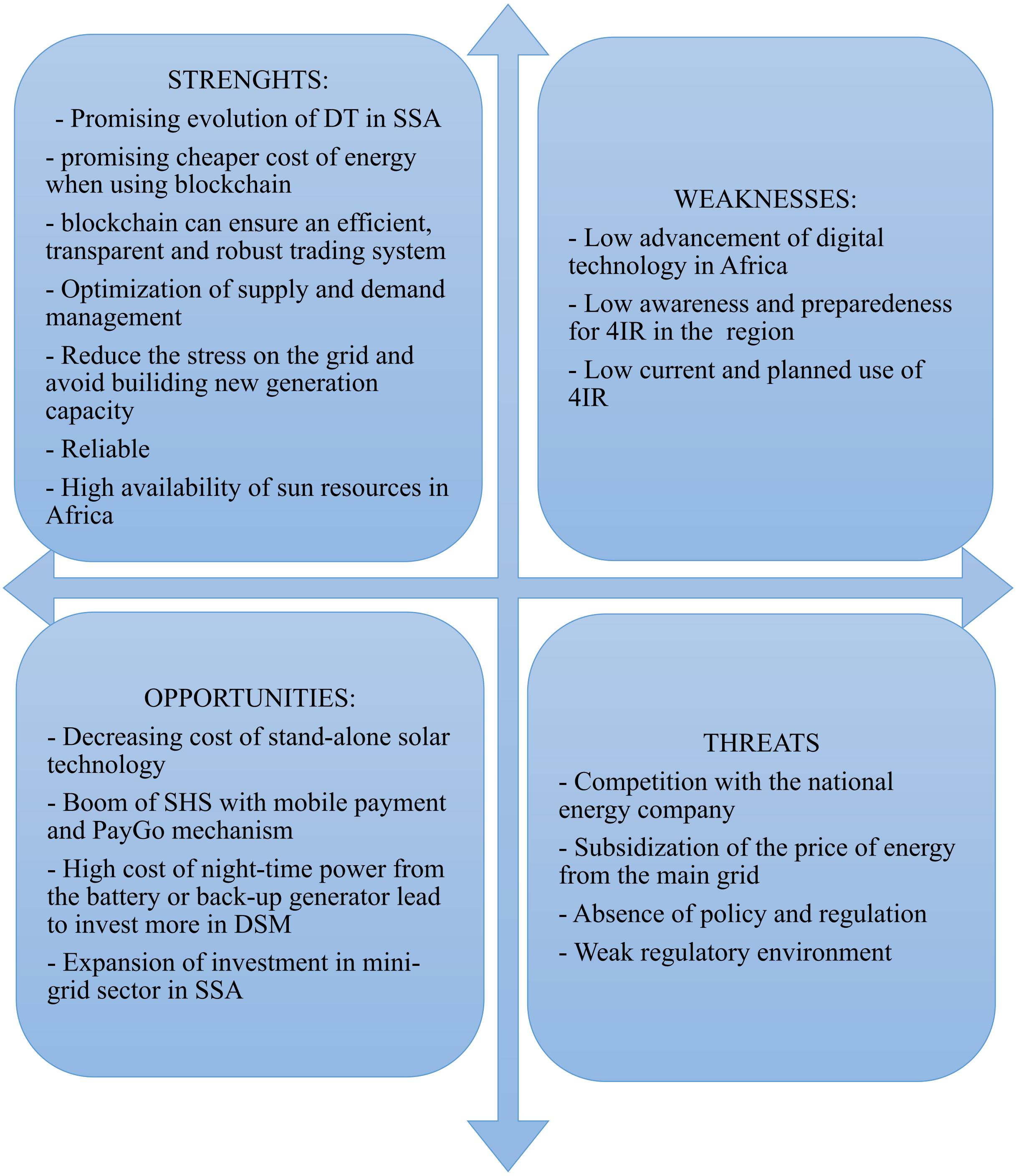
Another challenge is the unpredictability of the African regulatory environment in the face of disruptive technologies. Furthermore, not only the regulations are complex in the national level, but also, they are different from one country to another, or between regions, which hinder the interest of Fintech companies which want to work in a pan-African basis.

Moreover, knowing that the traditional system is predominant in Africa, bringing a prompt new technology is somehow disruptive and requires the new digital technology to coexist in the market with the traditional system temporary. For instance, the Kenyan bitcoin startup BitPesa was connected to the existing M-Pesa mobile money network in order to leverage the existing financial ecosystem (Ecobank, 2018).

5.1.5. Conclusion of the SWOT analysis

After conducting the analysis, the strength or benefit, the weaknesses, the opportunities and threats related to the adoption or promotion of peer-to-peer energy trading and blockchain can be summarized in the chart below.

Figure 26: SWOT analysis of the implementation of P2P energy trading and blockchain in SSA


STRENGHTS:
- Promising evolution of DT in SSA
- promising cheaper cost of energy when using blockchain
- blockchain can ensure an efficient, transparent and robust trading system
- Optimization of supply and demand management
- Reduce the stress on the grid and avoid builiding new generation capacity
- Reliable
- High availability of sun resources in Africa
WEAKNESSES:
- Low advancement of digital technology in Africa
- Low awareness and preparedeness for 4IR in the region
- Low current and planned use of 4IR
OPPORTUNITIES:
- Decreasing cost of stand-alone solar technology
- Boom of SHS with mobile payment and PayGo mechanism
- High cost of night-time power from the battery or back-up generator lead to invest more in DSM
- Expansion of investment in mini-grid sector in SSA
THREATS
- Competition with the national energy company
- Subsidization of the price of energy from the main grid
- Absence of policy and regulation
- Weak regulatory environment

5.2. Diagnostic assessment of Policy and regulation framework in blockchain/Peer-to-peer market energy in SSA

Currently, peer-to-peer energy trading are not really developed yet in Africa, the only existing projects are still at very early stage of a pilot phase, and there is no particular policy related specifically to the context. However, since P2P energy trading is one form of a mini-grid energy supply, it is very relevant to analyse the existing mini-grid framework which will also apply to peer-to-peer energy market.
The regulatory environment is quite different depending on the country.

5.2.1. Strength of the policy in digital technology and Blockchain in SSA

5.2.1.1. Willingness of African government in improving policy and regulation in mini-grid sector

Recently, increase in the understanding and awareness about the advantages of mini-grid in terms of reliability and socio-economic empowerment has been noticed in Sub-Saharan Africa, particularly in Eastern and Southern Africa

Mainstreaming off-grid renewable energy in national rural electrification strategies was one of the key messages from the IOREC (International Off-grid Renewable Energy Conference & Exhibition) 2016 in Kenya. The Director General of IRENA **Adnan Z. Amin** stated that "*The question is not whether universal access will happen through off-grid solutions but rather how do we make it happen quickly enough*?" (IRENA, 2017) Therefore, creating an ecosystem which accelerates off-grid deployment as shown in the figure 27 below is very essential, and dedicated policies and regulations is one of its foundation.

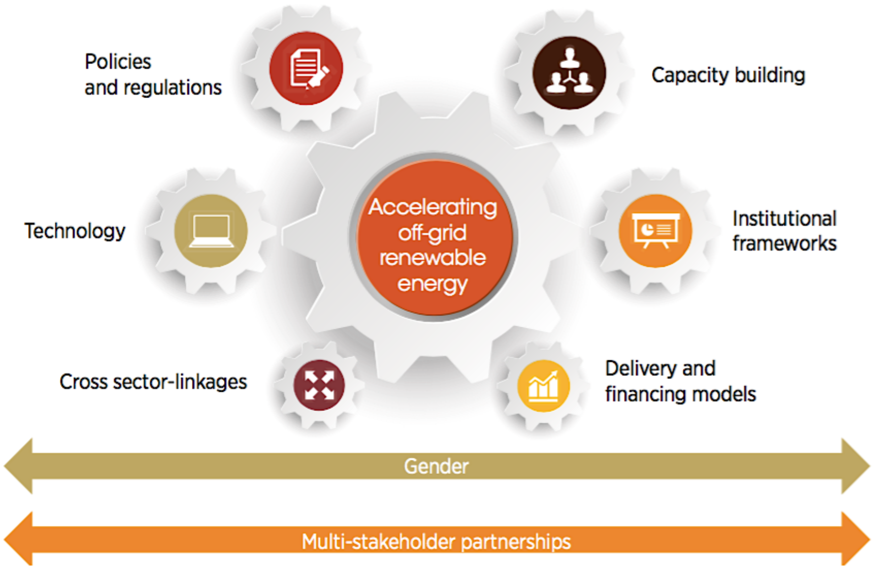


Figure 27: Elements for renewable energy mini-grids deployment (IRENA, 2017)

Off-grid renewable energy solutions need to be introduced as early as possible in the region and it has to pass through national electrification planning processes. Doing so would provide guidance to the public and private sector, as well as development banks and donors, to collaborate, mobilize and direct resources to off-grid and grid-based electrification options (IRENA, 2018b). Some countries such as Nigeria, Rwanda and Tanzania have recently incorporated mini-grid solutions in their energy plans and strategies in order to provide the basis for the expansion of electricity services.

International organizations are also taking part actively in promoting mini-grid sector in SSA. For instance, the GEF or Global Environmental Facility has led a huge mini-grid program of 344,310,000USD called GEF-7 Africa Minigrids Program. 24,235,308 USD were financed solely by GEF and the remaining were from co-financing with other partners. The main expected outcome of the project is to promote innovation and technology transfer for sustainable energy breakthroughs for decentralized renewable power with energy storage. It is a regional program for 48 months from 2019 and dedicated for 10 SSA countries which are: Angola, Burkina Faso, Comoros, Djibouti, Eswatini, Ethiopia, Madagascar, Malawi, Nigeria, Somalia and Sudan. The first component of the project consists in bringing technical assistance to Policy and Regulation in order to ensure that appropriate policies and regulations are in place including a mini-grid regulatory framework concerning tariff model, tax regime, and grid expansion risk (GEF, 2019).

5.2.1.2. Emergence of national and regional associations to lobby for favourable regulatory and policy frameworks for private sector mini-grid investment

For the most recent years, many private mini-grid developers are joining national and regional associations to lobby for policy and regulatory framework that are favourable for their investment. The associations play an important role as well in coordinating and closing the information gap between policymakers, practitioners and investors. Examples of such association are the Alliance for Rural Electrification (ARE), the African Mini-grids Developers Association (AMDA) and SEforALL Mini-Grids Partnership (5MGP). They provide interesting platforms where private and public sectors can consult and collaborate on building enabling regulatory and financial frameworks (EEP Africa, 2018).

Particularly, AMDA or African Mini-grid Developers Association has 8 principles divided into two categories: regulatory and financial. The regulatory issues cover the permitting policies, the tariff framework, the grid integration framework and the technical and safety standards. Then, the financial issues are about infrastructure financing, subsidy parity, hybrid energy systems and off-taker bankability (AMDA, 2018).

Creating similar groups and associations or a sub-group for Peer-to-peer energy trading and for smart grid would is solicited for the promotion of those new system in Africa.

5.2.2. Challenges on the policy and regulatory faced by peer-to-peer energy trading in SSA

5.2.2.1. Restricted private participation in mini-grid sector

One of the major barriers in the development of decentralized and distributed energy system in Sub Saharan Africa is the restriction of private sector to invest in electricity networks. According to the African Energy Outlook 2019, 16 out of 43 SSA countries do not allow for private sector to participate in electricity generation or networks, and 18 other countries allow only in power generation (IEA, 2019). In fact, transmission and distribution grids have monopolistic characteristics and are subject to severe regulation in many countries in the region whereas energy generation is more open. Nevertheless, in the last recent years, private investors were attracted in mini-grids and stand-alone systems due to more supportive policies and regulations and maturing markets as stated above.

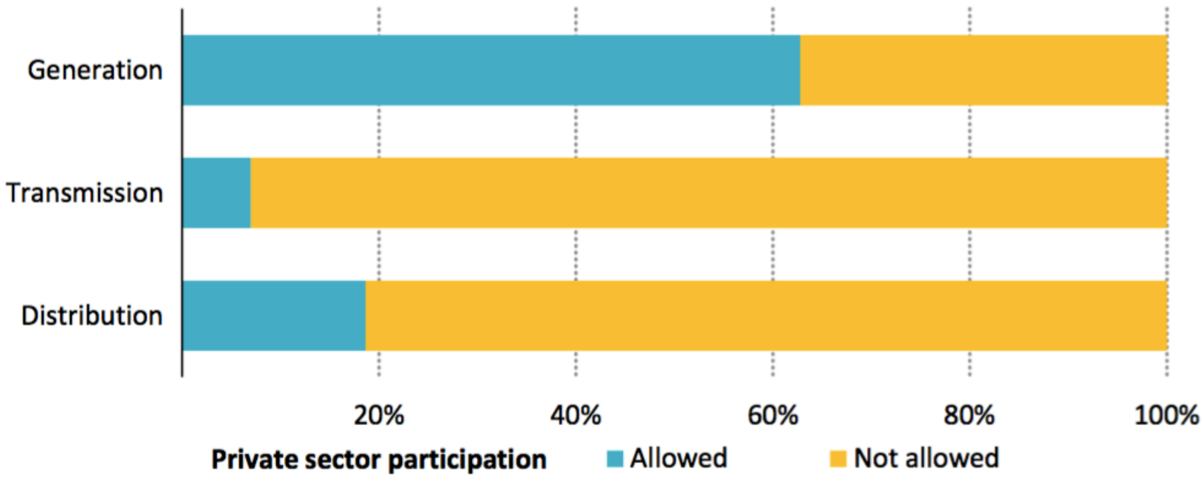


Figure 28: Private sector participation in the electricity supply chain in SSA (IEA, 2019)

5.2.2.2.Difficulty of regulatory process and licensing requirements

Regulatory process for the conventional mini-grid system is already expensive and time-consuming, so the regulatory process for P2P energy sharing community would probably be more complicated since it is a new system. Requiring concessions, licenses and environmental approvals often delayed project developments.

Some mini-grid projects are constrained to use temporary structures or to limit its size and location in order to avoid the complicate formal requirements. There is also the possibility of combining projects with similar size and technical standard in one programmatic permit.

Requesting license for a mini-grid setup is quite complicated in most of the Sub-Saharan African countries. After reviewing the policies documents of several SSA countries, generally, licensing requirements depend on the installed capacity of the mini-grid. Although most small mini-grids are exempt of license, requesting the exemption can be as difficult as requesting a full license, like the case in Uganda. Nevertheless, some countries are more favourable, for instance in Rwanda, license or environmental clearance is not required for mini-grids under 500kW. In Tanzania, the processes are clearer and developers can proceed quickly and smoothly, licensing is not needed for less than 1MW and tariff approval is not required below 100kW. Nevertheless, all projects must be registered with the EWURA or Energy and Water Utilities Regulatory Authority and get an environmental clearance (EEP Africa, 2018).

Since the P2P energy community is a form of mini-grid, it probably should follow the same requirement, though the case of P2P are not clearly stated in any policy documents.

5.2.2.3. Issues with the tariff framework

According to the EEP portfolio projects in Africa, mini-grid developers are also facing the issue with the tariff framework where regulatory bodies expect them to sell electricity at a similar price to the national grid. However, it does not account for the additional costs occurred with the bureaucracy and regulatory process. Furthermore, the grid electricity price is often not cost-effective cause it is heavily subsidized by the governments (EEP Africa, 2018). Therefore, in order for mini-grids developers to cover their cost, they have to secure grants or subsidies for their capital expenditure or also the operating expenses.

5.2.2.4. Uncertainty of the regulation about the future grid integration

One major issue of mini-grid is the unclear regulation regarding the grid integration. It affects the P2P energy trading community as well where the energy market within the community can sell their surplus to the main grid. The question is how will be the energy market mechanism function towards the existing main grid or the future grid connection. Some mini-grids are designed to be connected to national grid since the beginning of the project, so in this case they negotiate PPAs with the grid utility to feed electricity into the main grid. However, the PPAs process can take long time and some projects couldn't even be implemented due to failure in finding favourable agreement. However, when successful, this connection can provide financial sustainability to the mini-grid company.
However, many of mini-grid projects, are stand-alone grids and it will be the case of most of P2P markets which would be developed in Sub Saharan Africa. That is a source of serious challenges due to unpredictability of grid extension plan. According to EEP portfolio in Eastern and Southern Africa, several projects had to change location. Most of the rural electrification strategy in African countries do not provide details on how mini-grids will be connected to the national grid in the future if the main grid reaches to the location. That situation often limits private investment in the sector. Nevertheless, some countries like Tanzania has adopted new rules in 2017 which ensure compensation for private companies for the value of their mini-grid without the subsidies that they received. However, most other countries do not have specific guidelines or if they do, they have not been put in practice yet.

5.3. Conceptual modelling of policy and regulatory framework for P2P energy trading using blockchain in SSA

5.3.1. Parameters of study and implementation of P2P energy trading using blockchain

The diagram below shows an overview of the different parameters which need to be considered in the study and implementation of P2P energy trading using blockchain. Four main parameters have been identified, as shown in the diagram below. These are the policy and regulation, which is the main focus of the present research, the technology, the socio-economic aspect and the availability of renewable energy resources.

The research will focus mainly on the first point: the policy and regulation aspect. Nevertheless, the policy is inter-related with the 3 other points and can influence them. For instance, policy can be established to be in favour of the improvement of digital technology infrastructure, or regulation can influence the energy prices which is in the socio-economic parameter.

The analysis of these four parameters allows to know which blockchain use cases are suitable and we will study particularly the case of Peer-to-peer energy trading

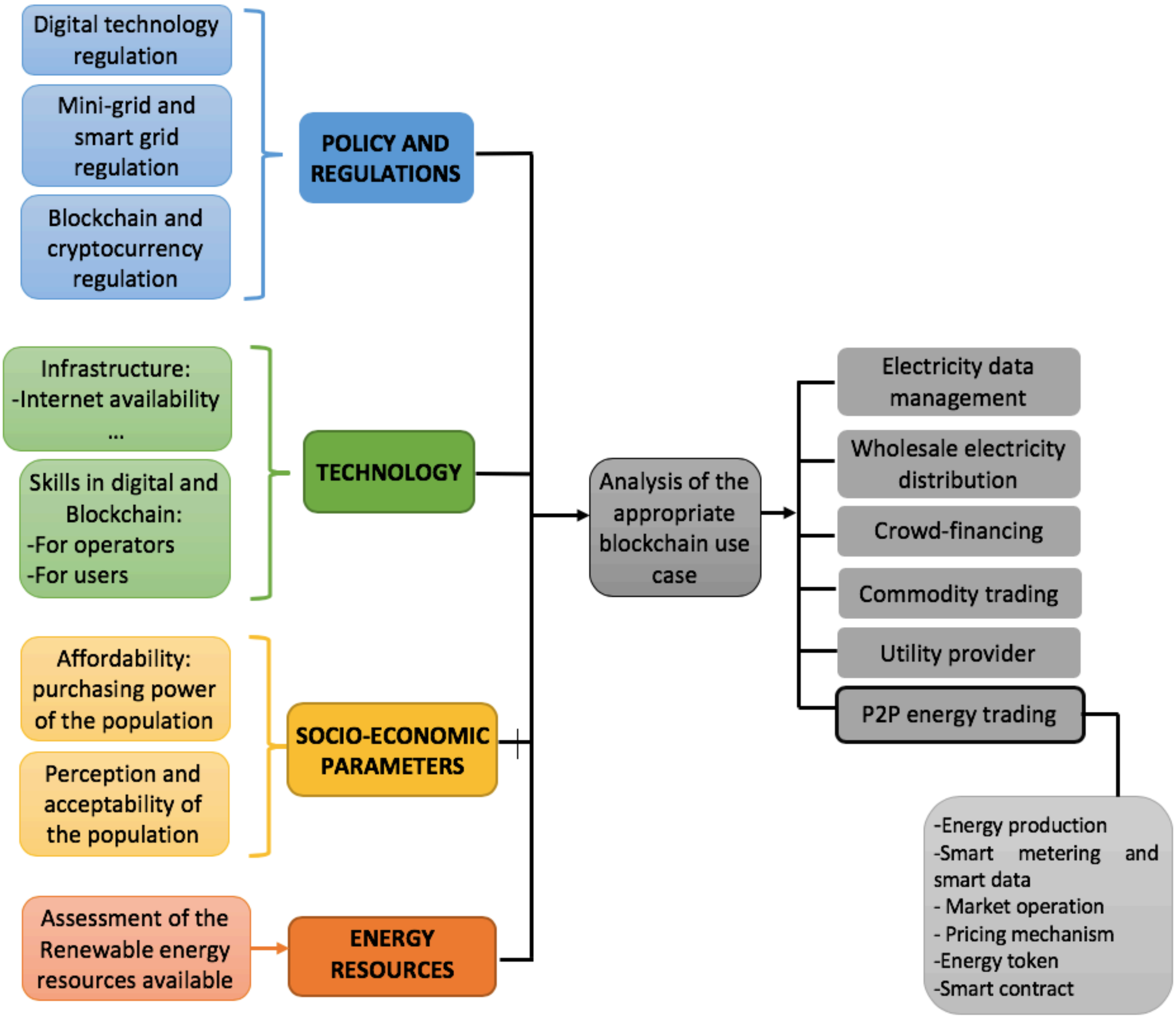


Figure 29: Elements for P2P energy trading and blockchain study

5.3.2. Required policy

The design of all the following conceptual frameworks has followed the Bobrow's principles of policy design. First, it was necessary to do the discipline breakout and consider all disciplines involved which are mainly the energy sector, law, economics principle and the technical aspect. Then, the minimum required elements for establishing peer-to-peer energy trading platform were analysed. Also, it was necessary to analyse the current African context and consider potential opposition to the policy. Also, the analysis of successful peer-to-peer energy trading enhanced by blockchain through the literature review contributes considerably to the design of the framework. Then, tinkering is also an important step since the existing policies always require continuous adaptation. In order to design the platform, a forward mapping was carried out base on designing a policy towards reaching the goal of improving the mini-grid electrification in Sub-Saharan Africa. The last step of Bobrow's principle is the judgement, which is necessary at the end of policy design.

A favourable and adequate policy is necessary to promote peer-to-peer energy trading in Sub-Saharan Africa. After analysing the requirement of P2P energy transaction system and the current situation of the policy in the region, four main areas of interventions have been identified.

The first is a supportive policy encouraging decentralization of power system. Therefore, it would be necessary that a well elaborated mini-grid policy would be mainstreamed in the national energy policy, especially for rural electrification plan. It will help to create an ecosystem which will encourage public and attract private sector to invest in mini-grid and will provide clear guidelines in their work. It will encourage banks and donors as well to fund such projects. Nevertheless, the energy supply system should ensure an effective and reliable energy supply and ensure functioning competition in the supply of energy.

The second point consists in encouraging pilot program in P2P energy trading enhanced by blockchain. Since P2P energy system and blockchain are both new concepts in Sub Saharan Africa, engaging in investment in the sector is like an exploration and investors find it may be risky. That is why government should support pilot program as test bed, in regulatory sandbox which provides a framework to allow FinTech start-ups and other innovators in blockchain technology to conduct live experiments in a controlled environment under a regulator's supervision.

Another important requirement is to favourize access to capital for platform developers. As already mentioned that the investment in the sector is new, it would be hard for start-ups to get funding for their project, therefore government can intervene to facilitate their access to financing. It can be through ensuring their guarantee, backing up their project or provide direct incentives through removing some taxes related to their work.

Then, one of the major concerns hindering the development of P2P energy trading and mini-grid solution in general is the difficulty of the regulatory process and license request. Therefore, bureaucracy related to that field should be limited and permit request should be facilitated either in time and cost so that the project will be competitive.

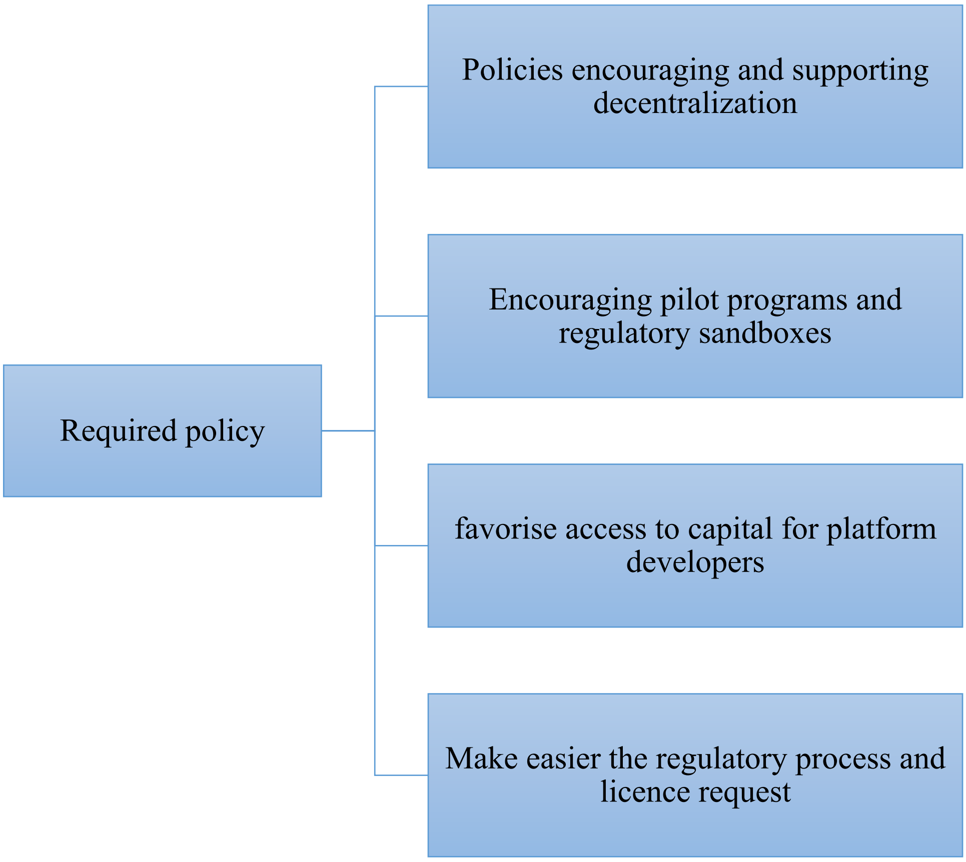


Figure 30: Schematic overview of the policy framework

5.3.3. Regulatory requirements

The design of the regulatory regulations followed the same Bobrow's principles. The regulatory requirement for P2P energy trading can be divided into two: the retail market and the distribution network.

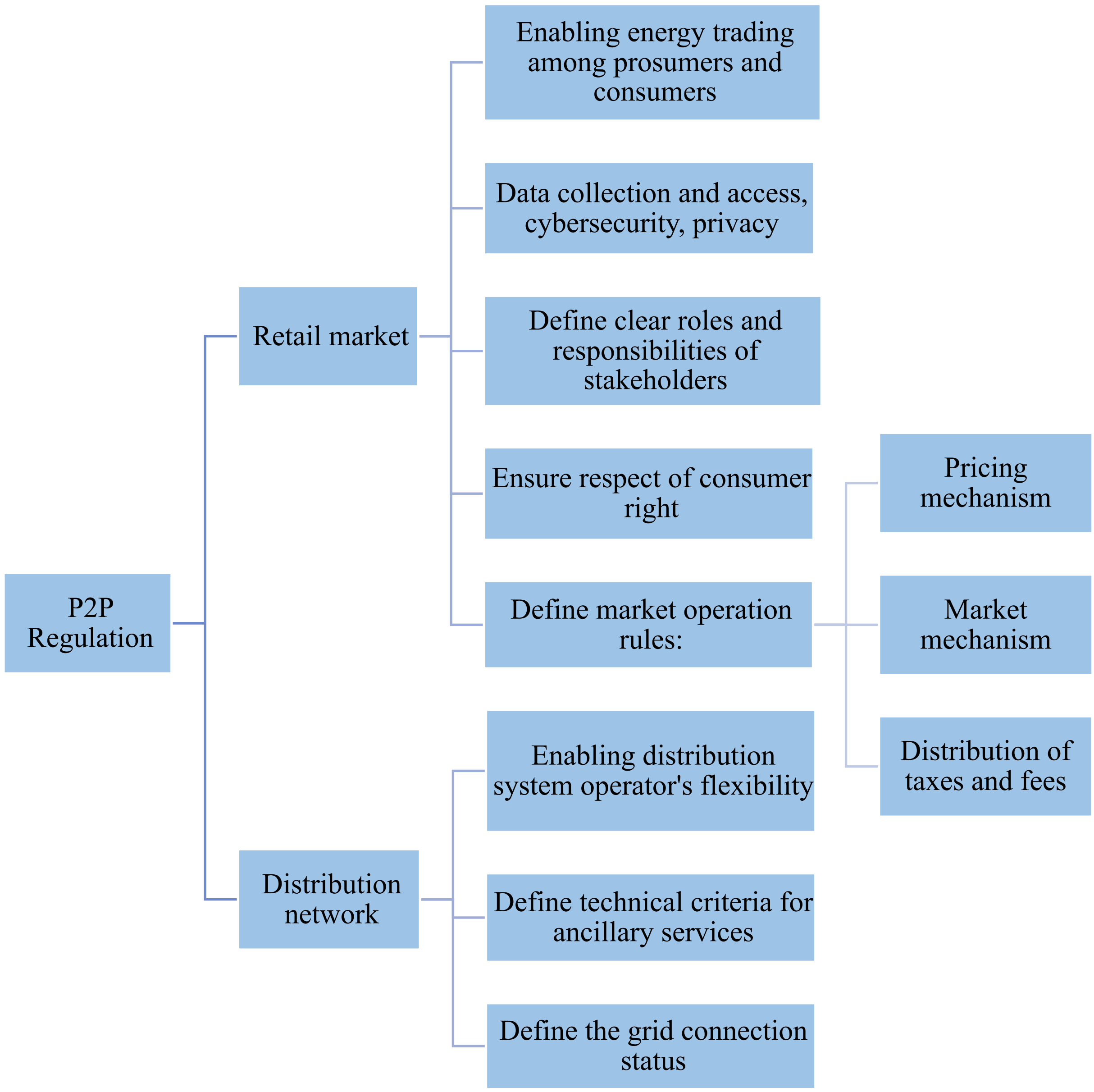


Figure 31: Conceptual model for the P2P energy trading regulation

5.3.3.1. Retail market regulation

The fundamental regulation required for a P2P energy trading is to enable energy trading among prosumers and consumers within the community. It should consist in providing the right to sell electricity or precisely a legislation permitting local peer-to-peer trading. It involves also defining well the statutes of prosumers and consumers and their respective roles and engagement.

The second requirement is to establish regulation on data collection and access as well as cybersecurity and privacy for the developers or platform owner and for the peer participants. In fact, the feature that all the data and transactions on a blockchain are visible to all blockchain nodes may threaten the privacy of the parties participating in the P2P community (Son et al., 2020). That is why a clear regulation in that point matters.

Then, defining clear roles and responsibility of stakeholders is also very important. This point will be detailed in another section below.

Furthermore, consumers are at the heart of P2P energy trading. Therefore, ensuring that their rights are respected among the stakeholders should be among the priorities. Consumers or prosumers need consumer protection. The aims of the regulation should be to provide a secure, affordable, consumer-friendly, efficient and environmentally friendly supply of energy to the consumers. Some relevant legal principles have their basis in civil law but particularly, prosumers should be recognized in legislation and consumer law safeguard should be implemented to consumer-to-consumer transaction and their rights and obligations in P2P should be well-defined.

Then, market operation rules have to be very well-defined. It involves the pricing mechanism, the market mechanism as well as the taxation and fees.

5.3.3.2. Distribution network

In order to procure flexibility from P2P platforms, enabling distribution system operator's flexibility is important.

Besides, it is also necessary to define technical criteria for ancillary services. Ancillary services refer to functions that help grid operators maintain a reliable electricity services and the proper flow and direction of electricity. It addresses imbalances between supply and demand, and help the system recover after a power system event. Ancillary services are basically about frequency control, voltage control and reactive power supply and black-start capability and grid restoration (Oureilidis et al., 2020). It includes loss compensation, load following, system protection and energy imbalance. They were traditionally provided by generators but recently due to the integration of intermittent generation and the development of smart grid technologies, there is a need for new type of ancillary services and complementary to the existing one. The new ancillary services provided by a distributed energy system include inertial response, active power ramp, frequency response, voltage control, fault contribution and harmonic mitigation (Oureilidis et al., 2020). Clear regulations are necessary to define and set the criteria of those innovative ancillary services.

Last, defining the grid connection status is necessary in order to ensure the developers about what will happen when the main grid will reach the community where they operate. In a case where P2P trading is using the main grid, regulation is also needed to determine network charges.

5.3.4. Basic elements for Blockchain regulation

5.3.4.1. General regulation on blockchain

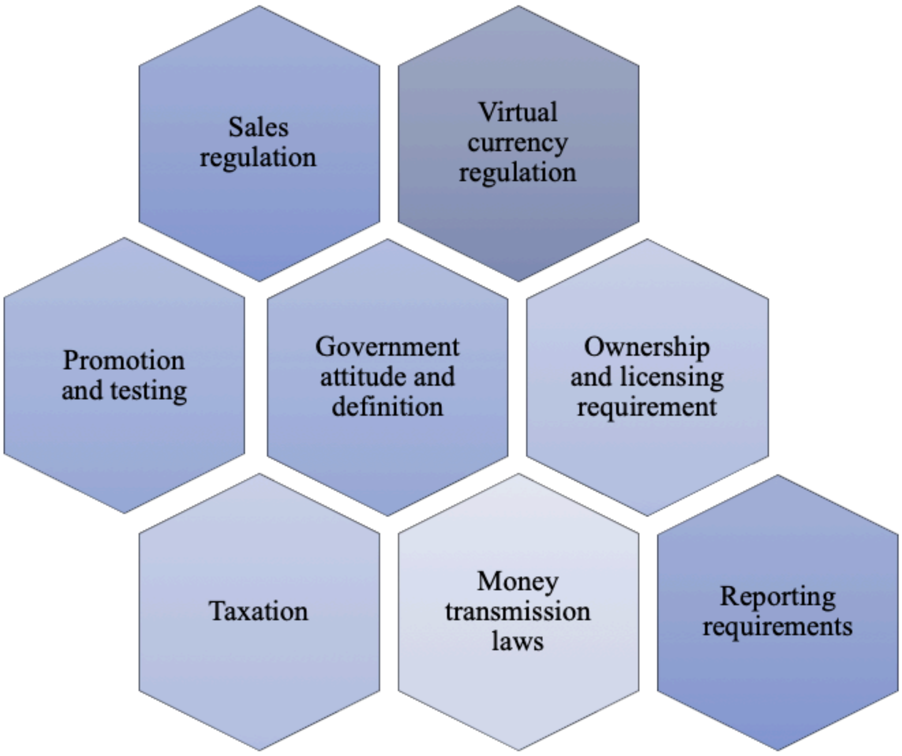


Figure 32: Elements for the Blockchain regulation

Blockchain situation in a country depends on several factors. The main one is the government attitude and definition which is most of the time determined by the Central bank or the national financial authority. It determines how are the government views and approaches on cryptocurrency. African governments need a full awareness that the digital age is progressing with an ever-increasing dynamism and African countries need to embrace these developments. A clear definition of cryptocurrency would be necessary to consider it as money or not, if it is a legal tender and to determine its situation compared to fiat currencies.

Government also needs to raise consumer protection and legal concerns and preview measures to limit fraudulent acts. Defining tokens and attitude toward the use of tokens should also be clearly defined.

Then, a legislation regarding cryptocurrency should be well defined. First, a clear definition of the concept cryptocurrency should be provided. And the legislation should cover issuing, mining, possession and trading in cryptocurrency. It is the same for security, asset and utility tokens.

After that, defining sales regulation is also important for cryptocurrencies. Commercial distribution may interfere with licensing requirements for distributors under financial supervisory law. The legal position of cryptocurrency is very complex. Some points need detailed assessment. First, it is necessary to determine if cryptocurrencies are considered as financial instrument or units of account under the countries' banking and trading authorities. Second, it should be defined if cryptocurrency is qualified as security and if rights are attached to the tokens and also if there is a minimum required fungibility. Then, the classification as security and token sale needs also to be defined and well regulated.

Another important point in blockchain regulation is the taxation. Handling cryptocurrencies can have complex tax implications especially in terms of classification for VAT-purposes which is not well-defined yet in any Sub-Saharan African countries. That basically involve the Ministry of Finance and include the VAT regime applied to exchanging cryptocurrency into fiat of vice versa, the taxability of the use of cryptocurrencies as a mean of payment, mining activity, offering digital wallet services and also the taxation applied to providing crypto exchange platform.

Promotion and testing are also very important for Sub-Saharan Africa region where blockchain is just at its very early stage. Sandbox or other light-touch regulatory regime should be made available for commercial or activities dealing in or handling of cryptocurrencies or any other types of tokens.

Then, there is also the money transmission laws and anti-money laundering requirements which is important to avoid any illegal activities. Defining ownership and licensing requirements is also necessary. It includes portfolio management, principal broking services, contract broking or investment broking. The position of the central bank towards mining activities should also be well defined as well as the reporting requirement which concerns mainly cross-border transactions involving cryptocurrencies.

5.3.4.2. Blockchain framework in P2P trading

Several elements enabled by blockchain need to be regulated in order to have an efficient performance of the P2P energy system.

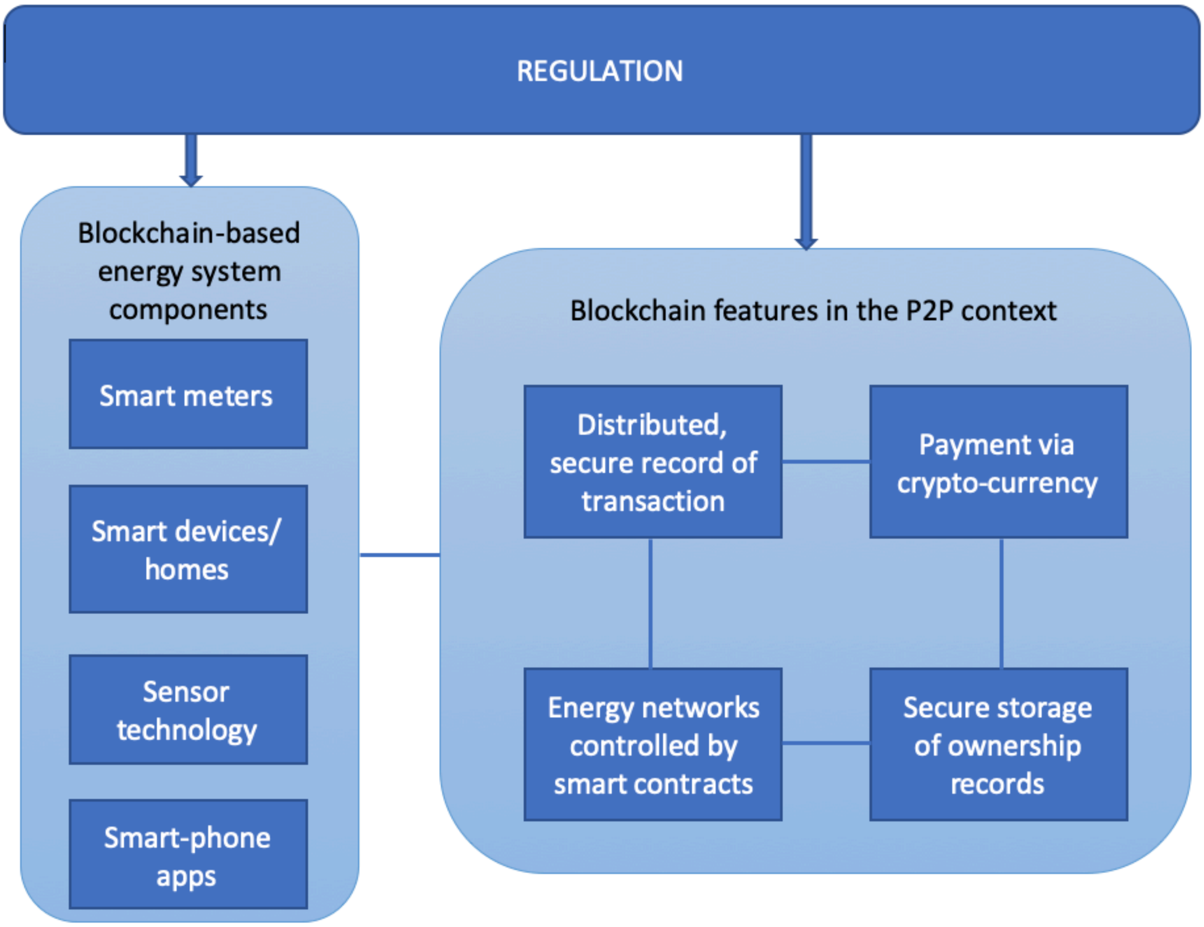


Figure 33: Conceptual model for the P2P energy trading integrating blockchain

Blockchain technology is promising in enabling decentralized energy supply system. It would enable the prosumers to sell directly the energy they generate to their neighbours. Blockchain systems initiate and transmit transactions while recording them in a tamper-proof manner. In a decentralized energy transaction and supply system, transactions between consumer and producer can be done automatically or manually and they are recorded on a tamper-proof way. And electricity is delivered via the network or the power grid. A clear regulation should govern the different elements and processes in the system.

In a P2P energy system using blockchain, supply and demand are balanced by smart contracts including balancing market, microgrids, virtual power plants and storage. Four main components are necessary in a blockchain-based energy system. They are smart meters, smart devices/homes, sensor technology and smart-phone apps. In order to use blockchain system, liberalizing metering operation business is necessary. Smart meters provide intelligent measurement for measuring and transmitting the energy demand of consumers and the energy output of producers.

Although blockchain is a new concept, the related legislations don't have to be all new. Some principles governing transactions using blockchain can be driven from the civil law principles or civil code of the country, but there can be any additional legal requirements for energy-related contracts. A new law dealing with energy supply contracts has to emerge but can be based on general civil law principles and other existing legislation, depending on the country. The contract's term has to be very clear, the price variations, termination deadlines, information on any maintenance service offered by the developers, the available method of payments, the liability of the parties as well as any eventual damages to pay on a breach of contract, information system, and eventual dispute resolution.

5.3.5. Stakeholders roles and responsibilities

P2P energy trading is relatively a new system in Africa and its adoption will bring considerable changes in the energy sector. Therefore, the regulatory changes involve a great number of stakeholders across the whole electricity supply chain, with different level of sensitivity towards the changes. The promotion of P2P energy trading will have impacts to the national energy utilities activities and also those operating in the market of solar stand-alone equipment.

However, the main stakeholders involved directly in the P2P energy activities are the consumers & prosumers and the P2P market operators or developers. The customers and prosumers are engaged in the P2P energy trading and provide services to the power system while the P2P market operators or developers develop and operate platforms for P2P transactions in collaboration with ICT companies. They ensure as well that the platform is secure and trusted. Legislation needs to be clear in order to strike balance between consumer protection, the developers benefits and the communities impacts. In the prosumers and consumers' side, it is necessary to know how do we manage to get people to trade their own energy, and establishing clarity on prosumers' rights and obligations is important. It is important as well to ensure that local stakeholders like the energy community and industry are engaged.

It is also necessary to recognize the crucial role played by local stakeholders, including public sector bodies in the context of peer-to-peer energy trading. Since African people have high consideration for public bodies, they can become a key intermediary between energy consumers and P2P market operators. Dialogues with industry and stakeholders involved in self-consumption projects are also recommended to learn from their experiences.

5.3.6. Necessity for developing education and skills in digital technology

In order to take full advantage of the opportunities from the fourth industrial revolution, African countries need to reimagine their education, employment and growth strategy (AfDB, 2020), Africa needs to prepare for the implications of the 4IR. In order for the continent to fully embrace the emerging technologies, developing digital technology skills is very necessary. The African economic outlook 2020, which is focusing on developing Africa's workforce for the future emphasizes the importance of investing in the development of critical future skills such as job-specific digital skills and job-neutral digital skills.

Innovation hubs are growing very fast in Africa and in 2019, the GSMA reported that there are 618 active tech hubs in the continent, which is 40% more than the previous year (Ajadi & Giuliani, 2019). For instance, the African Development Bank has launched the Coding for Employment program which plan to support the creation of 130 innovation centres across Africa by 2025 in order to promote a new generation of African youth skilled in the new digital technology. The program comprises of four main features: establishment of innovation centres of excellence, provision of demand-driven program, Creation of linkages to employment and to the digital eco-system and the last one is the promotion of research. The investment in digital literacy (computer and internet literacy) is also one of the preoccupations of African countries in order to increase productive capability (AfDB, 2020).

Rwanda is a very good example in terms of efforts for embracing the 4IR by fostering collaboration between research and industry. In 2016, the Rwandan government launched its flagship of 1.9 billion USD of digitalization project. They have the KIC project of Kigali Innovation City which is a platform of technology clusters supported by the government to promote collaboration between universities and industry.

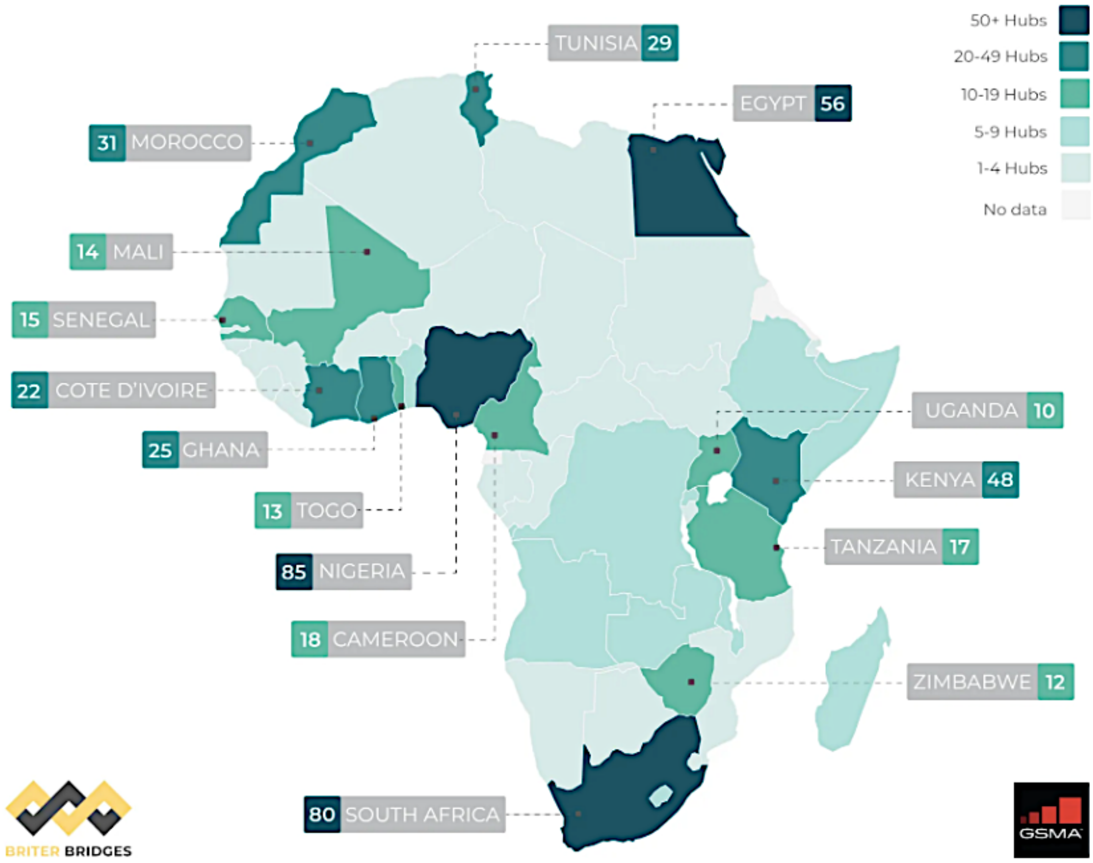


Figure 34: Mapping of the existing tech hubs in Africa in 2019 (Ajadi & Giuliani, 2019)

5.4. Case study: P2P energy trading and blockchain in Kenya: Case of Rehub company

5.4.1. Kenya digital technology situation

As it can be seen in the graphic below, Kenya has the highest internet penetration in Sub Saharan African countries. Its advancement in terms of ICT and technology compared to the other SSA countries was one of the reasons of choosing Kenya as a case study.

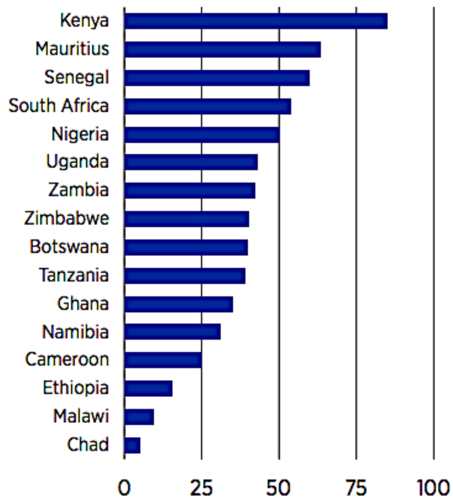


Figure 35: Internet penetration rates in some African countries (Kapoor et al., 2019)

Regarding the current use of digital technology in the Kenyan energy sector, the digital payment tools such as the Cash and PAYGo is particularly developed in Kenya compared to the other countries in the region. Also, for solar energy efficient appliances, among the 272,485 off-grid solar TVs sold in SSA during the second half of 2019, 130,198 accounts for Kenya alone, which is almost half. The same for refrigerators, 3,415 units of solar refrigerators were sold in SSA region and 1,592 units are only for Kenya. All of that is promoted by the PAYGo mechanism (GOGLA, 2019).

5.4.2. Mini-grid situation in Kenya, including P2P and its challenges

5.4.2.1. Kenyan mini-grid situation

Kenya is very enthusiastic for off-grid solutions. During the 3rd edition of the International Off-grid renewable Energy Conference and Exhibition (IOREC) in Kenya in 2016, the cabinet secretary of the Ministry of Energy and Petroleum in Kenya, Hon. Charles Keter, stated that Kenya was committed to ensuring universal access to energy by 2020 and this be achieved through exploitation of locally available energy sources including off-grid solutions (IRENA, 2017).

Although we are now in 2020 and this goal was not reached, Kenya has made significant progress in terms of rural electrification and mini-grid expansion. The total installed mini-grid in Kenya was estimated at 19.2 MW in 2014 predominated by 18.1 MW of thermal mini-grid plant and only 5% was from renewable energy where 0.55 MW of wind and 0.5 MW of solar PV.

The most common mini-grids ownership models in East African community are the utility-owned and private sector mini-grids. The national government of Kenya is operating mini-grids in Kenya which is predominantly diesel-powered. Besides, there are also several private sectors operating in mini-grids. Fully aware of the importance of mini-grid in achieving universal electrification by 2020, the Kenyan government has invited the private sector to join in promoting hybrid projects under the country's FIT that is applied to mini-grid of more than 500KW from renewable energies. Nevertheless, although the country is quite enthusiastic about the private sector participation, the mini-grid private market in the country has recently slowed down.

Particularly for P2P energy system, Kuruseelan and Vaithilingam cited Kenya in their article as among the countries where there is a growing interest in P2P energy sharing in off-grid rural areas, along with India and Bangladesh (Kuruseelan & Vaithilingam, 2019).

5.4.2.2. Challenges for off-grid solutions, including P2P

The New Climate Institute published a study on the role of renewable mini-grids in Kenya's electricity sector and stated that mini-grids are included but significantly under-represented in the 2018 Kenya National Electrification Strategy or KNES. The mini-grid sector is also predominated by public investment due to limited policy support for private sector. Nevertheless, it has been improved with the New Energy Act 2019 (Marie-Jeanne et al., 2019). The first private company allowed to build and operate microgrids in Kenya was in 2014. Kenya has shown openness to allow alternative options to get grid expansion (Ma et al., 2018)

Besides, off-grid solutions are more advanced in Kenya compared to the rest of countries in SSA region. However, although the Kenyan government is committed to off-grid solutions especially for rural areas, several challenges are hindering the development of such solution. The main challenge lays on the tariff framework due to the low purchasing power of the majority of the population. Tariff analysis is therefore one of the main focus of the early-stage feasibility work. In fact, there is a tension between the unified consumer tariffs and the higher cost of electricity supply in rural area which most of the time require subsidies (REN21, 2016). That challenge is affecting P2P project as well and studying the electricity price in the P2P market is very important before the deployment of such project. Nevertheless, the price in a distributed energy system tends to be lower and particularly the introduction of blockchain technology in the mechanism has also the advantage of lowing down the price.

Another challenge for private mini-grid developers not only in Kenya but the whole SSA are the regulatory uncertainty around the allowable consumer tariffs, asset taxation and depreciation, and other issues. There is also the uncertainty related to the national grid extension plans, on what happens after the main grid will reach the community covered by mini-grid.

5.4.2.3. Standard tariff model for mini-grid in Kenya

Kenya has a detailed standard tariff model called TAM (Tariff Application Model) designed to be used for all mini-grid tariff applications to the Energy and Petroleum Regulatory Authority of Kenya (EPRA). Its primary users are mini-grid developers, EPRA, electricity consumers and other interested stakeholders. The final version of this model was established in 2017 and it provide regulatory certainty, consistency, predictability and efficiency to mini-grid developers, investors and consumers. Any P2P energy project is expected to follow this model for its tariff setting. The Tariff Application Model consists of 10 sheets which are the guide, the capital cost details, the tariff inputs, the Loan Drawdown, the load profile, the tariff calculator, the loan repayment, financials, output summary and sensitivity (ERC, 2017).
Although peer-to-peer energy trading is a particular new model of mini-grid, its tariff model will have to be based on that general Tariff application model for mini-grid.

5.4.2.4. Kenyan Energy Act

The Kenyan Energy Act was established in 2019 and has brought considerable changes and improvement in terms of energy policy and regulation. The new act comprises of the energy policy and integrated energy plan for Kenya where it is emphasized that the government has the obligation to facilitate provision of affordable energy services to all persons in Kenya. It gives also details on the respective attributions of the four energy entities of the country which are the Energy and Petroleum Regulatory Authority, the Energy and Petroleum Tribunal, the Rural Electrification and Renewable Energy Corporation, and the Nuclear Power and Energy Agency (Government of Kenya(GoK), 2016).

The energy act gives also instruction for licensing in electrical energy. It is stated in the article 117 of the Act that a person who wishes to carry out the generation, exportation, importation, transmission and distribution and retail supply of electricity must apply for a license as the case may be to the Authority. Then the document gives details about the legislation for transmission and distribution of electrical energy in the country. It is also stated in the Energy Act that the Cabinet Secretary may upon recommendation of the Authority make some regulations as may be necessary or expedient for the achievement of the objectives of the act. Therefore, specific regulations for P2P energy trading can be developed based on the existing regulation.

5.4.3. Cryptocurrencies and blockchain situation and regulation in Kenya

In a public notice shared in December 2015, the Central Bank of Kenya warned the public that Bitcoins and virtual currencies are not legal tender in Kenya nor are they regulated (CBK, 2015). Although many Kenyans are enthusiastic towards cryptocurrencies recently, the Central Bank of Kenya or CBK is not in favour of the proliferation of this innovative finance and has shared an official notice to warn the public about virtual currencies. It stated that bitcoin is an un-regulated digital currency which is not issued or guaranteed by any government of the central bank. In Kenya, national and international transfer of money services is regulated by the Central Bank of Kenya Act and other legislation, but the cryptocurrencies are not recognized there. The Central Bank emphasized as well the risks associated with cryptocurrencies such as the intractability of the transactions, the inexistence of regulation applying in it and the fact that virtual currencies are speculative in nature.

Nevertheless, recently, the Kenyan government has recognized the importance of the potential development implications of the promotion of digital technology. Therefore, the Cabinet secretary on the Ministry of Information, Communication and Technology have created in 2019 a taskforce intended to explore and analyse the emerging digital technologies such as distribute ledger technologies, artificial intelligence and IoT (Ministry of Information Communication and Technology, 2019).

5.4.4. Practical study of the case of Rehub company in Kenya

5.4.4.1. Overview about the company and its project on P2P energy transaction

Rehub is a company created in Kenya in 2010 by some Kenyans passionate in renewable energy technology. Its main working area is Kenya but they extended their project to Zambia in 2017 with a grant funding. The main activities of the company are about consultancy projects for renewable energy, decentralized energy and particularly Solar Home System where RED+ is the name of the product. They are engaged in Renewable energy demonstration project as well. The main source of revenue of the company is from solar equipment installation. Currently, the company is having an innovation project in promoting renewable energy decentralized through managing domestic demand.

Rehub Company is now conducting a pilot study on P2P energy trading which is carried out in a school where three (3) dormitories are considered as three household participants in the energy trading. The main purpose of the project is to study the technical aspect of P2P energy trading and to collect data such as on the variation of energy consumption. The testing project will still take more than 6 months. It is progressing and giving promising result but carrying out the real project may still take up to 3 years or more.

5.4.4.2. Technical aspect of the P2P energy trading operated at RED+

The main point of P2P energy trading is to optimize the energy supply and demand. Without P2P energy trading, the energy is not consumed at the same time as it is produced. During some time of the day, the consumption in the household is very low when people go out while the energy generated by the solar panel is high. Besides, batteries cannot store all the energy generated, so the surplus is lost. Therefore, the goal of RED+ is to have more energy consumed at the time of production.

The technical aspect of the solution can be summarized as follow: The participants who own solar panels, called prosumers generate electricity from their own solar panels. The prosumers and consumers transact energy between them according to the availability of energy produced by each prosumer. An AI system monitors the energy production and the devices can be controlled through IoT. The data related to energy production from the solar panels are measured by the smart meter so that the energy generated by each prosumer can be known at any time. The smart meter measures the energy bought and consumed by each prosumer as well. Energy token are issued according to the data from the smart meter and help to keeping track on the amount of energy bought and sold by each prosumer." The RED+ market place is the platform where the selling and buying of electricity is occurring. Through software, the company optimizes the energy trading by managing the amount of surplus energy available for trading from the prosumers and the energy demand from the customers which varies with time. The price of electricity varies with time as well according to the supply and demand. The customers buy the energy tokens at the RED+ market place with a fiat payment.

The role of Blockchain in the system is to allow tokenized payment. They are using NEM blockchain. Since the project is just a test for now, the token does not have real value yet. The token will be converted to real value when the real project will start.

5.4.4.3. Identification of areas needing policy and regulations along the value chain of energy generation and trading

The conduct of the case study at Rehub has permitted to validate all the necessary points on policies and regulations required for P2P energy trading in SSA. But particularly for the case of Kenya, the following points are particularly emphasized. General policy and regulation on digital technology in the mini-grid sector is necessary as well as clear blockchain and cryptocurrency policy and regulation. For the specific regulations related to P2P, policy allowing individual to generate and sell electricity and regulating the energy production is necessary. It includes as well tax regulation for the prosumers and market operators getting income through selling electricity. A clear smart metering, smart energy data regulation as

well as market operation regulation and pricing mechanism are also highly recommended. Besides, regulation related to energy token and smart contract have also to be put in place.
For the particular case of pricing mechanism, peer-to-peer energy trading may face the issue with competitivity. Currently, the price of electricity from the grid is around 15 USD cents per kWh without tax and between 21 to 23 cents per kWh with tax. However, that price is highly subsidized. Therefore, that constitutes a threat for new project on peer-to-peer energy trading and private mini-grid in general. Furthermore, the Kenyan government has decided recently to remove the VAT exemption of solar product, which will have impact for the promotion of solar home system. Therefore, incentive measure for solar product and private mini-grid sector is highly necessary.

Through the interview with the CEO of the company, it is confirmed that a lot of regulation will be necessary to put in place in order to really implement P2P energy trading in Kenya. The good thing is that the government in Kenya is cognizant towards the P2P energy trading idea and blockchain. The government is currently reviewing different policy and regulation framework for instance net metering regulation and mini-grid regulation, and new regulation which will affect P2P energy sector is expected to be settled in the coming years.
For the case of virtual currency, it is true that the Central Bank of Kenya released a public notice for a caution on virtual currencies such as Bitcoin. Nevertheless, it is just to warn the public about the eventual fraudulent act and the risks they may encounter, but virtual currencies are not banned in Kenya, the government is even starting recognizing its potential.

5.4.4.4. Application of the policy framework for the case of Rehub in Kenya

After analysing the mini-grid situation in Kenya as well as its policy and regulation, and also after conducting the practical case study of Rehub and knowing the challenges encountered by the pilot project carried out by the company, the proposed policy framework should be as shown in the figure 36. Some of the elements in the policy framework such as the promotion of decentralization already exists in Kenya but need a reinforcement. It is the same for the license requirement which is stated in the Energy Act. Its request has to be facilitated. However, for pilot programs encouragement, regulatory sandbox and access to capital, they are not included yet in any Kenya energy policy documents, hence the government of Kenya should take measure in considering them, in order to promote the P2P energy trading in the country.

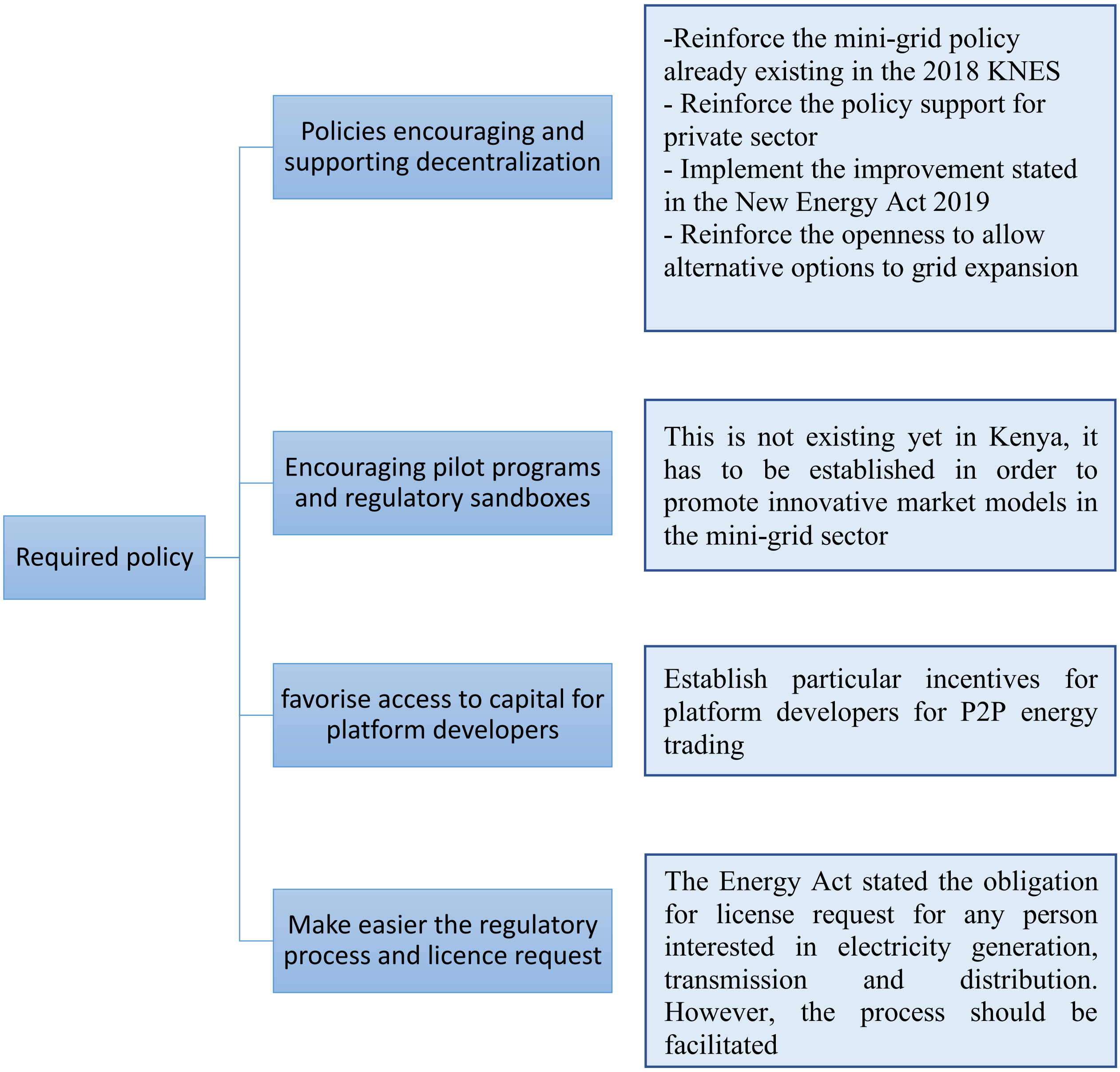


Figure 36: Application of the policy framework for the case of Kenya

5.4.4.5. Stakeholder analysis for the case of P2P energy trading in Kenya:

Currently, since the project is just in a pilot phase, the main stakeholders are the Rehub company as a developer and the community where the project is implemented, composed by the prosumers and consumers. However, for the real project which will be developed after the pilot phase, different other bodies need to be involved for the policy and regulation framework. Three main groups were identified: first the national energy entities which are composed by the Energy and Petroleum Regulatory Authority (EPRA), the Energy and Petroleum Tribunal and the Rural Electrification and Renewable Energy Corporation. Among other roles, the EPRA is responsible for regulating generation, importation, exportation, transmission, distribution, supply and use of electrical energy. Then, the Energy and Petroleum Tribunal which referred to as the Tribunal for the purpose of hearing and determining disputes and appeals in accordance the Energy Act or any other written law. Then, the Rural Electrification and Renewable Energy Corporation has the functions to oversee the implementation of the Rural Electrification Program, to develop and update the rural electrification master plans in consultation with Country Governments and also to undertake feasibility studies and maintain data with a view to availing the same to developers of renewable energy resources.

The second group of stakeholders is the one responsible for cryptocurrency regulation which involves the Central Bank of Kenya, the Capital Market Authority, the Kenya Revenue Authority, and the National Integrated Identity Management System. They are the ones who are involved in the blockchain and cryptocurrency regulation. Apart from that, since P2P energy platform is highly involving ICT, the Communication Authority of Kenya would also have a role to play.

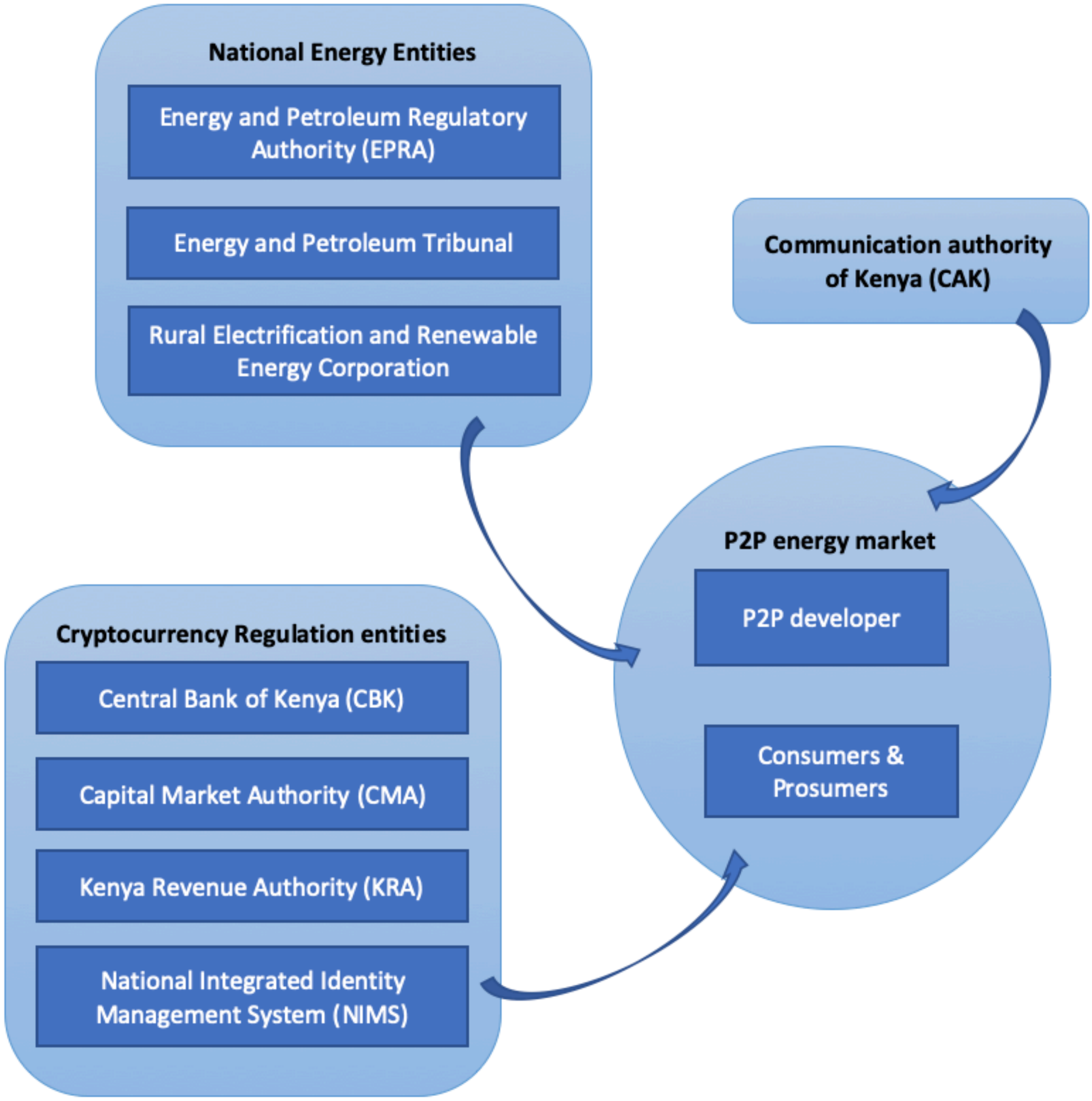


Figure 37: Stakeholder analysis for P2P energy trading using blockchain in Kenya

6. CONCLUSION AND OUTREACH

6.1. Summary of the findings

6.1.1. The current situation in SSA and diagnosis assessment of the policy and regulation

The aim of this research was to conduct a diagnosis assessment of the digital technology situation and policy in Sub-Saharan Africa, particularly for the blockchain which is a disruptive technology and to see in what extent the improvement in their policy and regulation would contribute in promoting the implementation of peer-to-peer energy trading in the region. The analysis of the success of peer-to-peer energy trading and blockchain projects all around the world have inspired to study the potential of this new technology for Sub-Saharan Africa where the electricity access is still very low compared to the rest of the world.

After a SWOT analysis of the current situation, it can be concluded that although the digital technology indicators are still very low in Sub-Saharan Africa compared to the rest of the world, there is a promising considerable evolution. Besides, peer-to-peer energy trading using blockchain can have promising cheaper cost for rural electrification and it would reduce the stress on the grid and limit the need of building new generation capacity. With the use of blockchain, an efficient, transparent and robust trading system can be ensured and it is expected to optimize the supply and demand management. It is also more reliable and the high availability of sun resources in Africa is a promising asset for the project. However, the continent still has quite low awareness and preparedness for fourth industrial revolution such as blockchain and IoT. Nevertheless, several opportunities can be exploited such as the decreasing cost of stand-alone solar technology, the boom of SHS and PayGo mechanism with mobile payment in Sub-Saharan Africa, particularly East-Africa. Also, the high cost of storage and back-up generator can also be a factor to promote the P2P energy trading. Also, there is the expansion of mini-grid investment in SSA. However, the promotion of the sector is facing issue with the weak policy regulatory environment.

Through the diagnostic assessment of the policy and regulation environment in Sub-Saharan Africa, it can be said that there is a willingness of African government and international organizations in improving policy and regulation in mini-grid. Besides, the emergence of national and regional associations, such as the AMDA (African Mini-Grids Developers

Association), to lobby for favourable regulatory and policy framework for private sector investment in mini-grid is expected to improve the policy situation. However, there is still considerable restriction of private participation in mini-grid sector and the African Energy Outlook 2019 stated that 16 out of 43 SSA countries do not allow private sector to participate in electricity generation or networks. Also, there is the difficulty of regulatory process and licensing requirements, the issues with tariff framework and the uncertainty of the regulation about the future grid integration.

6.1.2. Solution: the proposed policy and regulation framework

Several parameters are necessary to study the implementation of P2P energy trading using blockchain. Policy and regulation are one of them and all the other parameters are based or interrelated to it. In order to fully embrace all aspects involved in the system, the study carried out separately the general policy requirement, the regulatory requirement for P2P energy trading, the basic elements for blockchain regulation and finally the blockchain framework in P2P energy trading.

First, the general required basic policy should involve policies encouraging and supporting decentralization and also encouraging pilot programs and regulatory sandboxes. Access to capital for platform developers is also necessary and finally it is important to make easier the regulatory process and license request for new developers who want to operate in mini-grid sector including P2P energy trading. Then, for the specific regulatory for P2P energy trading, two blocs have to be considered, the retail market and the distribution network. The retail market involves enabling energy trading among prosumers and consumers as well as the data collection and access, cybersecurity and privacy. It is also necessary to define clear roles and responsibility of stakeholders and particularly ensure respect of consumer right. The last which is very important is to define the market operation rules including pricing mechanism market mechanism and the distribution of taxes and fees. On the other side, the regulation on the distribution network consists in enabling distribution system operator’s flexibility, defining technical criteria for ancillary services and defining the grid connection status.

In order to incorporate blockchain technology in the system, it is necessary first to implement a favourable situation for blockchain in the country and that is based on the government attitude and definition. Moreover, several aspects have to be well defined such as the virtual currency regulation, the taxation, the sales regulation, and the money transmission law. Then, for integrating blockchain in the context of P2P energy trading, there should be clear regulation for all aspects where blockchain is involved such as the smart meters, the smart devices, the sensor technology and the smart-phone applications. Clear regulation has also to govern and harmonize the blockchain features in the P2P context which are distributed and secure record of transaction, the energy networks controlled by smart contracts, the payment via cryptocurrency and the secure storage of ownership records.

In order for the policy and regulations to be successful, the stakeholders' roles and responsibilities have to be very well defined.

The conceptual modelling was validated with the case of Kenya where after analysing the situation in the country and conducting a practical analysis with one local company operating in the sector, all the identified policy and regulation intervention are necessary to put in place a favourable environment for the implementation of P2P energy trading project enhanced by blockchain technology.

6.2. Recommendation from the research findings

The present research can be used as a guideline for policy-makers of any Sub-Saharan African countries which are still questioning on the potential importance of embracing the disruptive technologies of the fourth industrial revolution especially the case of blockchain. It gives as well recommendations on the basic aspects to be considered in the elaboration of the policy and regulations as well as the interconnection between all the aspects. The study can give clear idea to investors as well and to operators who are interesting in operating in P2P energy trading and blockchain.

Nevertheless, it is impossible to establish a "one size fits all" solutions in this field. Although this research has provided the basic requirements for the policy and regulation framework for peer-to-peer energy trading and blockchain, different aspects can occur or some additional parameters may be required depending on the country of study. Besides, energy trading mechanism and blockchain technology are developing fast and have not settled down yet, therefore, some adaptation or update may be required when using the proposed models in the future and the policy and regulation already established need to be reconsidered in order to benefit from the technological and commercial changes. Furthermore, establishing the policy and regulation in this sector involve a large number of interests and stakeholders which can present different sensitivity towards the change and it requires a harmonized concertation and agreement.

6.3. Future prospection of research

The present research has focused mainly on the policy and regulation framework study. However, the field of implementation of digital technology in the mini-grid sector is very broad and involves many aspects (fig. 29). Therefore, further study on those other aspects would be necessary to complete this research. It includes:

- Conducting assessments of the potential economic and social impacts of P2P energy trading using blockchain.
- Studying the technical aspect of the implementation of P2P energy trading and blockchain in an African context
- Conducting the economic feasibility of blockchain-based P2P energy trading in Africa
- Building a business model and market design for blockchain-based P2P energy trading.

REFERENCES

AfDB. (2020). *African Economic Outlook 2020: Developing Africa's Workforce for the Future*. African Development Bank Group.

African Union Commission. (2015). *Agenda 2063: The Africa we want*.

Ahl, A., Yarime, M., Tanaka, K., & Sagawa, D. (2019). Review of blockchain-based distributed energy: Implications for institutional development. In *Renewable and Sustainable Energy Reviews* (Vol. 107, pp. 200–211). Elsevier Ltd. https://doi.org/10.1016/j.rser.2019.03.002

Ajadi, S., & Giuliani, D. (2019). *GSMA | 618 active tech hubs: The backbone of Africa's tech ecosystem | Mobile for Development*. https://www.gsma.com/mobilefordevelopment/blog/618-active-tech-hubs-the-backbone-of-africas-tech-ecosystem/

Alladi, T., Chamola, V., Rodrigues, J. J. P. C., & Kozlov, S. A. (2019). Blockchain in smart grids: A review on different use cases. In *Sensors (Switzerland)* (Vol. 19, Issue 22, p. 4862). MDPI AG. https://doi.org/10.3390/s19224862

AMDA. (2018). *PRINCIPLES | AMDA*. https://africamda.org/index.php/about-2/principles/

ARENA. (2017). *Peer-to-Peer Distributed Ledger Technology Assessment.* Sydney: AGL.

Armbrust, M., Fox, A., Griffith, R., Joseph, A. D., Katz, R., Konwinski, A., Lee, G., Patterson, D., Rabkin, A., Stoica, I., & Zaharia, M. (2010). A view of cloud computing. In *Communications of the ACM* (Vol. 53, Issue 4, pp. 50–58). https://doi.org/10.1145/1721654.1721672

Bankymoon. (2020). *Blockchain enabled solutions and services*. http://bankymoon.co.za/

Basso, T. (2014). IEEE 1547 and 2030 Standards for Distributed Energy Resources Interconnection and Interoperability with the Electricity Grid. In *NREL* (Issue December).

Blimpo, M. P., & Cosgrove-Davies, M. (2019). *Electricity Access in Sub-Saharan Africa: Uptake, Reliability, and Complementary Factors for Economic Impact* (World Bank & AFD (Eds.)).

BNP Paribas. (2019). *Blockchain is more than just numbers for these small farmers*. https://cib.bnpparibas.com/sustain/blockchain-is-more-than-just-numbers-for-these-small-farmers_a-3-3149.html

Bobrow, D. B. (2006). Policy design: Ubiquitous, necessary and difficult. In *Handbook of*

Public Policy (pp. 75–96). SAGE Publications Inc. https://doi.org/10.4135/9781848608054.n5

Bronski, P. (2018). *Belgium's Transmission System Operator Eyes Blockchain for Demand Response - Energy Web*. World Energy Web. https://energyweb.org/2018/02/28/belgiums-transmission-system-operator-eyes-blockchain-for-demand-response/

CBK. (2015). *Public notice*. Central Bank of Kenya. https://www.centralbank.go.ke/images/docs/media/Public_Notice_on_virtual_currencies_such_as_Bitcoin.pdf

Charg. (2017). *Energy IS Money - Charg Coin*. https://chgcoin.org/

Consensys. (2018). *Welcome to the Future of Energy- Grid+ White paper*.

Dearing, C. (2017). *Nobel Laureate Milton Friedman Predicted Bitcoin Era 17 Years Ago - Cointelegraph*. https://cointelegraph.com/news/nobel-laureate-milton-friedman-predicted-bitcoin-era-17-years-ago

Deing, J. (2019). *Peer-to-Peer Energy Trading Still Looks Like a Distant Prospect*. Greentech Media. https://www.greentechmedia.com/articles/read/peer-to-peer-energy-trading-still-looks-like-distant-prospect

Diestelmeier, L. (2019). Changing power: Shifting the role of electricity consumers with blockchain technology – Policy implications for EU electricity law. *Energy Policy*, *128*, 189–196. https://doi.org/10.1016/j.enpol.2018.12.065

Ecobank. (2018). *African crypto regulation*.

EEP Africa. (2018). *Opportunities and challenges in the mini-grid sector in Africa: Lessons learned from the EEP portfolio*.

Electron. (2018). *Electron brings together energy industry heavyweights to design the future of energy flexibility*. https://www.electron.org.uk/press-releases/electron-brings-together-energy-industry-heavyweights-to-design-the-future-of-energy-flexibility

ERC. (2017). *Standard Tariff Application Model (TAM) for Mini-Grids.* Nairobi: Energy Regulatory Commission.

ESMAP. (2019). *Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers. Executive Summary*. https://openknowledge.worldbank.org/handle/10986/31926

Fritzsche, K., Shuttleworth, L., Brand, B., Blechinger, P., & Africa, S.-S. (2019). *Potentials, challenges and options for sustainable energy access Exploring the nexus of mini-grids and digital technologies*.

Fung, B. (2014). *Marc Andreessen: In 20 years, we'll talk about Bitcoin like we talk about the Internet today - The Washington Post*. https://www.washingtonpost.com/news/the-switch/wp/2014/05/21/marc-andreessen-in-20-years-well-talk-about-bitcoin-like-we-talk-about-the-internet-today/

GEF. (2019). *GEF-7 Africa Minigrids Program*.

Ghatikar, G., Mashayekh, S., Stadler, M., Yin, R., & Liu, Z. (2016). Distributed energy systems integration and demand optimization for autonomous operations and electric grid transactions. *Applied Energy*, *167*(2015), 432–448. https://doi.org/10.1016/j.apenergy.2015.10.117

GOGLA. (2019). *Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data July - December 2019* (Issue December).

Gordon, P. (2019, July 16). *Shell buys into LO3 Energy blockchain-based community platform*. https://www.smart-energy.com/news/shell-buys-into-blockchain-based-community-energy-platform-lo3-energy/

Government of Kenya(GoK). (2016). The Energy Act. *Kenya Gazette Supplement*, *71*(71), 1–25.

Higgins, S. (2016). *How Bitcoin Brought Electricity to a South African School - CoinDesk*. https://www.coindesk.com/south-african-primary-school-blockchain

Hou, J., Wang, H., & Liu, P. (2018). Applying the blockchain technology to promote the development of distributed photovoltaic in China. In *International Journal of Energy Research* (Vol. 42, Issue 6, pp. 2050–2069). John Wiley and Sons Ltd. https://doi.org/10.1002/er.3984

Iansiti, M., & Lakhani, K. R. (2017). The Truth About Blockchain. *Harvard Business Review*, *95*(Jan-Feb), 118–127. https://enterprisersproject.com/sites/default/files/the_truth_about_blockchain.pdf

IEA. (2014). *Africa Energy Outlook: A focus on energy prospects in Sub-Saharan Africa.* Paris: International Energy Agency.

IEA. (2017a). Digitalization & Energy. In *Digitalization & Energy*. https://doi.org/10.1787/9789264286276-en

IEA. (2017b). Energy Access Outlook 2017: from poverty to prosperity. In *World Energy Outlook Special Report* (Issue October). https://doi.org/ceo871024 [pii]

IEA. (2019). Africa Energy Outlook 2019. *World Energy Outlook Special Report*, 288. https://www.iea.org/reports/africa-energy-outlook-2019#energy-access%0Ahttps://www.iea.org/reports/africa-energy-outlook-2019%23africa-case

IEA, IRENA, UNSD, WB, & WHO. (2019). *Tracking SDG 7: The Energy Progress Report 2019*. www.worldbank.org

IEA, IRENA, UNSD, World Bank, & WHO. (2020). *Tracking SDG 7: The Energy Progress Report 2020*. https://openknowledge.worldbank.org/handle/10986/29812

IEEE SA. (2016). *Electric Power Infrastructure (Building the Enabling Network for Distributed Energy Resources)*. Retrieved from IEEE SA: https://standards.ieee.org/project/825.html

IEEE SA. (2018). *P2418.5 - Standard for Blockchain in Energy*. IEEE Standard Association. https://standards-stg.ieee.org/project/2418_5.html

Internet World Stats. (2020). *Internet user statistics for Africa*. https://www.internetworldstats.com/stats1.htm

IRENA. (2016). *INNOVATION OUTLOOK RENEWABLE MINI-GRIDS*. International Renewable Energy Agency. www.irena.org

IRENA. (2017). *Accelerating Off-grid Renewable Energy: Key Findings and Recommendations from IOREC 2016*. https://doi.org/978-92-95111-07-3

IRENA. (2018a). *Off-grid renewable energy solutions: Global and regional status and trends*.

IRENA. (2018b). *Policies and regulations for renewable mini-grids*. International Renewable Energy Agency. https://irena.org/-/media/Files/IRENA/Agency/Publication/2018/Oct/IRENA_mini-grid_policies_2018.pdf

IRENA. (2019). *Innovation landscape brief: Blockchain*. International Renewable Energy Agency. www.irena.org

IRENA. (2020). *Peer-to-peer energy trading: innovation landscape brief.* Abu Dhabi: International Renewable Energy Agency.

ITU. (2019). *Measuring digital development: Facts and figures 2019*.

Kapoor, k., Mansaray, H., Sennett, L., Rivera, O. P., & Ocana, A. (2019). Fourth industrial revolution, jobs, and skills. In C. Monga, A. Shimeles, & A. Woldemichael, *Creating decent jobs: strategies, policies, and instruments* (pp. 297-334). Abidjan: AFDB.

Khatoon, A., Verma, P., Southernwood, J., Massey, B., & Corcoran, P. (2019). Blockchain in energy efficiency: Potential applications and benefits. *Energies*, *12*(17), 1–14. https://doi.org/10.3390/en12173317

Kirpes, B., & Becker, C. (2018). Processing Electric Vehicle Charging Transactions in a Blockchain-based Information System. *Undefined*.

Klein, L. P., Krivoglazova, A., Matos, L., Landeck, J., & De Azevedo, M. (2019). A novel peer-to-peer energy sharing business model for the Portuguese energy market. *Energies*.

Koffman, T. (2019). *Blockchain - Africa Rising*. Forbes. https://www.forbes.com/sites/tatianakoffman/2019/04/04/blockchain-africa-rising/#6e22abc7711f

Kogure, J., Kamakura, K., Shima, T., & Kubo, T. (2017). Blockchain Technology for Next Generation ICT. In *FUJITSU Sci. Tech. J* (Vol. 53, Issue 5).

Kotilainen, K. (2020). *Energy Prosumers' Role in the Sustainable Energy System* (pp. 1–14). https://doi.org/10.1007/978-3-319-71057-0_11-1

Kuruseelan, S., & Vaithilingam, C. (2019). Peer-to-peer energy trading of a community connected with an AC and DC microgrid. *Energies*, *12*(19). https://doi.org/10.3390/en12193709

Lightency. (2020). *Lightency-The Bright Side of Energy*. http://lightency.io/#/

Ma, Z., Bloch-Hansen, K., Buck, J. W., Hansen, A. K., Henriksen, L. J., Thielsen, C. F., Santos, A. Q., & Jorgensen, B. N. (2018). Peer-to-Peer Trading Solution for Microgrids in Kenya. *IEEE PES/IAS PowerAfrica*, 420–425. https://doi.org/10.1109/PowerAfrica.2018.8520980

Marie-Jeanne, K., Day, T., & Barasa, M. (2019). The role of renewable energy mini-grids in Kenya's electricity sector: Evidence of a cost-competitive option for rural electrification and sustainable development. In *Ambition to Action*. www.ambitiontoaction.net/

McKenzie, B. (2018). *Blockchain and Cryptocurrency in Africa*.

McKibben, B. (2017). *The Race to Solar-Power Africa*. The New Yorker. https://www.newyorker.com/magazine/2017/06/26/the-race-to-solar-power-africa

Mengelkamp, E., Gärttner, J., Rock, K., Kessler, S., Orsini, L., & Weinhardt, C. (2017). Designing microgrid energy markets: A case study: The Brooklyn Microgrid. *Applied Energy*, *210*, 870–880. https://doi.org/10.1016/j.apenergy.2017.06.054

Ministry of Information Communication and Technology. (2019). *Emerging Digital Technologies for Kenya EXPLORATION & ANALYSIS*.

Mollah, M. B., Zhao, J., Niyato, D., Lam, K.-Y., Zhang, X., Ghias, A. M. Y. M., Koh, L. H., & Yang, L. (2020). Blockchain for Future Smart Grid: A Comprehensive Survey. *IEEE Internet of Things Journal*, 1–1. https://doi.org/10.1109/jiot.2020.2993601

Morstyn, T., Farrell, N., Darby, S. J., & McCulloch, M. D. (2018). Using peer-to-peer energy-trading platforms to incentivize prosumers to form federated power plants. In *Nature*

Energy (Vol. 3, Issue 2, pp. 94–101). Nature Publishing Group. https://doi.org/10.1038/s41560-017-0075-y

Munsing, E., Mather, J., & Moura, S. (2017). Blockchains for decentralized optimization of energy resources in microgrid networks. *IEEE Conference on Control Technology and Applications (CCTA)*, *2017-Janua*, 2164–2171. https://doi.org/10.1109/CCTA.2017.8062773

Mylrea, M., Nikhil, S., & Gourisetti, G. (2017). *Blockchain for Smart Grid Resilience: Exchanging Distributed Energy at Speed, Scale and Security*.

Nakamoto, S. (2008). *Bitcoin: A Peer-to-Peer Electronic Cash System*. www.bitcoin.org

Ndung'u, N., & Signé, L. (2020). The Fourth Industrial Revolution and digitization will transform Africa into a global powerhouse. In *Capturing the Fourth Industrial Revolution: A regional and national agenda* (pp. 61–73). Foresight Africa 2020 report. https://www.itu.int/en/ITU-D/Statistics/Pages/publications/mis2017/methodology.aspx

Nieman, A. (2015). *A FEW SOUTH AFRICAN CENTS ' WORTH ON BITCOIN*. *18*(5).

Noor, S., Yang, W., Guo, M., van Dam, K. H., & Wang, X. (2018). Energy Demand Side Management within micro-grid networks enhanced by blockchain. *Applied Energy*, *228*, 1385–1398. https://doi.org/10.1016/j.apenergy.2018.07.012

Off Grid Energy Independence. (2019). *ENGIE acquires Mobisol, becomes market leader in off-grid solar Africa*. https://www.offgridenergyindependence.com/articles/18086/engie-acquires-mobisol-becomes-market-leader-in-off-grid-solar-africa

OneWattSolar. (2020). *Blockchain Powered Digital Electricity - OneWattSolar*. https://onewattsolar.com/

Oureilidis, K., Malamaki, K. N., Gallos, K., Tsitsimelis, A., Dikaiakos, C., Gkavanoudis, S., Cvetkovic, M., Mauricio, J. M., Ortega, J. M. M., Ramos, J. L. M., Papaioannou, G., & Demoulias, C. (2020). Ancillary services market design in distribution networks: Review and identification of barriers. *Energies*, *13*(4). https://doi.org/10.3390/en13040917

Parag, Y., & Sovacool, B. (2016). Electricity market design for the prosumer era. *Nature Energy*, *1*, 16032. https://doi.org/10.1038/nenergy.2016.32

Peck, M. E., & Wagman, D. (2017). Energy Trading for Fun and Profit: Buy your neighbor's rooftop solar power or sell your own-it'll all be on a blockchain. *IEEE Spectrum*, *54*(10), 56–61. https://doi.org/10.1109/MSPEC.2017.8048841

PLAAS. (2018). *Supply Chain Research Architecture*.

PricewaterhouseCoopers. (2016). Blockchain – an opportunity for energy producers and consumers? *Pwc.Com*, 1–45. www.pwc.com/utilities

Rao, P. (2018). Africa could be the next frontier for cryptocurrency. *Africa Renewal*, *32*(1), 27–27. https://doi.org/10.18356/f6b3e553-en

REN21. (2016). *EAST AFRICAN COMMUNITY RENEWABLE ENERGY AND ENERGY EFFICIENCY*.

Samuel, O., Almogren, A., Javaid, A., Zuair, M., Ullah, I., & Javaid, N. (2020). Leveraging blockchain technology for secure energy trading and least-cost evaluation of decentralized contributions to electrification in sub-Saharan Africa. *Entropy*, *22*(2), 226. https://doi.org/10.3390/e22020226

Singh, A., Parizi, R. M., Zhang, Q., Choo, K. K. R., & Dehghantanha, A. (2020). Blockchain smart contracts formalization: Approaches and challenges to address vulnerabilities. In *Computers and Security* (Vol. 88, p. 101654). Elsevier Ltd. https://doi.org/10.1016/j.cose.2019.101654

Solshare. (2020). *ME Solshare*. https://me-solshare.com/

Son, Y.-B., Im, J.-H., Kwon, H.-Y., Jeon, S.-Y., & Lee, M.-K. (2020). Privacy-Preserving Peer-to-Peer Energy Trading in Blockchain-Enabled Smart Grids Using Functional Encryption. *Energies*, *13*(6), 1321. https://doi.org/10.3390/en13061321

SunContract. (2017). Whitepaper - SunContract. 1-24.

The Law Library of Congress. (2018). Regulation of Cryptocurrency Around the World. *The Law Library of Congress*, *5080*(June). http://www.law.gov

Toffler, A. (1980). *The Third Wave* . https://books.google.dz/books/about/The_Third_Wave.html?id=ViRmAAAAIAAJ&redir_esc=y

Trotter, P. A. (2016). Rural electrification, electrification inequality and democratic institutions in sub-Saharan Africa. *Energy for Sustainable Development*, *34*, 111–129. https://doi.org/10.1016/j.esd.2016.07.008

Tushar, W., Saha, T. K., Yuen, C., Smith, D., & Poor, H. V. (2020). Peer-to-Peer Trading in Electricity Networks: An Overview. *IEEE Transactions on Smart Grid*, *11*(4), 3185–3200. https://doi.org/10.1109/tsg.2020.2969657

Tushar, W., Yuen, C., Mohsenian-Rad, H., Saha, T., Poor, H. V., & Wood, K. L. (2018). Transforming energy networks via peer-to-peer energy trading: The potential of game-theoretic approaches. *IEEE Signal Processing Magazine*, *35*(4), 90–111. https://doi.org/10.1109/MSP.2018.2818327

UCL. (2019). *Transactive Energy: knowledge sharing with Colombia and the UK | UCL*

Institute for Sustainable Resources - UCL – University College London. https://www.ucl.ac.uk/bartlett/sustainable/news/2019/oct/transactive-energy-knowledge-sharing-colombia-and-uk

United Nations. (2015). *TRANSFORMING OUR WORLD: THE 2030 AGENDA FOR SUSTAINABLE*.

van Soest, H. (2019). Peer-to-peer electricity trading: A review of the legal context. *Competition and Regulation in Network Industries*. https://doi.org/10.1177/1783591719834902

Vezzoli, C., Ceschin, F., Osanjo, L., M'rithaa, M. K., Moalosi, R., Nakazibwe, V., & Diehl, J. C. (2018). Designing Sustainable Energy for All: Sustainable Product-Service System Design Applied to Distributed Renewable Energy. *GreeenEnergy and Technology*. http://www.springer.com/series/8059

Wang, N., Zhou, X., Lu, X., Guan, Z., Wu, L., Du, X., & Guizani, M. (2019). When energy trading meets blockchain in electrical power system: The state of the art. *Applied Sciences (Switzerland)*, *9*(8), 1561. https://doi.org/10.3390/app9081561

WEF. (2017). *The Future of Electricity: New Technologies Transforming the Grid Edge*. https://www.weforum.org/reports/the-future-of-electricity-new-technologies-transforming-the-grid-edge

World Bank. (2018). *Off-grid Solar Market Trends Report 2018* (Issue January). https://doi.org/10.1017/CBO9781107415324.004

World Bank. (2020). *The World Bank In Kenya*. Retrieved from The World Bank: https://www.worldbank.org/en/country/kenya/overview

Wu, J., & Tran, N. K. (2018). Application of blockchain technology in sustainable energy systems: An overview. *Sustainability (Switzerland)*, *10*(9), 3067. https://doi.org/10.3390/su10093067

Zhang, C., Wu, J., Zhou, Y., Cheng, M., & Long, C. (2018). Peer-to-Peer energy trading in a Microgrid. *Applied Energy*, *220*(June), 1–12. https://doi.org/10.1016/j.apenergy.2018.03.010

Zhou, Y., Wu, J., Long, C., & Ming, W. (2020). State-of-the-art analysis and perspectives for peer-to-peer energy trading. *Engineering*, *xxxx*. https://doi.org/10.1016/j.eng.2020.06.002