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Digitalisation and sustainable energy transitions in Africa: assessing the impact of policy and regulatory environments on the energy sector in Nigeria and South Africa

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Abstract

Background: Digital technologies have unique characteristics for achieving radically disruptive transitions within the energy sector. They provide opportunities for new production and consumption models between micro-producers and consumers of electricity within communities in a way that transforms the traditional energy generation and consumption model. The study critically assessed the digitalisation of energy systems in Africa within the context of existing policy frameworks in the quest to achieve sustainable energy transitions in Africa. It investigated how digital technologies such as blockchain, digital platforms and smart grids were adopted and implemented within the energy sector to achieve new energy production and consumption models that are both environmentally sustainable and socially inclusive. This assessment was done within the context of existing policy and regulatory frameworks of the society where the use cases were domiciled.

Methods: The aim of the research was to investigate how sustainable energy transitions are being achieved in Nigeria and South Africa through the digitalisation of energy systems. A qualitative methodological approach was done in three stages—a document analysis that reviewed relevant literature on the energy sector policies in Nigeria and South Africa; the next step involved a comparative case study conducted to assess the characteristics of digital technology deployment in each country's energy transition. Finally, outcomes of the comparative case studies were then situated within the context of existing policies within the countries covered by the study.

Results: Results from the research indicate that Africa is still in the early stages of adoption and application of digital technologies such as blockchain and smart grids within the energy sector. The results also showed a disconnect between the policy environment and industry efforts at achieving this. The current applications as exemplified in the use cases by the three companies covered in this study indicates that Africa's sustainable energy transition is in a rudimentary or early adoption stage, and they are not currently aided by the policy environments in which such projects are domiciled.

Conclusions: The research provides deep insights into the current state and developments within the energy sector especially in relation to how digital technologies are being adopted and implemented in solving the energy poverty prevalent across sub-Saharan Africa.

Keywords: Blockchain, Smart grids, Digital technologies, Social and solidarity economy, Sub-Saharan Africa

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Background

Digitalisation has become an enabler of energy transitions, and it is transforming how energy is produced, distributed, and consumed. Digitalisation has far reaching transformational effects on society, particularly in how it is shifting the balance of power in ways that leads to new outcomes [1–3]. Countries across sub-Saharan Africa are struggling to cope with severe energy shortages which has led to high levels of energy poverty, which is made worse by the challenge of rapid population growth. Africa's population is projected to increase by over 1 billion people by the year 2050. These unique challenges faced by Africa makes the prospects of digital transformation of energy systems a unique opportunity for the continent to confront its future developmental challenges [4, 5].

In anticipation of the challenges associated with population growth that may not be sustainable, the United Nations has prioritised the need for responsible and equitable energy pathways through their Sustainable Development Goals (SDGs). However, about 1.2 billion people, located mainly in sub-Saharan Africa, still lack access to electricity. The need to expand access to electricity has therefore given rise to more research interests into sustainable energy transitions that focus on underserved regions of the world especially in sub-Saharan Africa [6]. Considering the critical role of energy to socioeconomic development and human wellbeing in every society, the need to find solutions to issues such as climate change, poverty eradication and energy security, has pushed the subject of sustainable energy transitions to a position of prominence among stakeholders in policy circles, industry and the academia [1].

This study investigates the digitalisation of energy systems in sub-Saharan Africa. It aims to analyse by unpacking the discursive layers of evolution within Africa's energy space. The analysis will be conducted within the context of the existing policy and regulatory environments in a group of African countries to identify possible areas of conflict that may hinder sustainable energy transitions facilitated by digital technologies. The study addresses the following research questions: what is the impact of the policy and regulatory environment on sustainable energy transitions in Nigeria and South Africa? How is technology being deployed to achieve sustainable energy transitions in Nigeria and South Africa?

A qualitative approach involving comparative case studies of the implementation of blockchain and smart grids within the energy sector has been used. The methodology involved extensive review of relevant business and academic literature focused on the subject area for the research. The choice of using a case study research design is because of its potential to investigate a contemporary phenomenon within real-life context. This is particularly useful when the boundaries between phenomenon and context are not clearly evident, and in which multiple sources of evidence are required [7–9]. The research contributes to the existing body of knowledge on digital technologies, blockchain technology and social and solidarity economy from an African perspective. The output will help policy makers better understand the landscape and dynamics of emergence, adoption and use of blockchain technology and how it can help achieve inclusive and sustainable development that would in turn promote gender equality, decent work, and food and livelihoods security.

Methods

The research adopted a qualitative methodological approach. A three-stage methodological approach was applied as follows: firstly, a document analysis is conducted to review and analyse energy sector related policy documents for Nigeria and South Africa. This was necessary to assess their focus on sustainable energy transitions and if they incorporated policy provisions that catered to digital technology mediation of sustainable energy transitions. A comparative case study analysis was then conducted to assess the characteristics of the use cases covered by the case studies in terms of how digital technologies was being used to mediate sustainable energy transitions.

Finally, the outcomes of the comparative case studies were then situated within the context of existing policy frameworks within the jurisdiction where such use cases were domiciled. The imperative was to establish fitness and synergy between practice as it related to industry and the policy environment, considering the opinion of Edomah [10]. Edomah argues that the relationship between resources, institutions, and political structures in the governance of energy infrastructure is quite complex, and that energy transitions were subject to influence by government policies implemented within and through institutions. He therefore advocated on the need for increased partnership and interaction between public and private institutions in the governance and provision of energy infrastructure.

Nigeria and South Africa were selected as case studies based on their socioeconomic significance in Africa and their status as the two largest economies on the continent. In selecting the companies, priority/preference was for sustainable energy transition projects with use cases involving the adoption and implementation of digital technologies such as blockchain, smart grid technologies, and platformisation within the energy sector. According to Woodside and Wilson [11], case study research presents an in-depth examination which is often undertaken over a time period, and of a single

Table 1 Case study assessment matrix

	The sun exchange	Bankymoon	Onewattsolar
Location	South Africa	South Africa	Nigeria
Innovation	Peer-to-peer platform for financing solar energy system installation and leasing platform	Blockchain enabled smart meters that facilitates payments for utilities using cryptocurrencies	Peer-to-peer platform for financing solar energy system installation and leasing platform
Business model	Two-sided marketplace that brings together financiers and consumers of renewable energy. Crowd fund installation of solar energy and lease generated energy to consumers, investors earn returns on investments through income generated from usage fee paid by consumers	Payment facilitation	Two-sided marketplace that brings together financiers and consumers of renewable energy. Crowd fund installation of solar energy and lease generated energy to consumers, investors earn returns on investments through income generated from usage fee paid by consumers
Sustainable energy transition compliance	Yes—the solutions provided by The Sun Exchange offers access to electricity to underserved communities in South Africa using renewable energy. It also leverages a flexible and convenient payment model that ensures that cost is not a barrier to access for users at the bottom of the society's socioeconomic pyramid	No—they provide access to energy traditional sources; their solution is more focused on providing access to energy through additional payment source which in this case is made possible by enabling the use of cryptocurrencies. In comparison with Alliander and Electron, the energy consumed by the end-users is not sourced from sustainable sources	Yes—like what The Sun Exchange offers, their solution offers access to electricity to underserved communities in Nigeria using renewable energy. It leverages a flexible and convenient payment model that ensures that cost is not a barrier to access for users at the bottom of the society's socioeconomic pyramid
Socioeconomic inclusiveness (cost of acquisition and use as a barrier)	Yes—cost is not a barrier to access and usage for the targeted user base	Yes—cost is not a barrier to access and usage for the targeted user base	Yes—cost is not a barrier to access and usage for the targeted user base

(Source: author)

case that focuses on issues such as a policy statement, programme, intervention site, implementation process or participant.

The justification for adopting the methodological approach of a comparative case study is predicated on the consideration that it enables the researcher to investigate a subject involving multiple cases through a systematic approach that produces more generalisable knowledge about causal questions such as "how" and "why" particular interventions succeed or fail. The comparative case study approach may be adopted for scientific inquiry when it is methodologically impracticable to conduct an experimental design or when there is a need to further interrogate how features within specific context influence the success of interventions. Comparative case studies involve the analysis and synthesis of the similarities, differences and patterns across two or more cases that share a common focus or goal [11–15]. Within the context of sustainable energy transitions, a comparative multiple case study was considered suitable because it enabled the researcher to compare various use cases of digitalisation within the energy sector by various actors who see business and socioeconomic value in applying digital technologies such as blockchain and smart grids within the energy sector.

The criteria used in selecting companies covered by the case studies were as follows: application of digital technologies as part of their business models or value chain; the offering of alternative models of production, consumption, or access to energy; and their operations domiciled in a country located in sub-Saharan Africa. The companies were assessed on the following criteria: innovativeness—use case built around adopting and implementation of digital technologies within the energy sector; business model—plan for the successful operation of a business that identifies sources of revenue, the targeted customer base, products, and details of financing; SET compliance—source of electricity generated and consumed must be from renewable energy sources; and socioeconomic inclusiveness—ensure that cost is not a barrier to access for the targeted user base.

From the list of companies and projects summarised in Table 1, a detailed assessment of the companies and projects led to the identification of Alliander, Bankymoon and Electron as three companies currently implementing use cases that involves both technologies in a way that closely fits the stated objectives of this study. In addition, the choice of the two countries covered in the research is based on the consideration of their strategic importance in sub-Saharan Africa, as the two largest economies on the continent. Nigeria and South Africa are two countries with significant levels of socioeconomic and developmental diversity particularly in their energy sectors.

Results

This section presents the findings of the research. It explores the current state of the energy sector in Africa, renewable energy policy landscape in Nigeria and South Africa, and the technology component which covers Digitalisation and Sustainable Energy Transitions. The African continent has immense natural resource endowments. However, a vast majority of its people are faced with severe energy shortages. This has resulted in dire socioeconomic consequences that results in high rates of poverty and underdevelopment [16]. To gain a better understanding of the abysmal state of energy poverty in Africa, it is instructive to note that the current total generation capacity of 48 countries in sub-Saharan Africa stands at 68 Gigawatts of electricity. This is just about what a country like Spain currently generates, and if South Africa is excluded, the generation capacity of the remaining 47 countries drops to about 28 Gigawatt (GW) which is equivalent to what Argentina generates, and about 25% of this 28 Gigawatt is not achieved as a result of several factors which includes aging plants, unreliable supply of necessary fuels for electricity generation, and poor maintenance of generating plants [17, 18]. Coupled with the severe shortage faced by many countries across the region is an unequal distribution problem which leaves many households in the rural areas disconnected from distributed networks when compared to those in the urban areas. Hence, Africans are faced with a twin energy challenge of energy poverty and high rate of energy inequality [3].

Current state of the energy sector in Africa

From the review of the trends in sustainable energy transitions across the world, it is evident that African countries dominate the list of the worst performers across the world. According to the World Economic Forum's Energy Transition Index (ETI) ranking for 2019, majority of the countries that occupy the bottom table of the ranking of 115 countries were from sub-Saharan Africa. Africa's two largest economies (Nigeria and South Africa) were ranked 109 and 114, respectively. The ETI provides a framework to benchmark and support countries in their energy transition efforts considering their current energy system performance, and the readiness of their macro-economic, social and regulatory environment for energy transition [19]. Kaseke and Hosking [20, p. 114] argue that energy is a prerequisite for economic growth and development. They further stated that the relationship between economic growth and electrical power demand is positively correlated. This view is supported by several researchers who have investigated the relationship between economic growth and energy/electricity demand within societies [21–23]. Nevertheless, new challenges such as climate change and environmental sustainability makes it imperative for African countries to re-evaluate their energy systems to become more efficient and environmentally friendly.

As the demand for energy in countries across sub-Saharan Africa continues to increase, so also is the pressure on available supply options. This results in imbalance between the supply and demand in ways that threatens energy security and hampers socioeconomic development. With this comes the need to explore avenues for achieving sustainable energy transitions in Africa [24]. Sub-Saharan Africa's energy supply is dominated by two main sources: cheap energy sources such as fuel wood-biomass and charcoal; and modern industrial energy sources such as hydro power and fossil fuel-based sources (gas and petroleum). These industrial energy sources are not readily available for electrification of rural areas because of the lack of infrastructure and capital required to make them available [3]. Between 2000 and 2015, the demand for electrification in sub-Saharan Africa grew by 45%, and this demand is projected to triple by 2030. This projected rise in demand for electrification offers huge potential for investments in the sector, especially those that focus on the use of renewable energy sources such as wind, solar and hydro power [3, 16].

Bos et al. [25] opined that some of the challenges faced by many African countries in their quest to expand access to electricity are: the financial outlay required to invest in the infrastructure, lack of requisite manpower needed in rolling out electrification projects, low take-up rates by potential consumers, as well as other institutional and supply-side hurdles. According to them, the most cited challenge is the enormous expense of extending lines to remote and often sparsely populated rural areas. Some typical examples include that of Western Kenya where the median infrastructure investment per connection was $2427 because of low connection rates, and Uganda where estimates place the cost of extending electricity lines at $8000 or more per connection in rural areas. In relation to take-up rates, Bos, Chaplin, and Mamun [25] refer to evidence from places like Botswana which showed that only 12% of households in electrified villages connected to the grid; Ethiopia in which only 39% of households in electrified communities connected to the grid, as well as in rural and peri-urban parts of Tanzania where connection rates were around 21% 2 to 3 years after the lines were built.

The attendant consequence of the energy poverty in sub-Saharan Africa has led to a situation whereby people are forced to generate their own electricity often within the confines of their homes, and in most cases deploying fossil fuel- based electricity generating sets and other solutions. This has led to a massive fragmentation within the energy space across sub-Saharan Africa. Examples of such fragmentation include "under-the-grid" electrification solutions which offer simplicity, speed, and agility, coupled with short installation time. They serve as reliable electricity alternatives for informal settlements and households. The "Pay-as-you-go" solar systems and appliances currently in use across Kenya provided by M-Kopa and expanding across East Africa is another example. The package includes a torch and a mobile-phone charger. Their solution provides a much lower barrier to entry when compared to the high upfront connection costs of on-grid solutions. A 15-W solar home system costs on average USD $9 per month for 36 months after which the household owns its system. Further evidence shows that the willingness to pay for decentralised renewables is much higher than a grid connection because they are seen as more reliable [26, 27].

Significant challenges within the sub-Saharan African energy sector calls for the need to explore alternative models that can help leapfrog these challenges in addressing the significant levels of energy poverty in their societies. It is however imperative to understand the crucial role of the policy and regulatory environments in facilitating sustainable energy transitions. This is because evidence has shown that governments that are able to draw up and implement the right policies and regulations succeed in creating enabling environments for socioeconomic development of their societies [28–30]. Hence, unpacking the discursive layers in sustainable energy transitions in Africa (facilitated by digital technologies) cannot be done in isolation of the existing policy and regulatory environments in the selected countries covered in this research.

Renewable energy policy landscape: Nigeria and South Africa

The renewable energy policy landscape presents a useful starting point for a contextual examination of sustainable energy transitions in Nigeria and South Africa. This is because it helps in framing the understanding of environmental conduciveness in terms of policies and regulations that can either catalyse or hamper sustainable energy interventions by various stakeholders in both countries. A review of evidence obtained from reviewed literature shows that the renewable energy policy landscape in Nigeria and South Africa differ in terms of maturity and scope [31–33]. Nigeria has several policies focused on the energy sector. These include the National Energy Policy of 2003 which articulates the government's position on development and exploitation of all Nigeria's energy resources, addressing environmental concerns, energy utilisation/efficiency, financing, and policy implementation. The Electric Power Sector Reform Act (EPSRA) of 2005 which seeks to transform the Nigerian electricity market from a government-owned and monopolistic market to a privatised entity that enables private investors to enter, invest in the market and make returns on their investments while supplying electricity to end-users; the Energy Commission of Nigeria Act of 1979; Nigeria Renewable Energy Master Plan developed in 2006, which articulates a vision of Nigeria achieving sustainable development through the use of renewable energies. Others are the Renewable Electricity Policy Guidelines of 2006, aimed at promoting renewable energy in the power sector; and the National Renewable Energy and Energy Efficiency Policy of 2015. Nigeria's REMP underlines the need for the creation of a specialised fund and Agency (NREA). The REMP also initiates a set of fiscal and market incentives to support renewable energy deployment. The REMP has a short-term plan which includes a moratorium on import duties for renewable energy technologies.

Nigeria also has a long-term plan which outlines fiscal policies that includes the implementation of customs duty exemption for imported renewable energy appliances, tax credits, capital incentives and preferential loans opportunities [34–37]. However, despite all of these policies and plans, the Nigerian Electricity Regulatory Commission (NERC) expressed its dissatisfaction with the absence of a policy on renewable energy in the country. The government agency complained that the situation is retarding solar energy's contribution to the power supply in Nigeria [37–39]. In relation to Nigeria's renewable energy policy landscape, Edomah [10] observes that there exists a complex relationship between resources, institutions, and political structures in the governance of energy infrastructure; therefore subjecting energy transitions to the influence of government policies implemented within and through institutions. He further posits that there is an increased need for partnership and interaction between public and private institutions in the governance and provision of energy infrastructure. He concludes that energy infrastructure provision is primarily a political choice; hence, technological changes in electricity supply systems are a major catalyst in shaping the kind of energy infrastructure a society ends up with.

In 2011, South Africa initiated a policy aimed at supporting renewable energy when the government hosted the 17th Conference of the Parties in Durban (COP17). Its previous efforts to generate electricity from renewable energy sources was done through the instrumentality of the Renewable Energy White Paper and the Renewable Energy Feed-In Tariff (REFIT). This unfortunately suffered setbacks because of the lack of political support for their implementation. Subsequently, the South African Government's National Treasury and its Department of Energy launched the renewable energy independent power producer procurement programme (REIPPPP) considering the climate change negotiations at the COP 17 in Durban that year. The REIPPPP currently counts as the most successful energy programme nationally [40–42].

However, in spite of the well documented benefits of South Africa's energy policies, particularly its renewable energy policies, Sebitosi and Pillay [43] argue that South Africa appears to be caught in a time warp with a weak policy environment, and a power sector that continues to plan its future in the traditional way. In addition, South Africa's primary policy focuses on appropriate energy pricing as the primary mechanism for driving its sustainable energy transitions objectives. According to Edkins et al. [31], South Africa's current policy environment is biased towards larger and more established and mature renewable energy technologies, while neglecting smaller and less mature ones. With the attendant consequences of leading to a highly undiversified renewable energy mix, which has considerable negative outcomes, in addition to a reduction in the ability of the policy to effectively capture other opportunities and advantages associated with small-scale renewable energy projects.

A comparison of the policy and regulatory environments of both countries presents interesting contrasts in terms of level of sophistication and energy sector realities on ground. Nigeria is arguably ahead of South Africa on the policy and regulatory front. However, Nigeria falls short in terms of how it has been able to effectively apply the policies and regulations in ensuring that it meets the energy requirements of the country. For South Africa, the level of sophistication of its energy sector (both conventional and renewable energy) is quite ahead of the level of sophistication of its policy and regulatory environments. The energy geographies of Africa exhibit much novelty and innovation. However, these dynamics have failed to scale the process of sustainable energy transitions in ways that would eliminate energy poverty issues but has led to changes in its characteristics and spatial patterns [44, 45].

Digitalisation and sustainable energy transitions

According to Gartner, "Digitalisation is the use of digital technologies to change a business model and provide new revenue and value-producing opportunities. It is the process of moving to a digital business" [46]. Digitalisation should not be confused with mere digitisation. This is because digitisation involves the replacement of a physical thing with a digital version, while digitalisation represents a much more fundamental, and pervasive transformation. It is one that seeks to create new sources of value by placing digital information at the core of the business. Digitalisation moves beyond simply recording data or using digital tools to support existing business; it requires reshaping the business to harvest value from digital technology use [47, p. 12]. The use of digital technologies to enable sustainable energy transitions involve the adoption and implementation of these classes of technologies in ways that leverage their unique characteristics to offer new models of production, distribution, and consumption of energy. Particularly, digital technologies such as blockchain, smart grids and digital platforms (platformisation) have demonstrated practical capacity for deployment within the energy sector.

To gain a better understanding of what class of technological artefacts fall under the classification of digital technologies, it is imperative to unpack the discursive layers on the evolution of these class of general purpose technologies [48–50] that currently form the foundation for the transformation being witnessed today across various aspects of society. According to Bharadwaj et.al. [51], digital technologies are electronic tools, systems, devices, and resources that generate store or process data. They can be viewed as combinations of information, computing, communication, and connectivity technologies. Yoo et.al [52] argue that digital technologies differ from earlier technologies in three unique characteristics: (1) the re-programmability that separates the functional logic of a device from its physical embodiment, (2) the homogenisation of data that allows for storing, transmitting, and processing digital contents using the same devices and networks, as well as (3) the self-referential nature yielding positive network externalities that further accelerate the creation and availability of digital devices, networks, services, and contents Yoo et al. as cited in [53].

Digital technologies can be deployed to facilitate new economic models that address production and consumption through digitally enabled optimisation of processes. Evidence from research has shown that optimisation of industrial processes either increases energy use or accelerates production or consumption [46, 54–57]. In view of the disruptive nature of digital technologies, and the inherent promise of achieving new and efficient models that displace existing production and consumption models in society in general and within business environments in particular, stakeholders now see the need to apply particular digital technologies such as blockchain and smart grids in the pursuit of sustainable energy transitions, with the particular objective of increasing access to energy to underserved communities such as found in sub-Saharan Africa [24, 58, 59].

In view of the current state of developments within the energy sector across sub-Saharan Africa, there is a lack of critical assessment of the digital technologies "mediated" sustainable energy transitions. This creates synergy gaps between industry stakeholders and public sector policy drivers, thereby leading to chaotic, fragmented and often conflicting nature of evolution within the energy sector which may be counterproductive in the long run. Edomah [10] argues that policy makers play a vital role in governing transitions in any given society through established institutional frameworks, and that energy infrastructure choices are influenced and ultimately determined by institutional dynamics and structures.

Smart grid solutions

As a result of the challenges of electricity grids experienced in countries such as the USA, UK, and across Europe over the last decade, there has been an acceleration of deployment of smart grid solutions. This has increasingly resulted in decentralisation of electricity production systems that are based on renewable energy sources, more energy-efficient behaviour by consumers, and the recent trend of connecting electric vehicles to the energy grid thereby resulting in significant impact on the energy industry in the coming decades [2, p. 630] [32, 33, 60].

Smart grids are a direct outcome of the digitalisation of energy systems through the adoption and implementation of digital and other advanced technologies for the monitoring and management of electricity transmission from all generation sources, to meet the varying electricity demands of end-users IEA 2001 as cited in [61]. The Department of Energy and the South African National Energy Development Institute (SANEDI) view a smart grid as "an electricity network that can intelligently integrate the actions of all users connected to it—generators, consumers and those that do both—in order to efficiently deliver sustainable, economic and secure electricity supplies". While Sustainable Energy Africa [62] defines it as "an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users." Niesten and Alkemade [2, p. 630] view a smart grid as an electricity grid that integrates information and communication technologies into the existing electricity network to allow for a two-way flow of information and electricity between generators and consumers. In all the definitions stated, a common feature of smart grids shared by all the definitions is the centrality of digital/ICTs in distinguishing the smart grids from the conventional grids; hence, the presence of these advanced technologies in the grid is what makes it 'smart'.

Smart grids employ innovative products and services that are combined with intelligent monitoring, control, communication, and self-healing technologies to achieve better facilitation and management of the connections and operations of all sources of energy. They provide consumers with more choices thereby enabling them to optimise their energy usage and consumption. This leads to consumers having access to more information and choice of supply which significantly reduces or eliminates the negative environmental impact of the whole electricity supply system, and delivers improved levels of reliability and security of supply [2, 63–65]. Sebitosi and Okou [65] list some of the benefits of smart grids to include the exploitation of dispersed resources (human and natural) through local exchange and storage of surplus electric energy, thereby leading to minimised transmission and distribution costs and losses. Another benefit is improved resilience to disruptions through self-sufficiency. Sebitoshi and Okou argue that there would also be greater end user engagement in energy investment and management as well as increased potential for more energy-efficient social practices. There are several initiatives across Africa that aim to leverage the benefits and advantages of smart grids to improve access to electricity and overall efficiency of the supply system. Prominent examples exist in South Africa spearheaded the Department of Energy and SANEDI.

Smart grids are widely recognised as an enabling technological component required for achieving sustainable energy transitions. However, such transitions have given rise to more complex government–utility–consumer relationships as evidenced from field deployments in various jurisdictions [32, 33, 60]. Milchram et al. [60] found that the proposition for smart grid systems in the United Kingdom and the Netherlands had a mixed effect on social and moral value concerns such as privacy and justice. They found that smart grids have the potential to effectively address justice issues, for example through the facilitation of small-scale electricity generation and transparent and reliable billing. However, they also found that while the current smart grid designs contribute to cost and energy savings, advance a more equitable and democratic energy system, they may also reinforce distributive and procedural injustices.

While investigating stakeholder relationships by examining the role of incumbent utilities for sustainable energy transitions through the use of smart grid in China, Ngar-yin Mah et al. [32] found that China has developed an incumbent-led model for deploying smart grids. This is characterised by the major-state-owned grid companies acting as enablers of smart grid deployments and the two main grid companies acting as a fundamental block to structural changes in socio-technical regimes. This discovery lends credence to the issues identified from previous research efforts into the deployment of smart grids. It is therefore imperative that conscious efforts be made by relevant stakeholders to ensure that deployment pitfalls are avoided if the full benefits of smart grids would be harnessed for successful sustainable energy transitions particularly across sub-Saharan Africa. A look at the policy environments of Nigeria and South Africa shows that Nigeria articulates fiscal policy measures aimed at providing the needed financing required by stakeholders. However, a shortage of funding opportunities continues to be a major challenge. While in South Africa, the policy orientation is towards achieving the right pricing that would attract private capital investments into the sector.

Blockchain technology in the energy sector

Blockchain technology occupies a prime position among digital technologies. It is used to power decentralised storage and sharing of transactional data across a large peer-to-peer network, where non-trusting members are able to interact with each other without an intermediary in a verifiable manner [66]. The technology is a distributed ledger that may be anonymous and permissionless. It is a time-stamped tamper-proof ledger that has the benefit of being able to remove the need for middlemen thereby eliminating friction and trust related issues among parties involved in transactions executed through a Blockchain ledger [67]. Disintermediation associated with Blockchain technology leads to cost reduction associated with certain business processes since they now become automated and independent self-executing processes as encoded in the smart contracts stored in the ledger.

There are basically three types of Blockchains—public, permissioned, and private [68–70]. The blockchain ledger is not stored in a centralised server, but copied and synchronised among parties of the network in a disintermediated fashion which eliminates the need of a middleman, thereby protecting the ledger from being a single point of failure, which deters any illegitimate tampering, the records stored in the blockchain database is protected by cryptography [67, 68, 71]. Blockchain technology is of particular interest because of its unique features some of which includes immutability of data recorded on it, and its ability to remove the need for a middleman from transactions involving two or more parties [69, 70]. There are three types of Blockchains (see Table 2): Public Blockchain, Private Blockchain, and Consortium or Federated Blockchain.

A Public Blockchain is designed to allow participatory access to everyone on the blockchain network with no requirements for trust relationships among the nodes. Transactions recorded on a public blockchain cannot be altered or cancelled. The following types of Consensus algorithms are used in a public blockchain: Proof-of-Work (PoW), Proof-of-Stake (PoS), and Delegated Proof-of-Stake (DPoS). The codes of a public blockchain

Table 2 Types of blockchain networks

Public blockchain	Private blockchain	Consortium or federated blockchain
Permission open to anyone to run Bitcoin/Litecoin full node	Permission does not open to anyone to run full node	Permission only opened to selected members of the consortium to run full node
Rights to conduct transactions is granted to anyone	Rights to conduct transaction is not granted to anyone	Rights to conducted transactions is only granted to selected members of the consortium
Permission to review/audit the blockchain is granted to anyone	Permission to review/audit the blockchain is not granted to anyone	Permission to review/audit the blockchain is granted to only selected members of the consortium

(source: author)

are open to be downloaded by anyone and they can start running a public node on their local device, participate in the consensus process by validating transactions in the network.

Case studies

A case study of Sun Exchange, Bankymoon and Onewattsolar was used to assess sustainable energy transitions in sub-Saharan Africa. This is because the two companies are market leaders in facilitating access to clean energy through digitalisation of sustainable energy transitions. Sun Exchange is a South African based start-up, while Onewattsolar is a Nigeria based start-up. The Sun Exchange operates a peer-to-peer platform for financing solar energy system installation and leasing platform. Through their platform, anyone anywhere in the world can purchase solar energy-producing cells and earn returns on their investments by leasing those cells to power businesses and organisations in emerging markets. This creates a win–win situation whereby the local communities get reliable cheap power, and the investors get a steady source of income through the usage fees paid by the consumers in the local communities.

The model goes through the following process: firstly, the Sun Exchange works with a group of solar energy companies as its partners (they may be based in any location around the world), identify projects where a small installation—a micro-grid of less than a megawatt—could make a significant impact. For example, clinics in rural areas or villages with unstable electricity supply. The next step is the planning and pricing of the installation. The planning and pricing info is made available online for prospective investors to purchase a few of the solar cells in the facility. The investors can purchase based on their risk appetite. Once the cost for installation is covered through purchase of solar cells by the investors, the array is constructed and put online within 60 days. The community is then given access to the electricity generated by the solar cells for a usage fee in an arrangement that is similar to payment for utilities, and the investors (and the Sun Exchange) get a part of that fee proportionate to their ownership of the array based on agreed revenue sharing arrangements [72].The Sun Exchange is also responsible for handling the leasing and fee collection alongside insurance and other related paperwork.

Onewattsolar provides a solution that essentially mirrors the business model of The Sun Exchange in terms of how the solar installation is funded and returns on investments paid to the investors who finance the installations. Also, Onewattsolar uses blockchain technology through the implementation of a "smart contract" that ensures accurate records of consumption of electricity and billing of consumers for precisely what they consumed. Essentially, a smart contract is a protocol written into the blocks of the blockchain that is intended to digitally facilitate, verify, or enforce the negotiation or performance of a contract; they allow the performance of credible transactions that are trackable and irreversible without the interference or mediation of a third parties [71, 73, 74].

Bankymoon is a South Africa-based software and consulting start-up with expertise in Blockchain technologies. Bankymoon offers consultation services to their clients by analysing existing systems and making recommendations based on the applicable use-cases. They also provide system integration services, offering their extensive experience in integrating blockchain technologies through the identification of relevant touchpoints within systems, and development of robust adapters using standards-based technologies. Finally, they offer bespoke custom software development for financial services with a blockchain-centric approach [73, 75, 76]. In 2015, Bankymoon made headlines when it announced Bitcoin's first innovative app, the 'Smart Grids and the Blockchain'. Through this app, Bankymoon provides Bitcoin payment gateways to smart metering vendors, allowing utility vendors to accept Bitcoin payments. It also recently launched a crowd-funding platform for public schools, allowing them to gain electricity credits [77, 78]. Users of the app provided by Bankymoon can top up their smart meters by using the Bitcoin cryptocurrency in real-time. Therefore, this makes it possible for customers outside the coverage of the traditional banking system to pay for electricity.

It also comes with the added benefit of avoiding high transaction fees associated with the traditional banking systems. The challenges faced by suppliers and municipalities within the energy sector in South Africa often leads to conflicts between suppliers and municipalities. This is partly because of the conflict prone architecture of the billing systems currently operated. One of the main consequences of this conflict prone billing system architecture is the problem of cost recovery with the attendant consequence of electricity price inflation. Hence, Bankymoon's Blockchain based, and Bitcoin powered 'smart meter' solution was developed with the objective of solving this problem. Every smart meter provided by Bankymoon has a unique Bitcoin address. When payment is sent to the smart meter in the form of Bitcoin cryptocurrency, the system automatically computes the tariff and then tops up the smart meter for the customer. This makes it possible for individuals to literally send utilities such as electricity to anyone using the Bankymoon smart meter from anywhere in the world by using Bitcoin cryptocurrency. Bankymoon's solution is an innovative approach that liberalises cross-border transactions in a uniquely different way. There is also the possibility for donors to send money directly to the smart meters supplied by Bankymoon through a crowd-funding platform (Usizo platform) created by the same company for schools in Africa [77].

The case study assessment matrix provides a review of the innovation type, business model template and sustainable energy transition compliance of the three companies covered in the case comparative case study assessment. From what can be seen, there is an innovation and business model preference for P2P and payment facilitation as the direct consequence or outcomes of the digitalisation of sustainable energy transitions in Nigeria and South Africa. It is pertinent to state that the digitalisation or the adoption and implementation of digital technologies within the energy value chain which results in transforming how energy is procured and consumed, is not only strictly restricted to sustainable energy transitions as evident with the case of Bankymoon. Bankymoon's solution focuses primarily on providing access to energy generated from conventional sources which cannot be classified as renewable energy sources. Their innovation is centred on payment facilitation built on blockchain technology and facilitated by cryptocurrencies as the medium of monetary exchange between the producers/retailers and consumers. Beyond the African environment, and in relation to sustainable energy transitions and digitalisation of energy systems, blockchain technology is currently being applied in several business use cases that facilitate exchange of assets, resources, and value. The most common use case applications of blockchain technology includes tokenisation of energy; disintermediation through peer-to-peer (P2P) energy trading; rewarding renewable energy adoption; accelerating adoption of electric cars; and reduction and tracking carbon emission. Table 3 gives a summary of these use cases and companies trying to solve the corresponding problems.

Conjoule is a platform that offers P2P trading among rooftop photovoltaic cell owners and interested public sector or corporate buyers. Greeneum is a decentralised and blockchain-based P2P platform for renewable energy, its GREEN token is a utility asset that incentivises users to reduce carbon emissions. Grid + facilitates energy asset tokenisation. It is a retail provider (i.e. buys on behalf of its customers at wholesale prices from outside) and offers a P2P trading platform among

Table 3 Blockchain companies and business use cases (Source: author)

Companies	**Business use cases**					
	Tokenization	P2P energy trading	Rewarding renewable adoption	Micro grids	Electric car adoption	Reducing/tracking carbon emissions
Conjoule		■				
Drift				■		
Greeneum			■			■
Grid+	■					
LO3		■		■		
MyBit	■					
Sun Exchange	■			■		
SolarCoin					■	
Swytch			■			
Veridium Labs						■
WePower	■					
OneWattSolar	■			■		

its customers. LO3 combines smart meters with blockchain at micro-grid levels that aims to revolutionise how energy can be generated, stored, bought, sold, and used, all at the local level. Drift is a start-up working to digitise, decentralise, and decarbonise energy systems. Veridium Labs aims to create a new asset class that tokenises natural capital, each token represents the removal of 1 ton of greenhouse gases from the atmosphere, or equivalent natural capital preservation activities (e.g., conserve 1 sq. meter of biodiverse tropical forest).

Tokens will be issued for validated projects to be used by firms to conform with environmental impact mitigation regulations, and more generally embed environmental replacements into the cost of their products. WePower is a platform for P2P trading of renewable energy, as well as fund raising for renewable projects by pre-sale of energy to be generated in the future. SolarCoin Foundation aims to foster solar energy generation installations; it awards crypto coins (for free, like air miles) to registered and verified solar energy producers. Each coin represents 1 MWh of produced solar energy [79]; OneWattSolar pays for, installs, owns and operates solar residential energy unit at zero upfront investment by home owners [80]; and Sun Exchange operates a peer-to-peer solar leasing platform through which anyone, anywhere in the world, can own solar energy-producing cells and earn returns by leasing those cells to power businesses and organisations in emerging markets, with installations and maintenance taken care of by Sun Exchange's selected installation partners [72, 81].

In bringing Blockchain technology and Smart Grids together, Alessandra et al. [82] proposes an innovative application of the Blockchain technology in operating a smart grid. They demonstrate how the Blockchain may play an important role in facilitating communications, transactions and security among the stakeholders involved in a smart grid, thereby providing an enhanced system. Their proposed solution permits for the creation of a decentralised energy market that can lead to significant displacement of the balance of expenditure towards energy investments of distributed resources. This also creates a potential redistribution of electricity to new energy market stakeholders, differently from the way the electricity is currently distributed and regulated. They cite the example of TransActive Grid, a New York based energy start-up that created and currently operates a similar peer-to-peer energy sales network based on Blockchain technology in which homes with solar panels on their roof can sell energy to neighbours on the same road not having their own solar systems. This is a classic example of the social and solidarity economy model powered by Blockchain technology [82].

Wu et al. [83] adopts a different approach in exploring the role of Blockchain technology in operationalising smart grids. Their proposal explores Blockchain technology in relation to demand side management of a smart grid and it presents an example of how blockchain can be used to facilitate machine-to-machine (M2M) interaction by framing an electricity market in the context of demand request. They used Blockchain technology to record data derived from power flow calculation model and electricity price customisation and applied smart contract to store transaction data and transfer assets automatically. There is no evidence of a commercially available implementation of their proposed solution which would provide an opportunity for comparison with the approach proposed by Alessandra et al. [82].

In another test implementation of Blockchain Technology on Smart Grids documented by Pop et al. [84], they investigated the feasibility of using decentralised blockchain mechanisms to deliver transparent, secure, reliable, and on-demand energy in producer–consumer settings within a smart grid distributed energy network. Their approach employed a blockchain-based distributed ledger which stores the energy production–consumption information collected from Internet of Things (IoT) smart metering devices in a tamper-proof manner. The smart contracts then define the expected energy flexibility at the level of each producer or consumer, the corresponding benefits or penalties, and the rules for balancing the energy demand with the energy production at grid level. Their system used a consensus-based validation for demand response programs validation and to activate the appropriate financial settlement for the flexibility providers. The prototype was implemented on the Ethereum platform using energy consumption and production traces of several buildings from literature data sets. The prototype results show that a blockchain-based distributed demand side management was a feasible option for matching energy demand and production in a smart grid.

Discussion

The quest to achieve sustainable energy transitions is gathering momentum, particularly as digital technologies are acting as transformational catalysts that are disrupting traditional models and leading to the emergence of new models within the energy sector across the world. Africa with its huge infrastructural deficits that has hampered its socioeconomic development over the decades is not being left behind in the pursuit of sustainable energy transitions. Africa's infrastructural deficits is particularly visible in the energy sector across the continent, this has manifested in significant level of underutilisation of its economic potentials which has ultimately resulted in high levels of poverty and unemployment among its population [5, 85].

The World Economic Forum's "Energy Transition Index" (ETI) compiles data used to measure the progress of various countries towards the achievement of sustainable energy transitions. According to the ETI rankings, countries in sub-Saharan Africa are under performing in their quest achieve sustainable energy transitions. This places most of them at the bottom of the ETI rankings, with Africa's two largest economies Nigeria scoring 109 and South Africa scoring 114 on an overall ranking of 115 countries [19]. Conversely, the poor performance by African countries is an indication of the huge opportunities for leapfrogging Africa's energy deficits using technology in ways that can directly usher the continent into a future of successful sustainable energy transitions that relies solely on renewable sources.

The solutions will also be socioeconomically inclusive by targeting users at the bottom of Africa's socioeconomic pyramid. The World Economic Forum notes that "accelerating the energy transition will require coordinated action across economic, technological and socio-political systems" [19]. Digitalisation of energy systems in combination with renewable energy sources promises a paradigm shift in the quest to improve the socioeconomic outcomes for marginalised societies all over the world, especially in sub-Saharan Africa. The quest to achieve the objectives of the SDGs may not be attainable if the same approach in governance, business and capitalism that may have contributed to creating these problems in the first place is maintained. Hence, there is an urgent need to explore new approaches to achieving the SDGs.

Situating the case studies of digital technologies mediated sustainable energy transitions covered in this research within the context of the policy and regulatory environments in which they are domiciled, it is observed that there is a disconnect existing between industry efforts and the policy environments governing such energy transitions. This disconnect hampers the ability for meaningful proliferation of such initiatives, particularly in ways that would translate to positive and impactful socioeconomic benefits across the society, this observation is also buttressed by Edomah [10] who commented that energy infrastructure choices were subject to the influence of prevalent institutional dynamics and structures. While Nigeria has policies and regulations that are better articulated than that of South Africa, its capacity to effectively implement those policies in ways that would $b=$lead to significant uptake in sustainable energy transitions is hampered by weak institutional environments.

Whereas the South Africa on the other hand has always been able to maintain a more efficient institutional environment which leads to better implementation outcomes even though there is still enough for improving its overall policies and regulations not only on its energy sectors, but with specific focus on achieving better outcomes in its quest for sustainable energy transitions which with favourable socioeconomic outcomes in the society. Also, the research by Monyei, Adewunmi and Jenkins [86] sheds light on the technical shortcomings of the solar home systems deployed by the Sun Exchange and Onewattsolar, which makes them practically not viable for addressing the incidence of energy poverty suffered who rely on such deployments. In relations to how digitalisation is impacting the outcomes of sustainable energy transitions in Africa, evidence obtained from the extensive review of relevant literatures indicates that there are emerging models of generation and distribution of energy that rely on digital technologies such as the Blockchain technology.

The level of sophistication in terms of how Blockchain is being adopted and implemented within the energy sector around the world, what we observe from the case study covered in that the current model of implementation in Africa is based on the context of a marketplace business model where energy generated in micro-grids is being traded. From the comparative assessments of three companies covered in sub-Saharan Africa. A detailed review of their models from publicly available sources (company websites, news articles and YouTube videos) indicates that only two (The Sun Exchange and Onewattsolar) of them effectively fall into the category of companies that have achieved a considerable level of digitalisation of energy production and consumption models that can be said to be compliant with digitally enabled sustainable energy transitions. Both companies rely on renewable energy source solar (energy) for the generation of electricity energy consumed by their users, they also rely on a digital platform based two-sided market that brings together project financiers and recipients whose regular usage fees serves as source of revenue for the investors. This financing model ensures that the users are not excluded based on the huge initial investment costs required for setting up the system.

Monyei et al. [86] in their research on off-grid rural electrification in South Africa through the use of solar home systems (which is what is offered by the Sun Exchange and Onewattsolar) argue that policies targeted at non-grid electrification may be practically and ethically flawed because they do not incorporate values into its delivery, they also do not adequately consider factors such as weather variation across areas in which off-grid solar home systems are deployed. Based on their data analysis, they established that solar irradiance stochasticity impacted significantly on the outputs of solar home systems, thereby depriving the users of the intended benefits of such systems, their data analysis showed that the varying figures of 7.5KWh per month for individual households using the off-grid energy systems was poor when compared to the traditional energy grid-based average of 45KWh per month per household.

In relations to the digitalisation of sustainable energy transitions in Africa, evidence suggests that Africa is still very much in the early stages of adoption and application of digital technologies such as blockchain and smart grids within the energy sector. Africa's sustainable energy transitions is in a rudimentary or early adoption stage. While it is noteworthy that two out of the three companies covered in this study adopt platformisation in their business model approach in connecting sustainable energy dependent electrification project financiers to end-users, it is also important to acknowledge that platformisation at their stage is not an indication of advancement or sophistication in the stage of sustainable energy transitions. Platformisation is a well-established approach to digitalisation of business models [87–89], it is quite effective and transformational but beyond creating a multi-sided (or two-sided in this case) marketplace, Africa's energy transition is yet to enter into the mass adoption stage.

When compared with what is obtainable in more advanced societies, we see an absence of micro-grids that involves multiple energy producers who can trade excess energy produced with other consumers. The current approach by The Sun Exchange and Onewattsolar is basically standalone and subsistent in nature, this leads to inherent inefficiencies because there is an absence of a mechanism that determines if the energy generated for any user is more or less than what that user requires. If the energy generated is more than what the user requires, there is no way the user can trade the excess, and if less, there is also no way the user can purchase extra from other producers with excess capacity. Hence, the current model suffers from a level of inefficiency that is yet to be quantified. In regard to long-term viability of these models, Africa's infrastructural deficits especially within its energy sector provides a fertile ground for these types of projects to thrive considering the gaps they can potentially fill in bringing electricity to underserved communities.

In relations to the solution provided by Bankymoon in South Africa, it depends on electricity being created through traditional energy production models from major South African utility providers such as Eskom which is largely fossil fuel based, the value which Bankymoon's solution offers is more on the payment side of access to electricity, as the case of their Usizo platform shows, for example, needy schools that have Bankymoon meters installed which are Blockchain-aware, allows anybody from around the world to make payments directly to the meter in the cryptocurrency of their choice and fund the energy or water needs of the school. The process of funding utilities for needy organisations through Bankymoon's Usizo platform is straightforward. Bankymoon advertises the organisation that requires funding for utility. When a school is advertised, the amount of Kilowatt-hour (kWh) of electricity required is stated alongside the cost per kWh. For example, school A requires 2993 kWh at $0.23 per kWh, the cryptocurrency payment address/barcode is displayed as part of the information on the school's advert page of the Usizo portal. Once payment is sent to the cryptocurrency address/barcode, the school is automatically given access to electricity through the smart meter because it now has "credit" on it for the amount sent by the donor. Unfortunately, as at the time of conducting this study, it was not possible to ascertain how many payments for utilities or frequency of such payments have been made by donors to needy organisations in South Africa; hence, the level of external dependency cannot be determined at this point.

Digitalisations of energy systems in combination with renewable energy sources are potential solutions to infrastructural challenges that involves both volatility of energy supply and available capacity. The review of the policy and regulatory environments of Nigeria and South Africa highlighted the differences in levels of sophistication and maturity of both countries energy sector policies and regulations, particularly in their attempt to formulate the right policies that would catalyse sustainable energy transitions in both countries. With the evident policy inadequacies and disconnect between policy objectives and sustainable energy transition realities which may be attributed to considerations such as weak institutional environments for the case of Nigeria and, and low level of policy and regulatory environment maturity for the case of South Africa.

In addition, the research identified the nature of digitalisation taking place within the energy sector, and how digital technologies were being adopted and implemented in developing new generation, distribution, and consumption models within the energy sector. Digital technologies such as blockchain and smart grids are being effectively leveraged in innovative ways that makes it possible for new energy production and consumption models that are socially inclusive and environmentally sustainable. They are also being leveraged to ensure that existing systems can be more efficiently utilised to reduced wastages within the system and make it more transparent and reliable by taking steps such as making consumption of energy adjustable to the fluctuations associated with production, and by replacing the traditional approach that relies on expensive capital investments in physical equipment such as cables, transformer stations and additional production capacity. Smart grid advocates argue that they are, in terms of socioeconomic considerations, an optimal solution to future challenges and therefore, they are beneficial to all.

Conclusion

The research assessed the digitalisation of energy systems in Africa within the context of existing policy frameworks in the quest to achieve sustainable energy transitions in Africa. This was done by investigating the role of digital technologies such as blockchain, digital platforms and smart grids adopted and implemented within the energy sector in achieving new energy production and consumption models that are both environmentally sustainable and socially inclusive. This assessment was done within the context of existing policy and regulatory frameworks of the society where the use cases were domiciled. From the literature and case study reviewed, the prospects of combining the potentials of smart energy grids and Blockchain technology presents a potentially viable solution that can be explored on a large scale in the quest to achieve the provision of affordable and clean energy to many marginalised societies across sub-Saharan Africa.

The energy poverty situation across sub-Saharan Africa has also led to the proliferation of private electricity generation, and what the use cases covered in this (particularly The Sun Exchange and Onewattsolar) research has shown is that there is a commercially viable possibility to digitalise Africa's sustainable energy transitions through the adoption and utilisation of digital technologies such as Smart Grids and Blockchain technology within its energy sector. Thereby, creating new models of production and consumption of electricity among many producers with the large pool of available consumers. This could help Africa bridge the gap in energy poverty and leapfrog the deficits created by the low level of availability of traditional energy grids across sub-Saharan Africa [86, 90].

While Blockchain technology in itself does not determine if the energy is 'clean', its role should be seen from the perspective of an 'enabler' because it enables and encourages a new form of energy marketplace which has the potentials of disrupting the traditional energy market which in itself is not clean because it is not based on renewal energy sources that are environmentally friendly and sustainable [74, 82]. The Bankymoon project of rolling out Blockchain payments based smart meters hold considerable prospects for commercial viability considering that the Blockchain smart meters are being implemented by Bankymoon throughout South Africa. Widespread adoption leads to economies of scale which is vital in ensuring that a solution gains traction in a way that ultimately leads to profitability for producers, while also addressing the pervasive energy poverty plaguing the continent.

It is yet to be seen how profitable and sustainable this model is, and further research would be required in the future to re-evaluate the system and other related issues. What can be learned from the current state of sustainable energy transitions in Nigeria and South Africa is that digital technologies offer the possibility of a more efficient way to leapfrog the infrastructure deficit required to address energy poverty in sub-Saharan Africa. This is because these set of technologies unlock the possibilities that would have required more financial resources to provide access to underserved segments of the society who may not be able to afford market determined pricing for energy. This makes it imperative for governments to take proactive measures in addressing the gaps existing in the policy and regulatory environments to ensure a higher level of uptake which would catalyse the process of sustainable energy transitions that would address energy poverty and lead to socioeconomic growth and development in societies across sub-Saharan Africa.

Abbreviations

SDGs: Sustainable Development Goals; SSA: Sub-Saharan Africa; GW: Gigawatt; ETI: Energy Transition Index; EPSRA: Electric Power Sector Reform Act; NERC: Nigerian Electricity Regulatory Commission; COP17: 17Th Conference of the Parties; REFIT: Renewable Energy White Paper and the Renewable Energy Feed-In Tariff; REIPPPP: Renewable Energy Independent Power Producer Procurement Program; SANEDI: South African National Energy Development Institute; PoW: Proof-of-Work; PoS: Proof-of-Stake; DPoS: Delegated Proof-of-Stake; PBFT: Practical Byzantine fault tolerance; dApps: Decentralised Applications; P2P: Peer to peer; M2M: Machine to machine; IoT: Internet of Things.

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