Leveraging Bitcoin mining to improve access to electricity in rural Africa

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Introduction

Context

In 2023, an estimated 600 million people in sub-Saharan Africa had no access to electricity.[1] Recognizing the huge gap in access to electricity, countries set bold targets for ending energy poverty by 2030 to align with the United Nations Sustainable Development Goals (SDGs). Meeting these targets requires significant investments, with some estimates putting it at USD22 billion a year[2]. Even as the continent is poised to double down on investment in renewables, natural gas will continue to play a critical role as a mediator between the ambitious energy transition targets set out by policymakers and the security of the African energy supply.[3]

In 2022, the African continent generated 892.7 terawatt hours of electricity, about 3.1 percent of the global output, down from 896.9 terawatt hours in 2021.[4] The top ten electricity producers alone accounted for 81 percent of installed capacity and 83 percent of electricity generation, with the remaining 44 countries covering the difference. With the top ten being responsible for the lion's share of installed capacity and electricity generation, this points to concerningly low levels of production among the remaining countries. To put this in context, out of all the 54 African countries, the top ten countries have only a fifth of the population (104 million) of the other 44 countries (502 million).[5]

Considering the urgency of expanding access, countries are seizing the opportunity to "leapfrog" traditional electricity models by promoting off-grid and mini-grid energy solutions for greater accessibility.[6] The growth in renewables has been driven by decreasing costs and improved efficiencies of renewable technologies, making small-scale renewable energy more affordable over the last decade. The renewable energy mix includes solar, wind, hydropower, and modern biomass paired with batteries and power packs to provide a package that is helping to alleviate Africa's energy access challenge.

The main grid has been the primary means of supplying electricity but extending it to new rural areas is costly. Cheaper off-grid options are needed as many utilities fall deeper into debt and electricity access becomes more critical.[7] Decentralized renewable energy (DRE), such as mini-grids, have increasingly drawn attention as a vital tool for addressing electricity challenges and improving access. Still, policy gaps and challenges impede sector growth.[8] Designing mini-grids to serve communities in rural locations has an inherent problem: households and businesses have not quite developed the consumption patterns required to sustain mini-grids financially in the short to medium term. As a result, mini-grid developers are seeking alternatives to the current model to increase uptake by encouraging local businesses' productive use of energy. One emerging solution proposed for addressing the low demand for energy on mini-grids is Bitcoin mining data centres.

Bitcoin mining as a productive use case

Organizations such as the Green Africa Mining Alliance (GAMA) propose colocating Bitcoin mining data centres at mini-grid sites to absorb stranded or excess energy that would otherwise go to waste, especially during off-peak hours. Bitcoin mining is an energy-intensive process that uses a proof-of-work consensus mechanism, which is the process of adding transactions to the blockchain by being the first to solve a mathematical problem via computation.[9] Bitcoin mining data centres can be designed to have real-time demand levelling, which allows them to moderate their energy use to match available supply, thereby improving mini-grid efficiency by reducing over or under-generation of electricity.[10] This ability to dynamically flex electricity consumption can incentivize additional renewable energy capacity buildout by reducing the period required to start seeing a return on investment.[11]

Bitcoin mining data centres are proposed as ideal anchor tenants for mini-grid developers because their operations often require substantial amounts of power, allowing developers to maintain a load profile that would guarantee the highest return on investment, often in the short to medium term for most developers. Bitcoin mining data centres are also considered location agnostic, meaning they can be set up in any location, even very remote rural areas.[12] While there are many types of digital asset mining data centres, this research will focus on Bitcoin mining data centres that have drawn the most attention and have been documented by several industry actors.

Purpose of the report

This report explores how Bitcoin mining can help solve the grid sustainability challenges faced by many African countries that have difficulties in extending electricity access to remote and low-income areas. Bitcoin mining consumes electricity to generate new Bitcoins and secure the Bitcoin network. By creating a steady and profitable demand for electricity, Bitcoin mining can support the development and operation of mini-grids, which are small-scale power systems that can serve off-grid communities.

The report consists of six main sections:

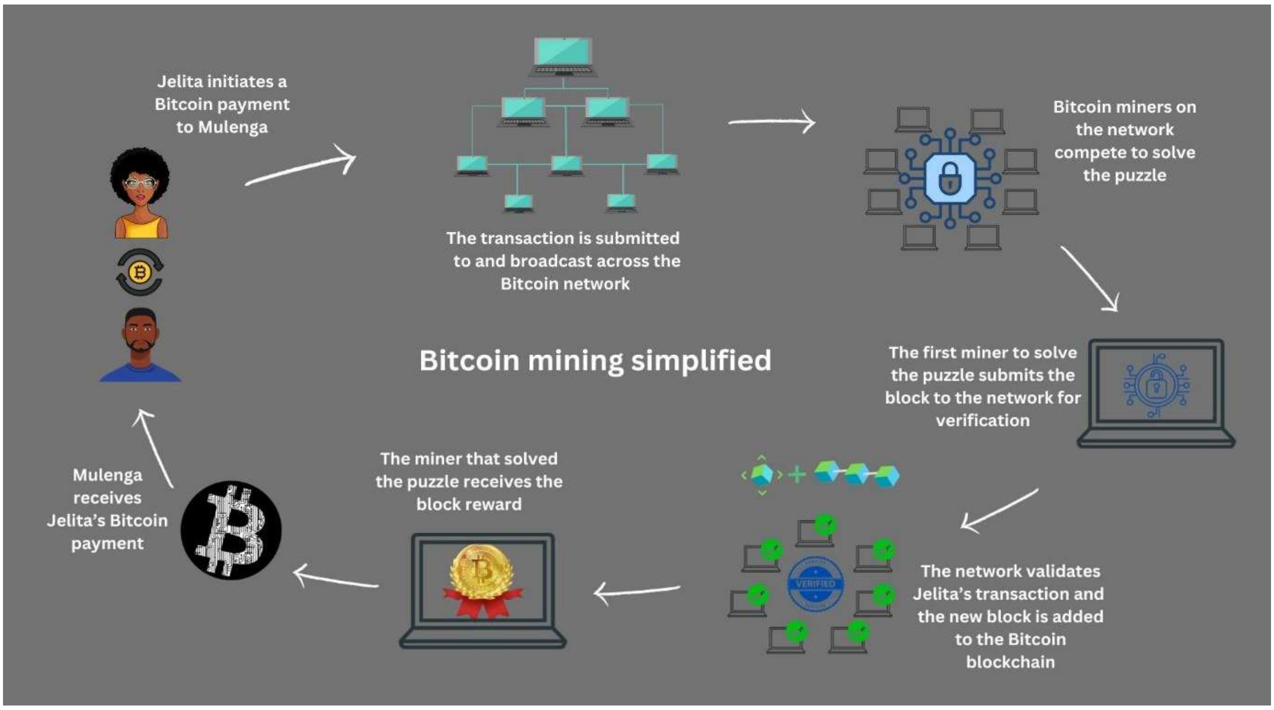
- the first section introduces the concepts and benefits of Bitcoin and Bitcoin mining, and explains how they can create value for mini-grid developers and customers;
- the second section analyzes the power situation in Africa, focusing on the main grid and mini-grid sectors, and the electricity generation capacity and costs in different regions;
- the third section presents the mini-grid market and the potential for Bitcoin mining on mini-grids;
- the fourth section provides an overview of global bitcoin mining trends and provides examples from selected countries;
- the fifth section evaluates the regulatory and business factors that affect the feasibility and attractiveness of investing in Bitcoin mining on mini-grids in Africa
- the final section shares some conclusions and provides some recommendations for regulators and Bitcoin miners to consider to build win-win partnerships

Concepts and benefits of Bitcoin mining

Understanding Bitcoin mining

A blockchain is a digital distributed ledger used to document transactions [13] and is sometimes called a decentralized database. In contrast to traditional databases, spreadsheets or ledgers, blockchain data is not stored in a central place. Instead, the data is stored in blocks that are copied and distributed among a network of peers (for example, individuals, organizations, businesses, and increasingly, data mining facilities), which explains the name *distributed ledger technology*.[14] Each block stores verified and validated transactions that are impossible to alter once added to the blockchain.[15] Bitcoin mining is the process of using specialized computers to discover new blocks, verify transactions and add them to the Bitcoin blockchain.

The verification and validation of transactions added to the blockchain uses a consensus mechanism called proof of work (PoW), which helps secure the network. Bitcoin mining uses PoW to contribute computation resources to maintain and secure the Bitcoin blockchain network.[16] Miners are incentivized to participate in the Bitcoin blockchain by block rewards, which they earn for successfully mining new blocks. The block reward includes two components- the first is the block subsidy and the second is the Bitcoin transaction fee.[17] The block subsidy is the amount of newly minted Bitcoin generated when a new block is added to the Bitcoin blockchain, while the transaction fee is the amount paid on each transaction submitted to and verified by the network.[18]



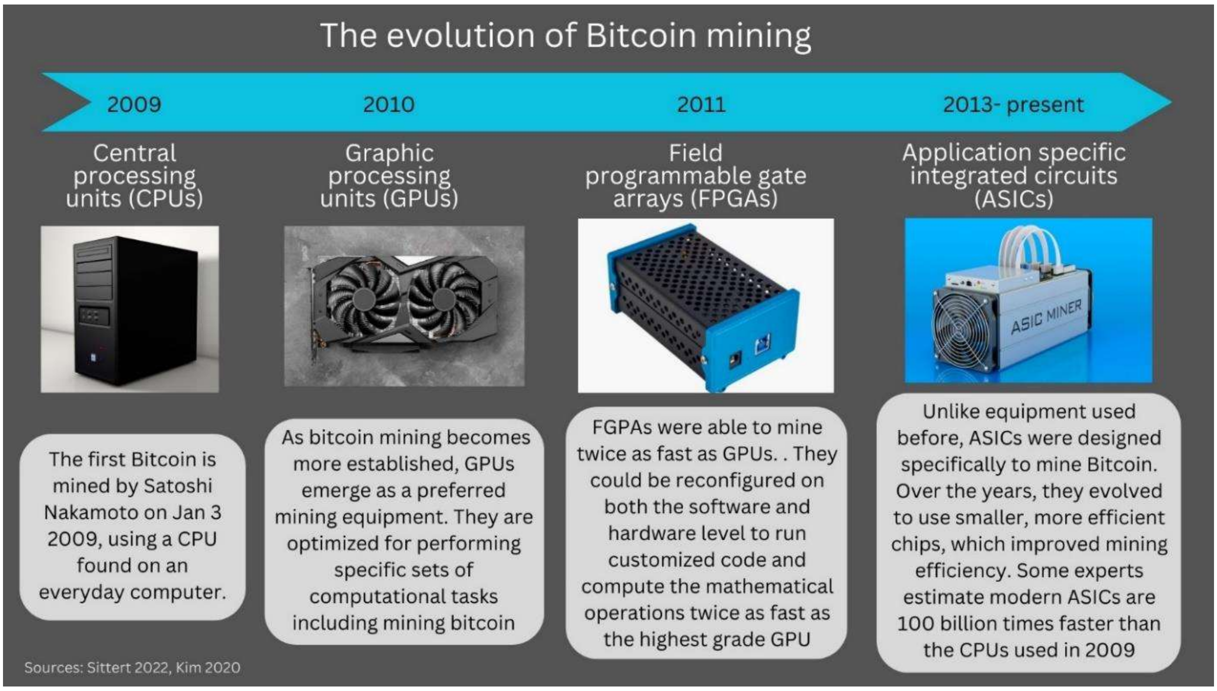
Miners must develop a good understanding of mining economics to stay profitable and competitive. One important aspect of Bitcoin mining they have to consider is mining difficulty. Mining difficulty refers to the level of complexity of the mathematical equation that miners must solve to find the hash for the next block. The difficulty of the mathematical problems is adjusted roughly every twelve weeks to ensure that blocks are added approximately every 10 minutes. The number of miners contributing to the network's total computational power affects the mining difficulty. The more miners there are, the higher the hash rate, resulting in an increase in mining difficulty. The opposite is true; fewer miners and a lower hash rate reduce mining difficulty. The regular adjustments in mining difficulty ensure Bitcoin's monetary policy functions as intended and safeguards the network's security.[19] Another important feature that ensures Bitcoin's monetary policy functions is the halving. The amount of Bitcoin awarded to miners is reduced by half every four years in an event known as the halving. The halving reduces the Bitcoin supply over time, which can increase its price (if demand stays steady). This is how Bitcoin's protocol creates scarcity, which makes Bitcoin attractive to many people.[20]

Bitcoin mining is price-sensitive. Therefore, Bitcoin miners seek out geographies where electricity prices allow them to remain profitable. According to the Cambridge Electricity Consumption Index, the average electricity price for Bitcoin mining globally is constant over time at 0.05 USD/KWh.[21] Therefore, miners aim to find electricity priced at this level or below. Some miners, however, are willing to pay up to 0.08 USD/KWh.[22] In 2023, more than 38 percent of Bitcoin mining hash rate (the hash rate represents the efficiency and performance of a mining machine)[23] was in the United States, making it the country with the largest share of Bitcoin mining operations. Bitcoin miners are drawn to the United States for several factors, one being the cost of electricity. Commercial electricity tariffs in states like Texas, where the largest Bitcoin mining data centres are located, are 0.069 USD/KWh.[24] Low electricity prices allow large Bitcoin mining data centres to keep costs down and maintain their profitability even in highly competitive environments when more miners enter the market.[25] Besides the price of electricity, Bitcoin miners are choosing to set up their operations in North America due to a high level of confidence in the regulatory and business environment.

Bitcoin mining over the years

The technology used to mine Bitcoin has evolved as the industry grew and more actors joined. In 2009, the early days of Bitcoin mining, the industry saw a lot of participation from individuals mining in their homes using central processing units (CPUs) installed on personal computers.[26] Due to the lack of mining competition, less computation energy was required to mine bitcoin. As the price of bitcoin started to rise and cryptocurrencies started to gain more attention, the number of miners grew, competition for block rewards increased and miners sought to gain an advantage over each other. Miners turned to graphics processing units (GPUs), which were reprogrammed to run mathematical computations required to mine Bitcoin more efficiently.[27] GPUs were quickly overtaken by field programmable gate arrays (FPGAs), which were remodelled to mine bitcoin and were considered more efficient and less costly.[28] Just two years after FPGAs became the preferred mining equipment, a China-based hardware manufacturer released the first set of application specific integrated circuits (ASICs). ASICs were designed specifically to mine bitcoin and quickly became the dominant bitcoin mining equipment. Since the introduction of ASICs in 2013, the industry has seen a dramatic change in chip size from 130 to 7 nanometres in recent years. As a result, modern units are estimated to be 1000 billion times faster than the humble PC of 2009.[29]

The face of bitcoin mining has also changed, from home miners using CPUs in 2009 to large bitcoin mining data centres and institutional investors who set up large mining farms with thousands of ASICs often collocated near electricity production facilities. The rise of large mining farms raised the bar for individual and small-scale miners.[30]



Monetizing stranded electricity

Mining digital assets such as Bitcoin is an energy-intensive process and has the potential to generate significant economic and technological benefits, such as the creation of new jobs and driving the development of innovative technologies. Digital asset mining data centres resemble cloud computing facilities owned by large corporations such as Google and Amazon. Mining data centres and cloud computing facilities both convert electricity using computers, data centre infrastructure and a highly skilled workforce into a digital product sent over the internet. However, a key difference is that traditional computing facilities have less operational flexibility. In contrast, digital asset mining data centres can ramp their production up and down depending on the grid's electricity demand.[31] Therefore, digital asset mining data centres such as Bitcoin miners can serve as a flexible load through participation in demand response programmes that help balance electrical grids. Digital asset mining operations can curtail their power usage at a moment's notice, allowing them to give power back to the grid if demand exceeds available supply.[32]

Risks in Bitcoin mining

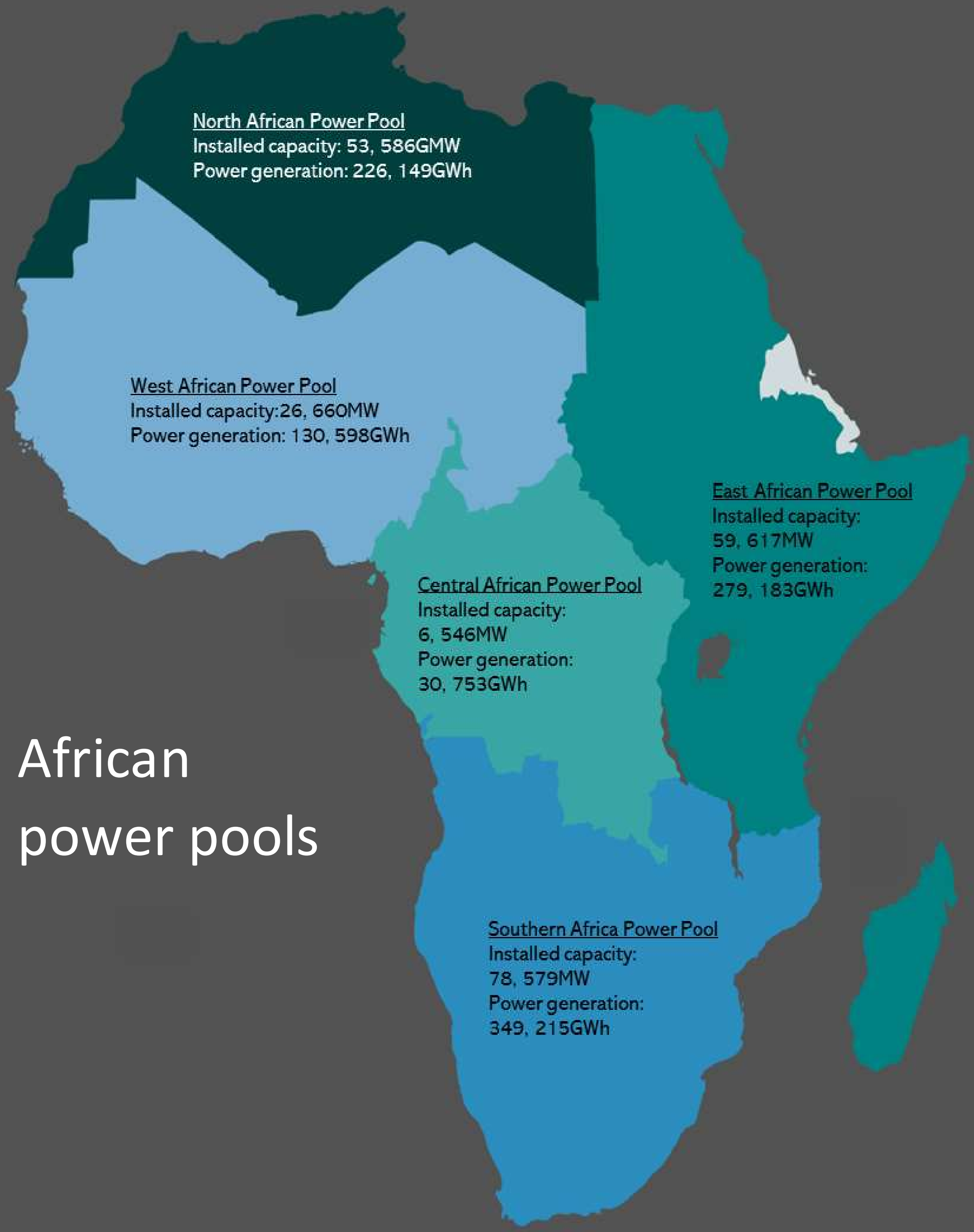
Several risks associated with Bitcoin mining should be considered before setting up a Bitcoin mining data centre.

Price volatility- the price of Bitcoin is very volatile because it is highly sensitive to supply and demand. Its market value is affected by how many coins are in circulation and how much people are willing to pay.[33] For example, at the beginning of 2021, the price was USD36 000; by June of that year, it had climbed to USD61 000 before falling back to USD31 000. In November of 2021, the price reached an all-time high of USD64 000 before plunging to USD24 000 in 2023.[34] The price rose again by the end of 2023, reaching USD44 000 in December.[35] This volatility affects Bitcoin miners, especially those who invest when the price is high but are forced out of the market when the price dips dramatically.

Regulatory risks- Regulatory risk in African countries are often a major deterrent to attracting investment in key sectors, including electricity. Bitcoin mining must navigate regulatory risk linked to a lack of regulation for Bitcoin mining and to the regulatory uncertainty related to government perceptions of cryptocurrencies. The regulation of the electricity sector is another important aspect of regulation to consider. It has implications on how easy or difficult it is to access power through public or private utilities and developers.

Technological risks – The next Bitcoin halving is anticipated around the end of the first quarter or the beginning of the second quarter of 2024 and is expected to reduce block rewards. Therefore, miners will depend more on transaction fees to maintain profitability. As a result, miners will face increased competition and possible changes in mining power distribution.[36] Research from Blocksbridge, a mining consultancy, revealed that in 2023, publicly listed miners spent between USD10 000 and USD15 000 to mine one Bitcoin. These costs are anticipated to double post the halving, with miners reaching a breakeven point between USD20 000-USD30 000. To remain profitable under these conditions, only the most cost-efficient miners will survive, while others might be forced to shut down. Two factors will be particularly important- accessing the lowest-cost energy and using the most efficient equipment.[37]

African power pools



Bitcoin mining opportunities

The main grid vs mini-grids

The number of people without access to electricity in sub-Saharan Africa has remained stubbornly stagnant at about 600 million since 2010 due to population growth.[38] Most countries experience long periods of electricity rationing due to chronic underinvestment in power infrastructure. In South Africa, for example, supply shortages and ageing grid infrastructure have resulted in increasingly high levels of load shedding since 2007, estimated to have reached up to 5% in 2022.[39]

Countries have increasingly turned to renewable energy and mini-grids to bridge the gaps in energy access. The International Energy Agency (IEA) estimates that between 2020 and 2030, Sub-Saharan Africa will see the fastest growth in renewables and take the highest share of new installations globally, led by hydropower and solar photovoltaics (PV). This would entail doubling hydropower output, accounting for nearly half of total generation, while solar PV will increase from next to nothing to as much as 20 percent. As countries continue to increase investment in the electricity sector, installed capacity is expected to rise from 260 GW to 510 GW.[40] Between 2020 and 2021, renewable power generation expanded, with wind and solar PV installed capacity reaching 6,491MW and 9,505 MW, resulting in 12.2 percent and 14.5 percent growth, respectively. In the previous decade, the continent saw 320 assets constructed with 14GW of electricity added, and this is expected to almost triple between 2020 and 2030 when an additional 648 assets are forecasted for construction and will generate about 77GW of electricity.[41]

By connecting distributed solar and storage with the grid and mini-grids, consumers can more easily climb the energy staircase through improved access to energy services and benefit from a new approach to integrated electricity planning. Centralized and decentralized electricity can collaborate to find the necessary technology, processes, and regulatory solutions to transform electricity systems into resilient networks that provide everyone with reliable, affordable, and universal access. [42]

The African power landscape – main grid

Of the 892.7 terawatts of electricity produced in Africa in 2022, the largest share was produced from natural gas (41 percent), followed by coal (26 percent), hydropower (18 percent), oil (8 percent), renewables (6 percent), nuclear (1 percent) and the rest from other sources (1 percent).[43] Consumption patterns generally follow the production patterns with the bulk of electricity consumption happening in North African economies (44 percent) and Southern Africa economies (38 percent), accounting for over 80 percent of the total electricity produced. In comparative terms, Central Africa has the lowest electricity consumption and production rates, followed by East Africa and West Africa.[44] The African power grid has many obstacles to overcome to achieve universal access. Governments, and the private sector and the development community need to work together to address insufficient power generation, poor transmission infrastructure, last-mile distribution challenges, affordability of power, and inadequate and inappropriate sector funding.[45]

Most countries are faced with an electricity production deficit. Consequently, there are very few opportunities for mining on the main grid except in cases where the main grid would have:

- excess energy because they have increased their installed capacity but have yet to secure investment or build out transmission and distribution infrastructure
- failing distribution and transmission infrastructure due to a lack of maintenance leads to power being stranded closer to generation facilities

Even as countries move to increase the amount of renewable energy on their grids, substantial transmission and distribution grid expansion will be required in the short term. On average, countries in sub-Saharan Africa experienced high transmission and distribution system losses (i.e. technical and nontechnical) ranging between 15% to 29%, compared to that of a developed country (7% - 10%). For example, South Africa accounts for 27% of Africa's current electricity demand, but frequent load-shedding due to unexpected coal plant failures has increased the investment in renewables.[46] However, current the state of the grid makes it difficult to take on additional supply. A recent renewable energy auction round in South Africa did not award any onshore wind capacity, as all proposed projects were in areas with no grid availability.[47] This meant independent power producers were unable to supply their power through the national grid and had to find alternative ways to sell off the power they were producing.

Regional power pools

There are five major power pools on the African continent- the Central African Power Pool (CAPP) covering central African countries; the East African Power Pool (EAPP) covering East Africa; the Southern Africa Power Pool (SAPP), which draws its membership from the Southern African countries; the West African Power Pool (WAPP) and the Maghreb Electricity Committee which includes North African countries.

In 2021, the African Union launched the African Single Electricity Market (AfSEM) as the continent's energy trading programme meant to interconnect all 55 African Union member states by 2024.[48] The operationalization of the AfSEM has several challenges to overcome, among them:

- The determination and calculation of electricity tariffs is not transparent;
- Electricity tariffs are not cost-reflective are unbundled;
- Power utilities are inefficient, affecting financial sustainability;
- Monitoring and evaluation mechanisms are weak;
- Lack of harmonised transmission and wheeling charge prices constrain cross-border and regional power trade;
- Lack of regional coordination and dispatch control centres and;

Tariff guidelines and principles are not harmonized to support power pool operations.

Table *1* the capacity factors across sub-Saharan Africa are quite low, with Central Africa having the lowest at 34 percent, although it does have the highest load factor at 84 percent. Southern Africa has the lowest load factor and also the lowest average number of annual outages, compared to Central and West Africa, which experience four times as many outages.

Table 1. Technical performance of the African power sector

Regional pool	Capacity factors[1]	Average load factor[2]	Average # of annual outages
CAPP	34%	84%	170
EAPP	58%	67%	104
SAPP	56%	58%	42
WAPP	48%	62%	171

Source: AfDB, EU 2021

The Africa Union developed an Action Plan for a Harmonised Regulatory Framework for the Electricity Market in Africa to address challenges in the power sector and improve interconnectivity by 2030.[49] The Action Plan was designed to build synergies among regional economic communities, their associated power pools, and other transcontinental energy development initiatives.

The East African Power Pool

Nearly all East African countries belong to the Eastern Africa Power Pool (EAPP). The EAPP was conceived in 2003 and was established with only seven members in 2005, but the number has now grown to thirteen, with the addition of Burundi, the Democratic Republic of the Congo (DRC), Djibouti, Egypt, Ethiopia, Kenya, Libya, Rwanda, Uganda, Somalia, South Sudan, Sudan and Tanzania[3]. The power pool aims to provide the region with reliable, affordable, and sustainable energy by developing electricity infrastructure, an efficient cross-border power market, and enhanced operational readiness.[50]

The power pool has plans to complete interconnection among all members by 2025 to leverage differences in load profiles and generation structures. Several countries (DRC, Ethiopia, Libya, Rwanda, Sudan and Tanzania) face supply risks during peak demand in the range of 1,000 to 1,500 MW but are unable to benefit from electricity imports due to a lack of generation and transmission capacity. The region expects to see an increase in the installed capacity from 4GW in 2020 to 29GW by 2023, led mainly by investments in wind and solar, which will result in increased cross-border power exchanges.

Among East African countries, Egypt had the highest installed capacity in 2021 and the second highest in Africa, after South Africa. Egypt generated 12 percent of its electricity from renewable sources. Ethiopia has the second largest installed capacity (4,862.769 MW) but lagged behind Sudan on total electricity generation at only 15,943.28GWh against Sudan's 18,284.62GWh as shown in **Figure *1***. A strong economic player in the region, Kenya comes in fourth with an installed capacity of 3,217 MW, producing 12,775.40 GWh of electricity. Among these top three producers in the region, Ethiopia has the largest share of electricity generated from renewable sources at 100 hundred percent, followed by Kenya with 93 percent and Sudan at 59 percent [51]. **Figure *1*** does not include Egypt because the country's installed capacity and electricity generation are far larger than the others in the

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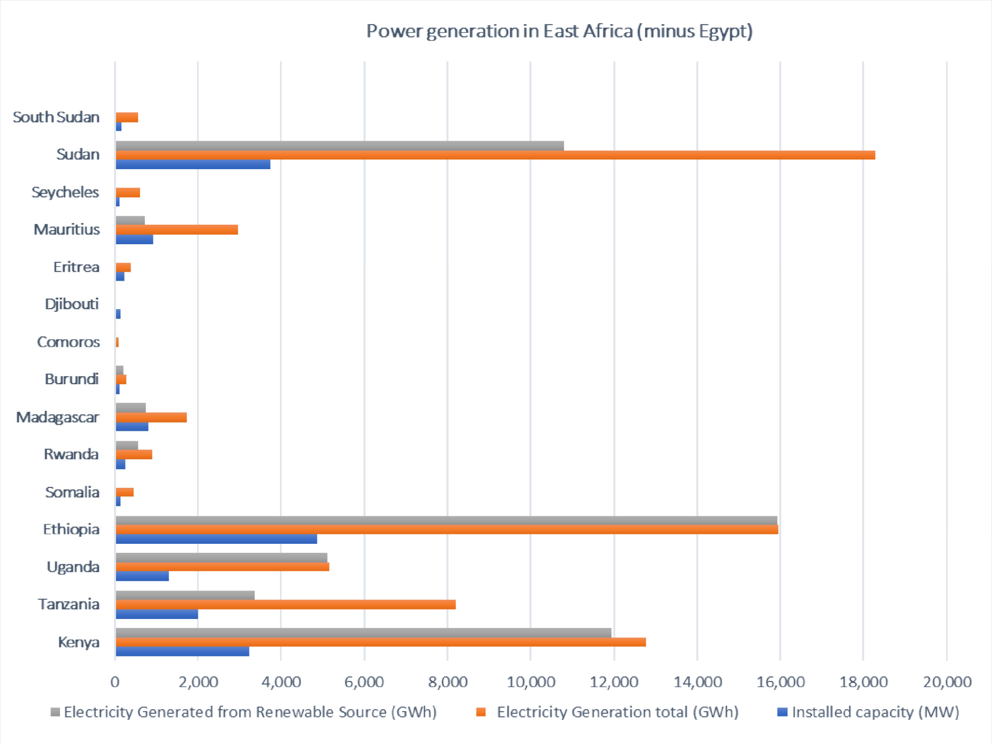
[1] The capacity factor of a power utility is a measure of how often a power plant produces electricity compared to its maximum potential output. It is calculated by dividing the actual electricity output over a period of time by the theoretical maximum output over the same period. For example, a power plant with a capacity factor of 50% means that it operates at half of its full capacity on average. The capacity factor can vary depending on the type of power plant, the fuel source, the weather conditions, the maintenance issues, and the market demand. (NMPP Energy, 2021)

[2] The average load factor of a power utility is a measure of how well the power utility uses its maximum capacity over a period of time. It is calculated by dividing the average power demand by the peak power demand during the same period. A high average load factor means that the power utility has a steady and consistent power demand, while a low average load factor means that the power utility has a variable and fluctuating power demand (Electrical Engineering. XYZ)

[3] Some countries belong to more than one power pool. DRC and Tanzania are also members of the Southern Africa Power Pool

region, making the chart data for most countries difficult to read.

Figure 1. Electricity production in East Africa



Source: Africa Energy Portal

The Southern Africa Power Pool

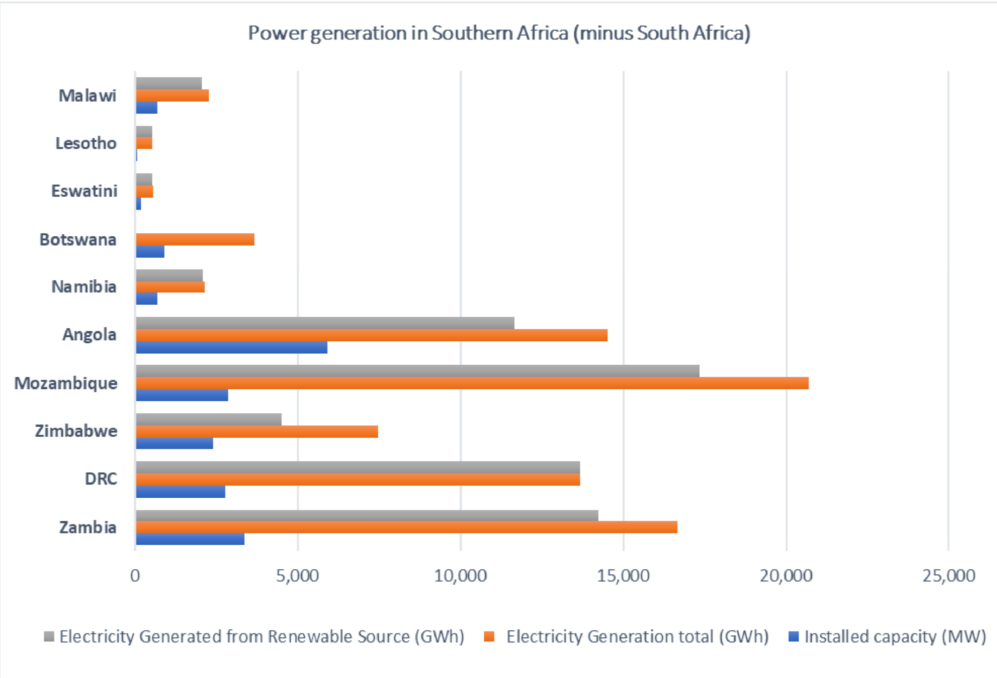
The Southern Africa Power Pool was created in August 1995 and included member states of the Southern Africa Development Community (SADC). The current membership consists of twelve countries- Botswana, Mozambique, Malawi, South Africa, Eswatini, Lesotho, Namibia, Angola, the Democratic Republic of the Congo (DRC), Tanzania, Zimbabwe and Zambia.

Between 2011 and 2019, about 24,488MW new generation capacity was installed, giving an annual average of 2,449MW. By 2021, the installed generation capacity for all SAPP countries was 80,923MW, while the operating capacity of 65,198MW. This was against a demand and reserve of 55,235 MW, resulting in an excess generation capacity of 9,963MW. South Africa alone accounted for 7,959MW of this excess generation capacity, while DRC has up to 1,064MW excess generation capacity. A lack of transmission interconnections between Angola, Tanzania, Malawi and other SAPP countries makes them unable to participate in the competitive electricity market. In Angola alone, up to 2,190MW of excess capacity is available but could not be accessed by other member countries due to the absence of interconnectors. A total of USD91.1 million was exchanged on the market in 2021, a drop from 145.8 million, attributed to reduced power demand due to the COVID-19 pandemic.

In 2001, SAPP launched the short-term energy market and developed a competitive electricity market in 2024.[52] SAPP published monthly market performance reports and between April and August 2023, the average standard price for power ranged between 0.062USD/KWh and 0.037USD/KWh, average off-peak prices ranged from 0.089USD/KWh to 0.05USD/KWh while the average peak prices ranged from 0.09USD/KWh to 0.02USD/KWh.[53]

South Africa is by far the largest power producer in the region and across the entire continent, with an installed capacity of 61,454MW and achieving electricity generation of 280,649 GWh in 2021. The country is heavily dependent on coal for its power generation but also has 16,884MW (six percent) of electricity produced using renewable sources. This number is expected to steadily increase as the country implements its just energy transition plan. Mozambique was the second largest producer in the region, with 2,867 MW installed capacity and 20,696 GWh electricity generation. Zambia was the region's third-largest producer, with an installed capacity of 3,368, generating 16,674 GWh.In both Zambia and Mozambique, over eighty percent of their power generation comes from renewable sources, as shown in **Figure *2***. **Figure *2*** does not include South Africa because the country's installed capacity and electricity generation are far larger than the others in the region, making the chart data for most countries difficult to read.

Figure 2. Electricity production in Southern Africa



Source: Africa Energy Portal

The Central African Power Pool

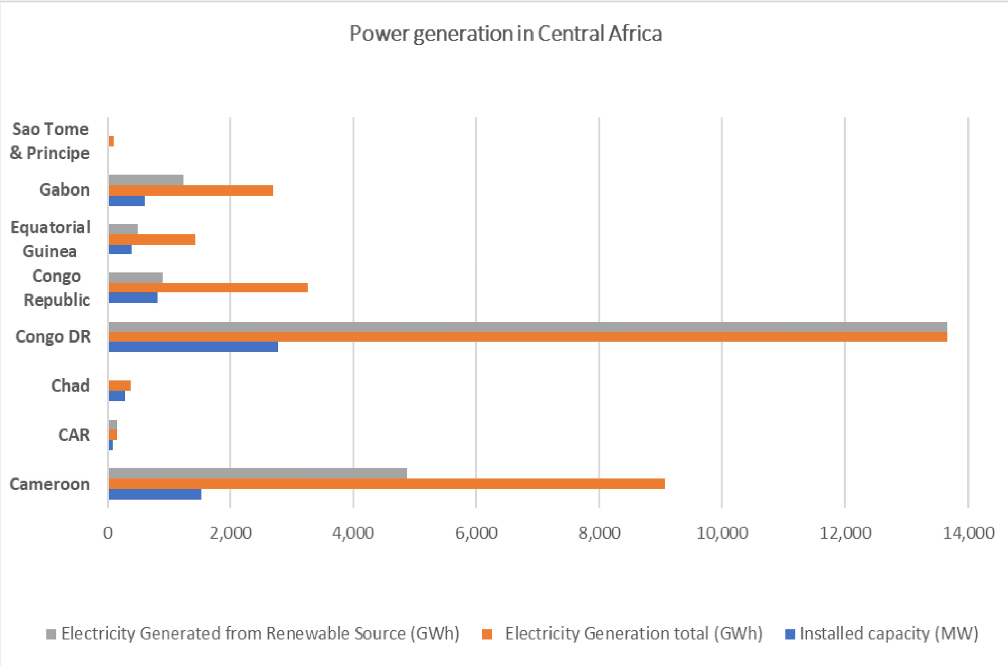
The Central African Power pool draws its memberships from Burundi, Cameroon, Congo, Gabon, Equatorial Guinea, Central African Republic, Democratic Republic of the Congo (DRC), Rwanda, São Tomé and Príncipe and Chad.

Despite more than seventeen years of existence, the CAPP is the weakest power pool on the African continent. CAPP has an estimated 650 TWh annual hydroelectric potential, representing almost 53% of the continent's hydroelectric potential. The DRC alone has 110GW of estimated hydropower potential. Some experts have estimated that the Inga hydroelectric project can meet about 40 percent of the electricity demand on the continent.[54] The reality, however, is that CAPP has the lowest installed production capacity at 6,547 MW in 2021 and the lowest average national rate of access to electricity electrification rate at 30.1 percent compared to other regions(**Figure *3***).

Central Africa has fewer electricity interconnections than other regions, and barely any electricity trade is happening. Regional institutions are still relatively weak compared to other regional power pools. By 2021 the only cross-border interconnection lines were between the DRC and Congo, Cameroon and Chad, and ongoing interconnections between DRC and Angola, and DRC, Rwanda and Burundi. The region has recently experienced political instability, which has inhibited investment in infrastructure, including energy infrastructure.[55]

According to the Africa Energy Portal data, in 2021, Angola will be the largest producer in the region with an installed capacity of 5,918.59MW and generate 14,532.90GWh of electricity. DRC is the second largest producer with an installed capacity of 2,770.40MW, generating 13, 671GWh of electricity from renewable sources. Cameroon came in third with 1,532.98 installed capacity, generating 9, 067GWh of electricity. About 80 percent of Angola's power was generated from renewable sources compared to 53 percent for Cameroon.

Figure 3. Electricity production in Central Africa



Source: Africa Energy Portal

The West African Power Pool

The West African Power pool includes Ghana, Senegal, Nigeria, Togo, Benin, Côte d'Ivoire, Togo, Guinea Bissau, Guinea, Sierra Léone, Mali, Liberia, Gambia, Morocco, Benin, Mauritania, Burkina Faso, Niger. WAPP was established in 2006 and has the highest number of member utilities amongst all the power pools on the continent. This indicates high participation of private sector companies in generation, distribution, and transmission. Nigeria has the highest number of member utilities (11) followed by Ghana (10).

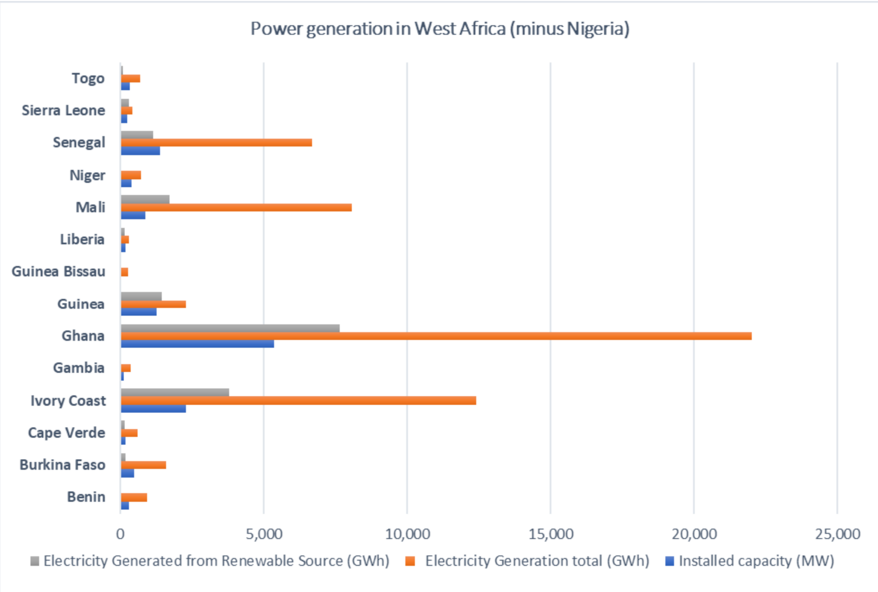
Energy resources in the region are unevenly distributed. Countries with gas reserves can produce cheap and flexible electricity. Others have hydrogeological resources at their disposal, while others with limited hydro and fossil fuel-based sources have significant solar generation potential. Then there are some with no particular resource advantage and rely on imported fuels, which are often expensive to run thermal power plants.

The region has some of the highest electricity costs linked to a lack of strategic planning for the evolution of their energy markets, leading to an excess of costly unused generation capacity or a deficit in production, leaving national demand unmet. With increased investment in natural gas-powered generation facilities, one study suggests three countries are likely to become year-round exporters of excess power- Ivory Coast (743MW), Ghana (279MW), Mauritania (88MW), Guinea (161MW during the wet season) and Cameroon (21MW) who trade this power with other countries in the region. [56]

Nigeria is by far the largest power producer in West Africa, with an installed capacity of 13,212MW, generating 73,195.88GWh of electricity in 2021.[57]

Figure *4* does not include Nigeria because the country's installed capacity and electricity generation are far larger than the others in the region, making the chart data for most countries difficult to read. About 80 percent of Nigeria's energy is generated using natural gas; about 14 percent is powered through large and mini hydro stations; solar accounts for 5 percent.[58] Ghana is the second largest producer with an installed capacity of 5,367MW and 22,035GWh generation capacity. Ivory Coast is the third largest producer in West Africa with 2,282MW installed capacity and 12,403GWh of electricity generation. About a third of power generated in both Ghana and Ivory uses renewable sources.

Figure 4. Electricity production in West Africa

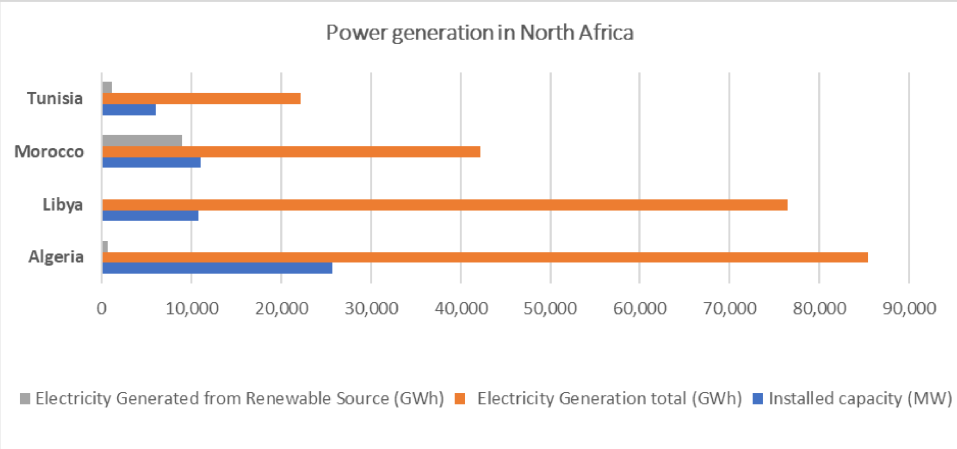


Source: Africa Energy Portal

North Africa power landscape

The Maghreb Electricity Committee (COMELEC) was established in 1974 and its membership includes Algeria, Tunisia and Morocco. Membership was extended to Mauritania in 1975 and later to Libya. Egypt is not a member of the power pool but will be covered under the North African region. As seen in Figure *5* Algeria is the highest producer in North Africa, with 25,738MW, and it generated 85,390GWh of electricity in 2021. Libya is the second highest producer with 10,817MW installed capacity, which generated 76,448GWh. Algeria and Libya both generated less than 1 percent of their electricity from renewables, drawing about 99 percent of it from natural gas and oil.

Figure 5. Electricity production in North Africa

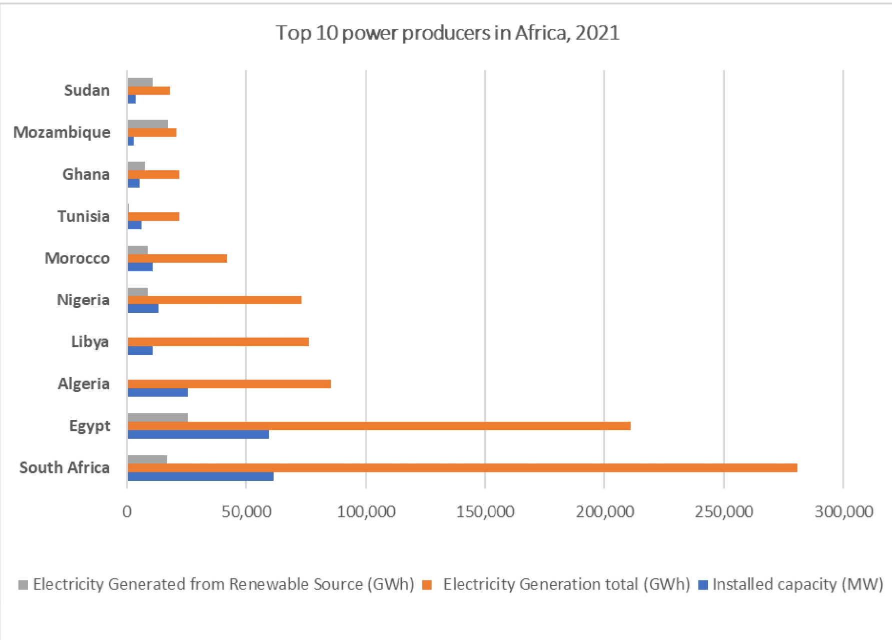


Source: Africa Energy Portal

The top ten largest and cheapest producers

South Africa dominates the charts in terms of production, having the highest installed capacity (61,255 MW) and electricity generation (280,649 GWh), primarily from fossil fuels (only 6 percent is generated from renewable sources) as shown in **Figure** *6*. Egypt is the second largest producer with 59,617MW installed capacity, only about 1,847 MW less than South Africa but generated far less power (210,832GWh). The next four largest producers are mostly North African (except Nigeria), but their combined electricity generation still falls short of South Africa's total, even with its failing electricity infrastructure. With the exception of Ghana, electricity penetration outside of urban centres in the last three countries is very low, leaving rural residents with a higher incidence of energy poverty.

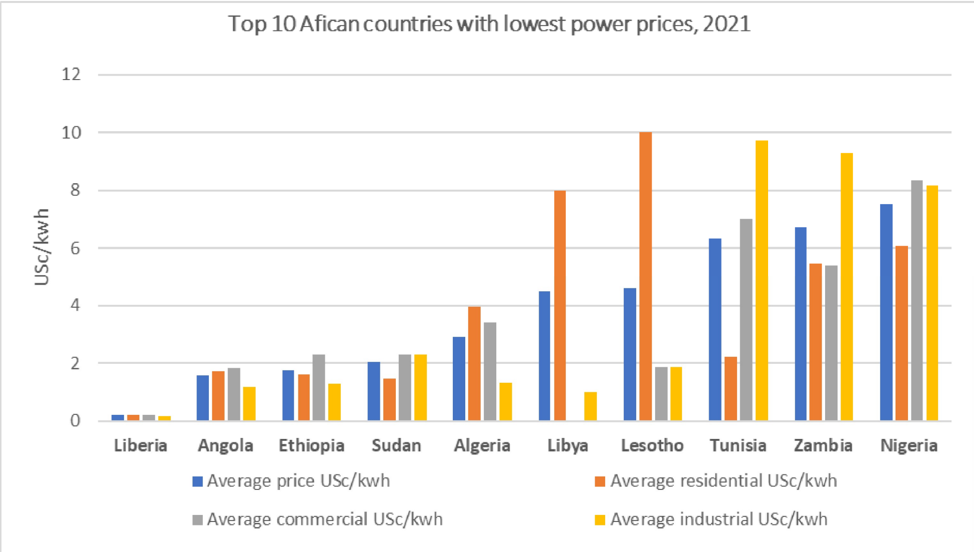
Figure 6. Top largest African electricity producers



Source: Africa Energy Portal

According to BloombergNEF 2021, Liberia had the cheapest average power price at 0.002USD/KWh on average, followed by Angola at 0.016USD/KWh, while Nigeria closed out the top ten with 0.075USD/KWh (**Figure** *7*). Seven of the top ten countries had average prices lower than the global average price for bitcoin mining which is 0.05USD/KWh.

Figure 7. Top ten cheapest African electricity producers



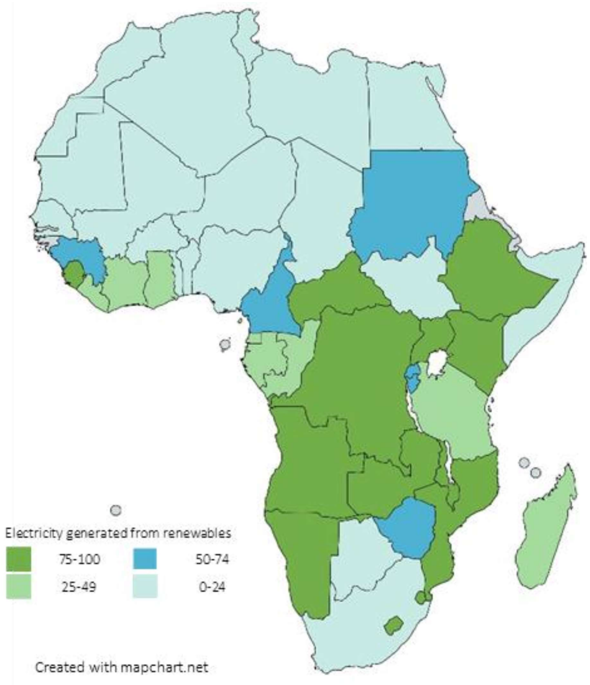
Source: BloombergNEF

Renewable energy on the main grid

As seen in Figure 8, the majority of African countries, just under 50 percent had less than 25 percent of renewable sources in their energy mix. Countries like Libya, Botswana, and Djibouti have zero renewable resources. Among the other 50 percent, Cameroon, Sudan, Zimbabwe, Guinea, Rwanda and Burundi have between 50 to 25 percent of renewable sources in their electricity generation mix. Only three countries- Ethiopia, DRC and Lesotho drew 100 percent of their power from renewable sources.

As countries continue to build out their power infrastructure to include mini-grids, the renewable energy mix is expected to increase, especially among sub–Saharan African countries. North African countries have the highest electrification rates and have achieved universal access due to abundant natural gas and other fossil fuels. There is less incentive among North African countries to invest in renewables and the private sector market is not as robust as in other parts of the continent.

Figure 8. Renewable energy generation across Africa



The African power landscape – mini-grids

Grid extension has been the predominant approach to provide electricity access but many countries are coming to the realization that the areas that the main grid can reach more economically than off-grid alternatives are slowly being exhausted and the incremental costs of adding new rural customers are becoming prohibitive. With technological improvements and ever-reducing costs, more countries are turning to renewable energy systems. This is important as it allows governments and utilities to take a least-cost approach that takes advantage of the breadth of technology options.[59] Due to high capital expenditure costs involved in expanding existing grids, many countries are turning to mini-grids to fill the gaps in access to electricity, especially to reach rural communities that are often more isolated from national grids. Mini-grids are electric and power generation and distribution systems ideal for supplying electricity to small and medium-sized communities or towns, especially in rural areas.[60]

While information on the number of mini-grids in each country are sparse, estimates are available for numbers across the continent. In 2022, there were an estimated 3,100 mini-grids across Africa with a total capacity of 1,960MW and another 9,000 mini-grids were planned as shown in **Table *2.* Installed mini-grid projects by region *Table 2***. The 3,100 mini-grids led to 6 million connections, enabling 27 million people to access electricity. At 1, 960MW, the continent has the highest mini-grid installed capacity, followed by the United States and Canada (1.8 MW) and East Asia and the Pacific (1.5 MW).[61]

Table 2. Installed mini-grid projects by region

Region	Number of mini-grids	Number of connections (millions)	Number of people (millions)	Total capacity (MW)	Total investment (USD millions)
South Asia	9,592	2	12	407	1,555
East Asia and Pacific	7,227	2	6	1,530	6,271
Africa	3,174	6	27	1,960	7,238
Europe and Central Asia	624	<1	1	1,110	6,092
United States and Canada	615	<1	1	1,783	6,447
Latin America and the Caribbean	286	<1	2	390	810
Middle East and North Africa	39	<1	<1	46	158

Source: ESMAP 2022

More than 4,000 mini-grids are currently in the planning stage across the continent.[62] The Africa Minigrid Developers Association (AMDA), which represents private sector mini-grid developers in Africa, maintains a database of projects undertaken by members. AMDA's 2022 report revealed that Kenya has the highest number of mini-grid sites (145) followed by Sierra Leone (66) and Mali (28).[63]

Renewable-based mini-grids are emerging as the least-cost option for reaching underserved communities. Yet, guaranteeing the financial viability of mini-grids is crucial to providing a reliable and sustainable solution. Mini-grid developers need to prioritize productive energy, as rural energy demand does not increase as fast as expected, and load growth is essential for their business viability.

Moreover, mini-grid companies are usually the first to engage underserved communities for the long haul, creating a unique chance to foster sustainable rural development with partners.[64] New developers face a revenue challenge due to low consumption in the initial years of mini-grid operations. Since most mini-grid development costs are fixed, attracting more customers and boosting average consumption are essential to lowering electricity prices. Household energy consumption is often low because poor households need time to save for energy-consuming assets and must carefully decide how to spend their very limited incomes.[65]

As mentioned before, introducing more productive users to the customer base can reduce mini-grids' cost of service per unit of electricity (ESMAP 2019).[66]

The World Bank's Energy Sector Management Assistance Program (ESMAP) shared a model to demonstrate how productive uses reduce the levelized cost of electricity (LCOE) for solar-powered mini-grid systems. The model showed that typical load factors for mini-grids are about 20 percent because the system capacity is largely unused for most of the day. Conservative assumptions estimate that by adding productive use load from commercial businesses and activities, the load factor can go up to 40 percent. This additional load reduced the LCOE in 2018 by 24 percent, from 0.55USD/KWh to 0.42USD/KWh. By 2021, as component costs reduced and the load factor increased, the LCOE reduced further by 26 percent from 0.38USD/KWh to 0.28USD/KWh.[67]

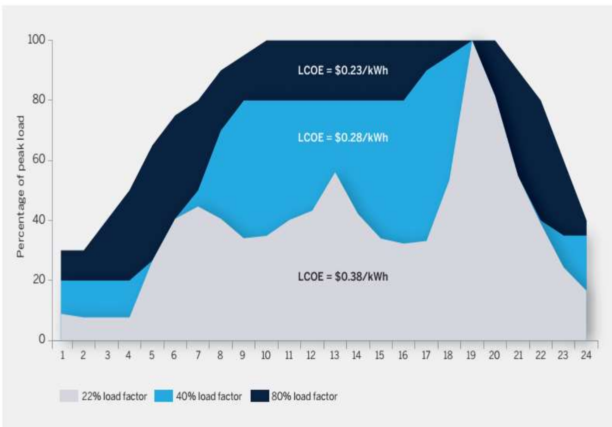
By increasing demand from productive use businesses to achieve a 40 percent load factor, it is possible to decrease the levelized cost of energy (LCOE)[4] by 25 percent or more. As seen in Figure 9, further increasing demand from commercial users to achieve an 80 percent load factor can reduce LCOE by up to 37 percent. The World Bank, through its ESMAP programme, estimated that increasing productive uses and decreasing component costs should lead to lowering mini-grid LCOE to 0.22USD/kWh by 2030.[68] This would make access more affordable for rural household consumers in the long run as demand and technology improves.

Considering the lag between installing a mini-grid and realizing effective demand through household consumers and productive use business, contingencies need to be built into electrification efforts to account for potentially limited impacts on productive use.[69] Introducing innovative partnerships between Bitcoin mining data centres and renewables-based mini-grids can increase electricity demand, expand the profitable electrification business model, and reduce the over-dependence on government subsidies, aid and charitable donations. GAMA asserts that small-scale Bitcoin mining data centres can be the missing link to closing the gap between perceived risks associated with mini-grids and investors' risk/return expectations by aligning the incentives of financiers, developers, consumers and other stakeholders, such as multilateral organizations.[70]

To encourage investments in mini-grids, governments must introduce supportive regulation. Countries such as Tanzania, Kenya, Uganda, Nigeria and Ghana, have put in place frameworks and supportive policies to expand energy access through mini-grids. Nigeria, for example, has well-established regulations for mini-grids with clear specifications on the technical and quality standards and certifications developers are required to meet. The country has a willing buyer-willing seller model that allows developers to enter into direct agreements with community consumers in the areas they serve.

Figure 9. Levelized cost of energy scenario for solar powered mini-grid

Developers are also protected in the event that the main grid expands its coverage to territory covered by the mini-grid.[71]



Source: ESMAP analysis.
kWh = kilowatt-hour; LCOE = levelized cost of energy; PUE = productive use of electricity.

[4] The levelized cost of energy (LCOE) combines into a single metric all the cost elements directly associated with a given power technology, including construction, financing, fuel, maintenance and costs associated with a carbon price. It does not include network integration or other indirect costs (IEA 2023)

Mini-grids as a viable option for Bitcoin mining in Africa

To ensure financial sustainability, mini-grid developers build their business models to take into account revenue streams possible from different customer segments. One commonly used approach is the ABC model. It allows developers to diversify their customer base into three groups. A represents the **Anchor** customers with a high consumption load, such as factories, manufacturing plants, resorts or mines. B are productive use income-generating **Businesses** serving local communities, such as grain mills, agriculture processing units, irrigation pumps, bakeries, grocery shops, etc. While C stands for **Community** consumers such as households, community centres and churches.[72] The order of consumption reduces from A to C, with anchor tenants being the largest electricity consumers and community consumers being the smallest.

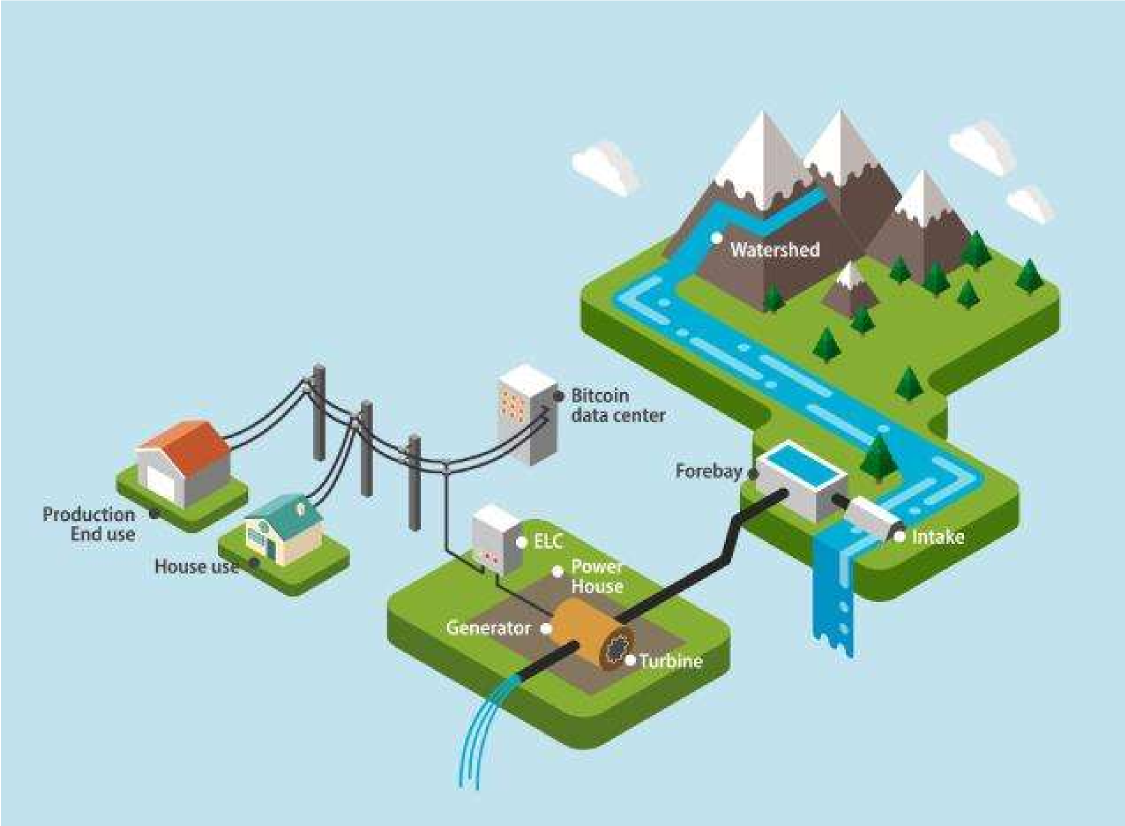
Bitcoin data centres are ideal anchor tenants for mini-grid developers because their operations often require large amounts of power, allowing developers to maintain a load profile that would guarantee the highest return on investment. Bitcoin data centres are also location agnostic, meaning they can be set up anywhere, even in very remote areas.[73] Miners need to optimize their operations and control their production costs to stay competitive in the global bitcoin mining industry. Electricity is the main input cost that impacts operation, so bitcoin miners always look for the cheapest sources of electricity, which are usually linked to under-used hydro, wind and solar power.[74]

It has demonstrated, despite some risk from bitcoin mining rewards, how bitcoin mining in solar microgrids can boost investment value and benefit communities with cheaper and more power.[75] Therefore, introducing innovative partnerships between Bitcoin data centres and renewables-based mini grids can increase the productive use of electricity and allow the expansion of profitable electrification business models. Innovative partnerships like this reduce the over-dependence on government subsidies, aid and charitable donations. GAMA asserts that small-scale Bitcoin mining data centres can act as the missing link to closing the gap between perceived risks associated with mini-grids and investors' risk/return expectations. It does so by aligning the incentives of financiers, developers, consumers and other stakeholders, such as multilateral organizations.[76]

By collaborating with local energy providers, unused energy sources can be unlocked, allowing Bitcoin mining data centres to operate in areas with poor grid access. Applying strategies like load balancing, energy storage solutions, and smart demand-side management guarantees efficient resource use and low environmental impact.[77] By being anchor tenants, miners offer mini-grid developers steady, reliable, and paid energy demand, reducing the difference in risk-return prospects between energy developers and financiers. As a result, Bitcoin mining data centres enable lasting and lucrative private investment for mini-grids.[78]

While there are opportunities to power Bitcoin mining data centres from the main grid in cases where utilities have excess or stranded energy, case studies in African countries have shown that mini-grids are the better alternative because they have higher stranded energy levels. The main grid is usually concentrated in urban areas, which draw most of the demand and a lot of the power, leaving every little excess energy except during off-peak hours. However, it is possible to find stranded energy on the main grid in some countries due to poor and decaying infrastructure that limits the grid's ability to transmit power to all areas where it is needed.

Figure 10. Components of sustainable hydro mini-grids



Source: GAMA 2023

The environmental impact of Bitcoin mining

Bitcoin mining consumes a lot of energy and is often criticized for this. By December 2023, the energy used by Bitcoin mining reached 141.2 TWh globally. [79] One key concern related to this is the industry's carbon footprint. According to the Cambridge Bitcoin Electricity Consumption Index (CBECI), in 2022 bitcoin mining was estimated to be responsible for 48.35 MtCO2e of greenhouse gas emissions (GHG) which was about 0.10% of the world's greenhouse gas emissions which was close to the emissions of countries like Nepal (48.37 $MtCO_2e$) and the Central African Republic (46.58 $MtCO_2e$), or half of what was emitted by the gold mining industry (100.4 $MtCO_2e$). The CBECI further reported that fossil fuels made up nearly 62.4% of the total electricity mix, while sustainable energy sources comprised 37.6% (including 26.3% from renewables and 11.3% from nuclear).[80] Other industry researchers have disputed these figures by pointing out that Bitcoin mining's sustainable energy usage is closer to 52.6%. This is on account of the CBECI's methodology's omission of, among others, data related to off-grid and flare gas mining, whose impact was estimated at plus 10.8% and 1.0%, respectively. Further, information on the updated geographical hash rate following miners moving out of Kazakhstan would also account for about 1.8%.[81] While there are different views on Bitcoin's carbon footprint, what all sides agree on is that Bitcoin mining's energy consumption is bound to continue growing, therefore, directing more investments to reduce the industry's GHG emissions will an area of great interest going forward.

Global Bitcoin mining trends

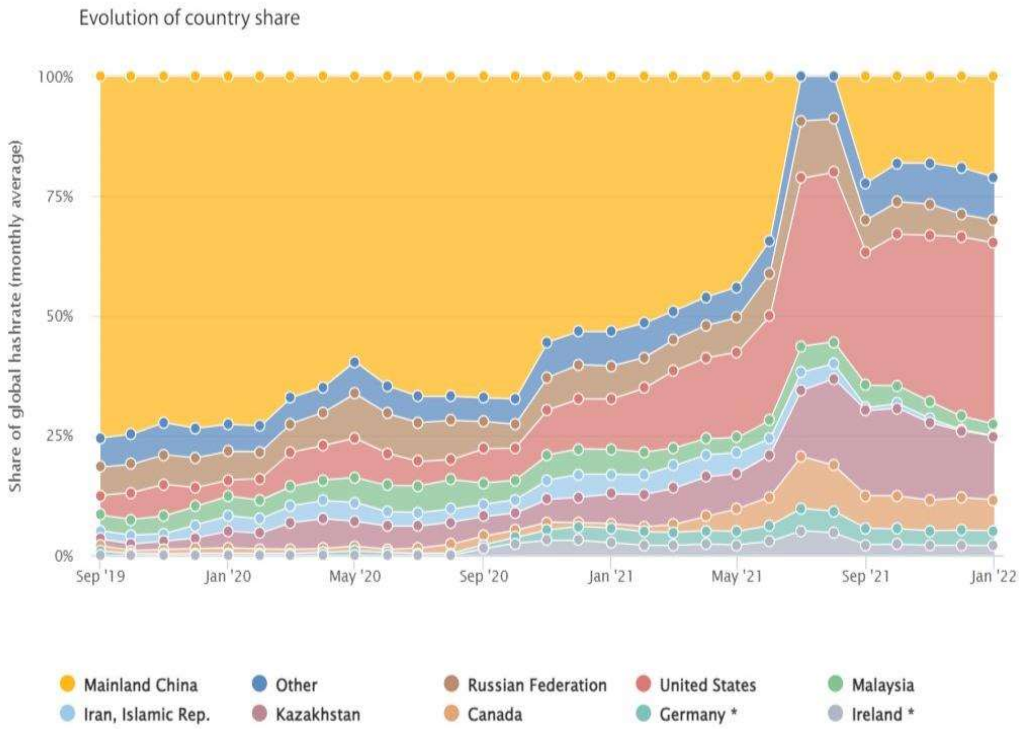
Key players in Bitcoin mining

As seen in

Figure *11*, for several years, China dominated global hashrate as far as Bitcoin mining share was concerned. Hashrate is the amount of computing power that a network (such as the Bitcoin network) uses to process transactions. It shows how many calculations the network can do per second in different units, such as billions, trillions, quadrillions, and quintillions. For instance, a hashrate of 1TH/s means the network can do one trillion calculations every second. The hashrate of a network depends on how many miners are in it. The more miners there are, the higher the hashrate is because they are all trying to get the reward. The fewer miners there are, the lower the hashrate.[82]

In 2019, the country was responsible for up to 25% of global hashrate. By the following year, the United States started to stand out as an emerging player and took up a higher percentage of Bitcoin mining. In 2021, following the ban on crypto asset mining in China,[83] significant shifts in bitcoin mining were recorded, with the US' share doubling its share of hashrate to 35 percent from the previous year. Kazakhstan also saw a jump in its share of hashrate as miners who had operations in China relocated to the country. By the beginning 2022, China's share of hashrate recovered slightly to about 25 percent. Canada also benefitted from the reset on the global bitcoin mining industry following the China ban and recorded an increase in its share of global hashrate, coming in fourth place after the United States, China and Kazakhstan.

Figure 11. Evolution of bitcoin mining hashrate country share



Source. CCAF

Examples of Bitcoin mining partnerships in Africa

Kenya

Gridless Compute in Kenya saw an opportunity to partner with a local mini-grid developer, Hydrobox, to buy up excess power. Hydrobox has two business models. On the one hand, it develops, finances, owns and operates mini-grids, then sells the electricity generated in rural communities but it also builds, develops and operates mini-grids on behalf of clients. Hydrobox's solution used standard containerized units to set up the microgrid, thereby reducing costs, lead times and making installation possible even on challenging terrain.[84] Gridless colocated their Bitcoin mining data centre at the Hydrobox site in Gitugu and is one of the anchor clients, allowing the developer to monetize the stranded energy, resulting in improved revenue collection and a reduction is energy rates for the 5,000 people served by the mini-grid. The Gridless' Bitcoin mining data centre serves as a buyer of last resort for approximately 350kW when demand is low and can also reduce power usage when demand is high, ensuring that the local community served by the grid are prioritized in terms of power supply.[85]

Ethiopia

In 2023, the Ethiopian government started to fill up the Grand Ethiopian Renaissance Dam (GERD), which is expected to generate more than 5,000MW of power.[86] However, the country is yet to secure the funding to complete works to build transmission and distribution lines to get this power to end consumers. QRB Labs recognized the opportunity to put this stranded energy to use. They, therefore, started a lengthy process of engaging the national utility company Ethiopia Electric Power (EEP) to sell this excess energy to Bitcoin mining data centres.[87] QRB Labs is an Ethiopian company that offers data centre services to international clients focusing on location-agnostic higher energy computations such as Bitcoin mining. The company collocates their scalable modular data centres within EPP substations across Ethiopia to access the stranded energy.[88] Ethiopia is a rare example of an African country that has opened up licensing for Bitcoin miners on the main grid.

Uganda

In Uganda, Sustain Solar designed and delivered a containerized solar plant to generate electricity for processing high-value crops in the Kayunga district. The solar plant was built with a higher capacity than the current demand in the community in anticipation of the growth of economic activities and required loads. Sustain Solar partnered with Earth Wind and Power, a Norwegian company innovating sustainable methods of growing green computing power, to conduct the pilot. A third company, INENSUS, a German consulting and engineering firm specialized in rural electrification, also joined the team. These three companies designed a pilot introducing Bitcoin miners in containerized solar units that use up excess electricity.

Nigeria

In June 2023, the Nigeria Federal Government introduced the Electricity Act, empowering state governments to manage their energy infrastructure, including electricity. This development made it easier for private investors to obtain licences to generate, transmit, operate, trade, distribute and supply electricity.[90] As a result, state governments have more autonomy and businesses can engage utilities at the state level to negotiate power purchase agreements.

Trojan Mining operates a hydro-powered fleet that launched in 2021. The founder of Trojan Mining belonged to a local youth empowerment organization and used that platform to engage local government officials and the utility

INENSUS built a controller that regulates the Bitcoin miners' consumption based on information on the primary load's consumption patterns and the weather conditions that will determine how much solar power can be generated. This ensures the miners only use excess electricity and do not take up power required by primary users.

Following what was considered a successful pilot, the team plans to commercialize the model for other mini-gird developers to buy in.[89]

company to sign a power purchase agreement at a competitive rate to ensure the profitability of the mining operations.

Malawi

Following a successful execution of their project in Kenya, Gridless Compute turned to Malawi where they identified a site with 80kW of stranded energy serving a community of 1,800 households or approximately 9,000 people. Once more, Gridless collocated about a dozen Bitcoin miners at the site, allowing the mini-hydro plant to become self-sustaining and decreasing the power cost to its residential clients.[91]

Gridless Compute provides Bitcoin mining containerized solutions and technical expertise to businesses and mini-grid developers. The company builds bespoke Bitcoin mining units that are assembled in Kenya and transported to countries across Africa.

Top image: A containerized bitcoin mining unit that can be transported on a truck.

Image left: Bitcoin miners (ASICs) stacked into a container.

The business and regulatory environment

As explained before, because Bitcoin mining is price-sensitive, therefore, bitcoin miners seek out countries that offer lower prices at or lower than the global average price of 0.05 USD/KWh. The cost of electricity has been explored in a previous chapter and this chapter will include another dimension to aid the analysis- the business and regulatory environment. The business and regulatory environment greatly influences foreign Bitcoin mining operators' willingness to invest in any country or jurisdiction.

There is very little information on the regulation of bitcoin mining in Africa. Only Ethiopia is known to have introduced a licencing framework for bitcoin mining. As a proxy, this report examined various governments' positions on cryptocurrencies. While the government's position on cryptocurrencies does not reflect its position on Bitcoin mining, it indicates a country's openness to new ideas and innovation in the digital space, especially related to cryptocurrencies. While the type of regulation and stakeholders associated with Bitcoin mining and cryptocurrencies are different, actors from one sphere can influence the other.

The business enabling environment assessment is informed by the World Bank's 2020 Ease of Doing Business report. Unfortunately, the publication of the report was discontinued in 2020 so this is the most recent data set. The Ease of doing business scores were designed to measure the strength of a country's business environment on the basis of economic performance in ten areas. This report focuses on four of the ten areas: starting a business, getting electricity, enforcing contracts and resolving insolvency.[92]

The report also uses the Africa Development Banks' Electricity Regulatory Index (ERI). The ERI aims to use a standard methodology to evaluate electricity regulation and the regulators. The ERI also aims to identify and resolve issues and challenges affecting the sector, then mobilizes all stakeholders to work together to overcome any obstacles to developing the electricity sector. It is a composite of scores obtained under three key pillars: the Regulatory Governance Index, the Regulatory Substance Index and the Regulatory Outcome Index.   The Regulatory Governance Index assesses the regulatory framework's institutional and legal design, which determines the regulator's mandate. The Regulatory Substance Index evaluates the electricity sector regulator's performance in carrying out its mandate by developing and implementing practices and policies that affect regulatory outcomes. The Regulatory Outcome Index measures the regulator's impact on the sector and how regulatory actions and decisions can achieve expected results for the industry.[93] The ER also includes the regulatory performance of a country's mini-grid and off-grid systems.

Cryptocurrency regulation

At the global level, the regulation of crypto asset activities by different jurisdictions hardly included or specified mining in their regulatory guidance, according to a study by the Cambridge Centre for Alternative Finance (CCAF). However, mining has attracted regulatory attention recently, which has led to the development of custom legal frameworks for mining activities in some cases. Miners from the same region disagree a lot on their present regulatory environment. This variation in opinion suggests that miners either have limited awareness of the current regulation or that regulation is vague and inconsistent.[94]

Only a handful of African governments, such as South Africa and Botswana, have legalized cryptocurrencies as digital assets but do not recognize them as legal tender. The South African government requires citizens to declare income earned from cryptocurrency as part of their currency gains. Botswana also recognizes cryptocurrency as a digital asset and companies offering cryptocurrency-related services are required to obtain a licence from the non-Bank Financial Institution Regulatory

Authority. The Central African Republic is the only African country that has legalized the use of cryptocurrency and recognizes Bitcoin as legal tender.[95] Other countries such as Zambia, Mozambique, Nigeria and Kenya have regulatory sandboxes in place to allow financial services providers, including companies offering cryptocurrency-related services, to test new financial services or models with live customers subject to certain safeguards and oversight. These virtual or digital models allow companies to operate legally and interact with regulators while the government considers the most appropriate legislation framework to introduce.

In other cases, countries such as Kenya, South Africa, DRC, Nigeria and Ghana have established innovation offices that serve as a platform for financial services providers, including cryptocurrency services providers, to engage with regulators and better understand the regulatory frameworks and their requirements.[96] There appears to be an overlap between countries with regulatory sandboxes or innovation offices in place and countries that have legalized or, at the very least, allowed cryptocurrency services providers to operate within their borders legally. Therefore, regulatory sandboxes and innovation offices are good indications that a country is open to innovations, especially in the fintech and cryptocurrency space.

Narrowing down the focus countries

Figure 12 shows the overlap between the top ten largest producers and the top ten cheapest producers, giving the top five countries- Algeria, Libya, Nigeria, Sudan and Tunisia. North African countries dominate the list of the top ten largest producers of electricity and also feature prominently on the list of countries with the cheapest average electricity prices. However, as mentioned before, price is not the only factor that bitcoin miners consider; the business and regulatory environment are also important. Governments' position on crypto mining is unclear, and nearly all have prohibited the use of cryptocurrencies.[97] The government is the sole participant in the electricity sector with very little private sector participation except in Egypt and Morocco, where IPPs are present. Among the top five countries at the intersection of the largest and cheapest electricity producers, Nigeria is the only one with an active Bitcoin mining community and a government that recently became friendly to cryptocurrencies.[98] Like Nigeria, electricity penetration in Sudan is low, with high supply deficits and power cuts. However, Sudan does not have a

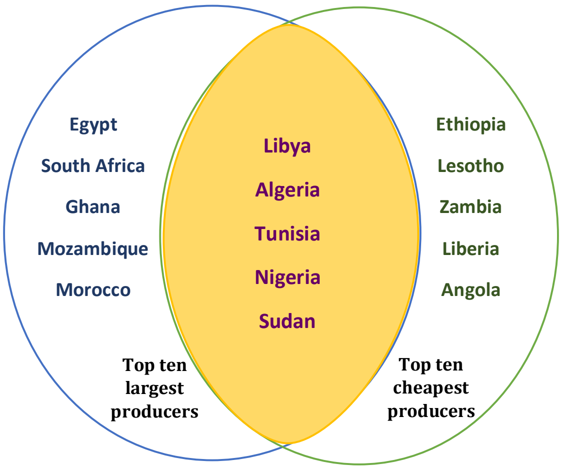


Figure 12 Top largest and cheapest producers

government friendly to cryptocurrencies and the country is embroiled in a civil war, making it unattractive for investments. Chapter 6 analyses the business and regulatory environment among the fifteen countries shortlisted for this report, plus Kenya. *Kenya is neither one of the top ten cheapest nor largest producers but has been included on the list because the country has made strides in Bitcoin mining and some of the most documented use cases for Bitcoin mining data centres being colocated at mini-grids are from Kenya. A report from AMDA also revealed that Kenya has the highest number of mini grid among their registered members.[99]

Analysing the business and regulatory environment

North Africa highlights

Tunisia and Algeria appear to be attractive investment options due to favourable scores for starting a business, getting electricity, and the presence of IPPs, which could be alternative partners if on-grid power is deemed too expensive to run a Bitcoin mining data centre profitably as shown in **Table *3*. Business and regulatory environment in North Africa** However, both governments' positions on cryptocurrencies and Bitcoin mining are unclear. Enforcing contracts and resolving insolvency scores for both countries are also weak and need improvement to boost confidence. While Morocco has higher electricity prices, it does have an abundance of electricity but, similar to Algeria and Tunisia, the government has not been friendly towards cryptocurrencies in general and there has not been a lot of participation of private sector companies in the energy sector.

Table 3. Business and regulatory environment in North Africa

	Algeria	Libya	Tunisia
Electricity production and price (2021)	Third largest producer of electricity (85,390GWh) in Africa and has the fifth cheapest electricity prices at 0.029USD/KWh	Fourth largest producer of electricity in Africa with an installed capacity of 76,448GWh and average prices at 0.045USD/KWh	Seventh largest producer of power in Africa witł 22, 142.53 GWh and maintains seventh place in the ranking of cheapest average electricity prices 0.063USD/KWh
Ease of Doing Business (2020)	Ranked 157, scored poorly in the categories of starting a business and resolving insolvency	Lowest rank among North African countries at 186. Scored poorly on enforcing contracts and resolving insolvency	Best Ease of Doing Business rank (78) among North African countries scored well in starting a business and accessing electricity
Industry regulation (2022)	High ERI score of 10 (out of 43) placing it in the category of countries with substantial regulation	N/A	N/A
Crypto/mining regulation	Crypto banned	N/A	Crypto banned
Private sector participation (2021)	Generation and supply of electricity are mostly a government function. No independent power producers (IPPs) operate in the country	No IPPs- most generation and distribution entities are state-operated and are highly subsidized.	Has four IPPs producing electricity using a mix o solar, gas and oil
Other factors	Politically stable	Experiencing civil unrest	Politically stable

Sources: World Bank 2020, BloombergNEF 2021, Africa Energy portal 2021, Africa Development Bank 2022

Libya appears to be strong contender at first because it has some of the lowest power prices, but when other factors are considered, it does not appear to be an attractive option for investments. Recent political instability in Libya raises concerns about the country's ability to support private sector investments in general, specifically the power sector. A political stalemate between rival political factions has compromised the political and governance institutions in the country, leading to significant insecurity and economic loss.[100]

West Africa highlights

Nigeria was ranked 113 for Ease of doing business and scored favourably under starting a business but poorly for getting electricity and resolving insolvency as shown in **Table 4**. The country has drafted a digital asset bill but has yet to enact it. In 2021, the government prohibited businesses from dealing with cryptocurrencies, but this did not stop the growth of peer-to-peer transactions.[101] The price of electricity is higher in countries such as Ethiopia and Libya. Still, the country has a plethora of IPPs that Bitcoin miners, such as Trojan Mining,[102] have benefitted from by negotiating more favourable pricing that allows them to operate profitably

Table 4. Business and regulatory environment in West Africa

	Liberia	Ghana	Nigeria
Electricity production and price (2021)	Cheapest electricity prices (0.002USD/KWh), and second lowest power generation level in West Africa at 314GWhs. Per capita electricity consumption among the lowest on the continent at 77KWh	8th among the top ten producers of electricity on the continent, generating 22,035GWh of power in 2021, with average prices reaching 0.017USD/KWh	fourth largest power producer on the continent 73,196GWh and number nine among the top ten countries with the lowest average prices at 0.075USD/KWh
Ease of Doing Business (2020)	Scored well for starting a business, but poorly across most other categories, earning a rank of 175	Ranked 118 - scored well in starting a business and getting electricity but poorly in resolving insolvency	Ranked 131- scored well under starting a business, but had weak scores for resolving insolvency and getting electricity
Industry regulation (2022)	performed relatively well (0.628) in the ERI scores, ranking in 10th place	Fourth best performer on the ERI scores with 0.709	Ranked 14th on the ERI scores with 0.614
Crypto/mining regulation	No regulation in place	No regulation in place, but crypto assets allowed	Crypto assets allowed
Private sector participation (2021)	Electricity sector is underdeveloped and has no registered IPPs	9 operational IPPs powered mostly by gas and two solar PV	23 IPPs operating in the electricity industry, most of which are gas-powered and a handful of hydro and solar PV
Other factors	Politically stable	Politically stable	Politically stable

Sources: World Bank 2020, BloombergNEF 2021, Africa Energy portal 2021, Africa Development Bank 2022

Although Liberia has made gains in sustaining peace, some of the root causes of the civil war are yet to be sufficiently addressed.[103] Therefore, confidence in governance and institutional structures is very low across the three countries. All three countries also had some of the lowest scores for resolving insolvency and enforcing contracts. Ghana is one of the few countries in West Africa that has achieved over 80 percent access to electricity at a national level and scored every well across different categories under the Ease of Doing Business survey. However, the price of electricity is much higher than what most bitcoin miners are willing to pay, therefore, any type of mining would have to happen under negotiated rates probably with independent power producers such as mini-grid developers.

Southern Africa highlights

Table 5 Business and regulatory environment in Southern Africa

	Angola	Lesotho	South Africa	Zambia
Electricity production and price (2021)	Second-highest installed capacity in the Southern Africa and the fourth-largest producer of electricity with 14,533GWhs. Second lowest average electricity price on the continent at 0.016USD/KWh	One of the smallest producers in Southern Africa with 531.57GWh and priced the electricity generated at 0.046USD/KWh on average. More than 95 percent of the electricity is generated from renewable sources	Largest electricity producer (280,649.13GWh); with average electricity prices at 0.101USD/KWh in 2021. Largely dependent on coal-powered thermal energy	Third largest producer in Southern Africa, generating 16,674GWh and the average price of electricity was 0.067USD/KWh. 85 percent of its electricity is generated from renewable sources
Ease of Doing Business (2020)	Ranked at 117, scored poorly at enforcing contracts and resolving insolvency. Its doing business score was also quite low at 49.	Ranked 122 and had weak scores for getting electricity, enforcing contracts and resolving insolvency	Ranked just below South Africa at 85. Had a high score for starting a business but scored lower in the categories of getting electricity and enforcing contracts, which scored 62.1 and 50.8, respectively.	Ranked 84th with a strong score in the starting a business category. The doing business and getting electricity scores were not very strong at 67 and 68.8, respectively, but they were better than the scores for enforcing contracts and resolving insolvency
Industry regulation (2022)	16th place on the ERI rankings with a score of 0.608	ERI score of 0.608, which resulted in it placing 26th on the rankings	21st place with an ERI score of 0.55	ranked just above Angola in 15th place with a similar ERI score of 0.608
Crypto/mining regulation	No regulation in place	No regulation in place	Regulations on crypto assets in place, crypto mining centres operational	Crypto assets transaction allowed
Private sector participation (2021)	One IPP in operation	No on-grid IPPs	Close to 100 registered IPPs producing electricity from renewable sources, with solar PV leading, followed by wind and a handful of hydro plants	6 IPPs operating
Other factors	Politically stable	Politically stable	Politically stable	Politically stable

Sources: World Bank 2020, BloombergNEF 2021, Africa Energy portal 2021, Africa Development Bank 2022

South Africa is the second largest economy on the continent and has a strong business and regulatory environment that attracted international investors as seen in **Table 5**. Despite being the largest electricity producer on the continent, the country is still plagued by load shedding that makes grid power unreliable for many commercial and industrial operations. The power deficit has increasingly attracted investment in renewables and various off-grid solutions which could are unable to sell their power to the main grid due to grid unavailability. These developers could potentially sell off stranded energy to bitcoin miners.

Zambia was in 85th place in the 2020 Ease of Doing Business report, just behind South Africa. There is considerable private sector participation in the electricity sector, with several IPPs on and off the grid producing a mix of renewable and fossil fuel-powered electricity.[104] The country has been open to innovation in fintech, including cryptocurrencies, with companies such as Yellowcard having a presence in the country and operating in the Central Bank's sandbox for fintech companies.

Angola scores well in terms of the price of power on the grid and starting a business. It also has IPPs operating in the sector that could be an alternative power partner for Bitcoin mining data centres. However, the government is known to have cracked down on Bitcoin mining in 2022, targeting entities whose operations were deemed illegal.[105] The country also scored poorly in enforcing contracts and resolving insolvency, reducing its appeal to investment. Angola had the largest excess installed capacity (2,190MW) among countries in the SAPP, so this might still raise its appeal to Bitcoin data centres because it is not interconnected to other countries in the region and is yet to build out transmission and distribution lines.

East Africa highlights

Table 6. Business and regulatory environment in East Africa

	Ethiopia	Egypt	Kenya	Sudan
Electricity production and price (2021)	Second highest installed capacity in the region with 4,862MW and produced 15,943GWh, priced at 0.017USD/KWh	Largest producer in East Africa and the second largest (210,833GWh) in Africa. Tenth place among the top ten countries with the lowest electricity prices at 0.0782USD/KWh	Fourth largest electricity producer in the region, generating about 12,775GWh of electricity. Its average price was 0.102USD/KWh just below the regional average of 0.147USD/KWh	Third largest installed capacity (3,751MW) in East Africa and largest electricity producer with 18,285GWh, nearly 100 percent from hydropower plants. Had second lowest electricity prices in the region after Ethiopia at 0.02USD/KWh
Ease of Doing Business (2020)	Had a poor rank at 159, but scored relatively well in the category of starting a business. Scores for getting electricity (60) and enforcing contracts (63) were not as strong. Resolving insolvency scored very low at 30.	Ranked 114 because it scored poorly on enforcing contracts and resolving insolvency, among other things	One of Africa's best scores, ranking at 56. Ranked high on scores for starting a business and getting electricity. Although resolving insolvency and enforcing contracts scores were not as strong, they were relatively better than other African countries.	Ranked among the bottom 20 countries globally at 171, with a score of 44.8. Starting business score was slightly better than Ethiopia's at 77, but scores for getting electricity and enforcing contracts were much weaker. Resolving insolvency was the weakest score at 28/100.
Industry regulation (2022)	Ranked 20th on the ERI assessment with a score of 0.561 indicating a medium level of regulation of the electricity subsector	Ranked second on ERI scores, indicating a substantial level of regulation for the electricity sector	Relatively strong ERI score of 0.695, which placing 5th on the rankings	N/A
Crypto/mining regulation	Crypto regulation pending but bitcoin mining licence framework in place	Crypto banned	Crypto assets allowed and bitcoin mining companies already established and operating	Crypto banned
Private sector participation (2021)	No on-grid IPPs	Over 35 IPPs connected to the grid, 90 percent of which use solar PV to produce electricity	17 IPPs producing from a mix of solar PV, wind and hydro	No IPPs operating
Other factors	Experiencing civil unrest	Politically stable	Politically stable	Experiencing civil unrest

Sources: World Bank 2020, BloombergNEF 2021, Africa Energy portal 2021, Africa Development Bank 2022

Kenya has the highest ranking among African countries for Ease of Doing Business and has robust private sector as shown in Table *6*. The country has attracted international investments across various sectors and regulations in place to assure investors. Although it is yet to finalize their regulation of cryptocurrency assets, companies can operate within the country with under existing frameworks and innovations for peer-to-peer lending and transactions.[106] The government revealed a plan in 2023 to tax digital assets at 3 percent during the 2023-2024 financial year.[107]

Ethiopia has the cheapest electricity prices among East African countries but took 159th place in the Ease of Doing Business rankings, showing low scores for resolving insolvency. However, it had a better-than-average (among sub-Saharan African countries) score for enforcing contracts at 63 points out of 100, beating scores of South Africa (57) and Kenya (58).[108]

Ethiopia is the first African country to have made significant progress with introducing a licencing mechanism for Bitcoin mining but is yet to finalize the national framework for regulating cryptocurrency. The country has an abundance of hydropower[109] following the completion of the Great Ethiopian Renaissance Dam. Still, it requires additional investment to build transmission and distribution lines, which can take years to secure and deploy. Therefore, Bitcoin mining is one option the government is considering to facilitate the monetization of this excess capacity in the short to medium term.

Sudan's economy has been severely constrained by the political fallout that followed the 2019 ouster of the Al Bashir regime.[110] The political instability has hindered international investments in the past and is likely to continue for some time. Further, the country has a huge electricity deficit and no information on mini-grid developments as an alternative for accessing stranded energy.

Key takeaways from the assessment

Table 7 shows an overview of how the top producers and cheapest producers rank against each other. Kenya, Ethiopia, Zambia and South Africa stand out in terms of how they scored positively across different criteria. Despite an average electricity price that would make it unattractive to most Bitcoin miners, Kenya is one of the few pioneers of Bitcoin mining on the continent. The country has an open policy for innovation, which allows cryptocurrency companies to operate even though it is yet to introduce separate legislation for cryptocurrencies. The country has among the top scores for Ease of Doing business on the continent, attracting foreign investments across different sectors, including the technology space. But it still lags behind South Africa in terms of overall investment across all sectors. Despite it's failing infrastructure, South Africa still remains Africa's second largest economy and has a well-established regulatory framework to support and protect local and international investments.

Table 7. Business and enabling environment analysis

Country	Average electricity price	Starting a business	Getting electricity	Enforcing contracts	Resolving insolvency	ERI score	Mini-grid systems	Crypto regulation status
	USD/KWh	0-100	0-100	0-100	0-100	0-1	0-1	Yes/No
Algeria	0.029	78	72.1	54.8	49.2	0.644	0.5	N/A
Angola	0.016	79.4	54.1	28.1	0	0.608	0.643	N/A
Egypt	0.078	87.8	77.9	40	42.2	0.785	0.929	N/A
Ethiopia	0.017	71.7	60.1	62.8	30.3	0.561	0.929	In place
Ghana	0.017	85.5	77.4	54	25.4	0.709	0.679	N/A
Kenya	0.101	82.7	80.1	58.3	62.4	0.695	0.786	Pending
Lesotho	0.458	88.2	52.9	57.2	37	0.49	0.714	N/A
Liberia	0.002	88.9	39.1	35.2	40.6	0.628	0.714	N/A
Libya	0.045	73.1	59	48.4	0	N/A	N/A	N/A
Morocco	0.106	93	87.3	63.7	52.9	N/A	0.286	N/A
Nigeria	0.075	86.2	47.4	61.5	30.6	0.614	0.786	Pending
South Africa	0.101	81.2	68.8	56.9	54.6	0.55	0.536	In place
Sudan	0.02	76.7	51.3	47.8	28.8	N/A	N/A	N/A
Tunisia	0.063	94.6	82.3	58.4	54.2	N/A	N/A	N/A
Zambia	0.067	84.9	62.1	50.8	49.3	0.608	0.857	Pending
Scoring label	a (2021)	b (2020)				c (2022)	c (2021)	d (2023)

Sources: BloombergNEF, World Bank, Africa Development Bank, Africa Energy Portal, own research

Category	Scale			
a- Average electricity price (USD/KWh)	0.0 - 2.59	2.60 - 5.09	5.10 - 7.59	7.60 - over
b – Ease of doing business	76.00 - 100	51.00-75.99	26.00-50.99	0.0 - 25.99
c – Electricity regulatory index (ERI) score	0.80 - 1.00	0.60 - 0.79	0.50 - 0.59	0.0 - 0.49
d – Crypto regulation status	In place	Pending	Discussion	None
e – Independent power producers	Yes			No

Notes: Ethiopia- Bitcoin mining licencing in place, crypto regulation pending; Kenya- Crypto transactions permitted but legislation is pending; Nigeria- Crypto transactions permitted but legislation is pending; South Africa- Digital asset regulation in place; Zambia- Crypto transactions permitted but legislation is pending

Ethiopia scored well because it has some of the cheapest electricity prices and a booming private sector. Its Ease Doing Business scores demonstrate how well the economy is performing relative to other African countries. The country also has the added advantage of being one of the few countries with a licencing regime for Bitcoin miners. Further, the expanded installed capacity means the country has resulted in stranded energy being available to Bitcoin miners while it builds out its national grid. Electricity prices in Zambia are above the preferred global average of 0.05 USD/KWh but still within a reasonable range considering what Bitcoin miners pay to mine in other countries. The country scored relatively well under several Ease of Doing Business criteria and the government it also crypto friendly.

The country has ambitious plans for developing mini-grids over the next few years, which would present an opportunity for partnerships with Bitcoin mining data centres to ensure short- to medium-term financial sustainability.

Egypt also scored well under various Ease of Doing business indicators and the country has a well-developed electricity sector that supplies sufficient power to meet demand. The government has also opened up the electricity sector to private sector operators, which might be a good entry point for bitcoin mining. However, the government has not been friendly to crypto companies operating within the country and its position on Bitcoin mining is unknown.

Building a digital innovation ecosystem

This paper started by describing how Bitcoin mining is part of a wider ecosystem of data centres. Investment in data centres around the world is expanding rapidly and the African region is far behind, despite acknowledging the importance of building such infrastructure. The Africa Union Data Policy urges member states to "Adopt more sustainable electricity generation models domestically and across the region, to ensure the foundational digital infrastructure supports sustainable domestic and cross-border data activities that have fewer extractive impacts on the natural environment." [111] In 2023, there were only 121 data centres across Africa, with South Africa hosting 50 data centres followed by Nigeria with 15 each, then Kenya with 10 and Morocco with nine.[112] Data centres are essential infrastructure for the digital economy, and they bring several benefits, among them improving data sovereignty, reducing latency and costs of digital infrastructure, stimulating innovation and growth, and expanding digital inclusion.

Just like Bitcoin mining data centres, traditional data centres that provide cloud computing services are energy-intensive. The main difference is that traditional data centres require consistent access to electricity sources. Therefore, the current state of electricity infrastructure in most African countries cannot reliably provide a quality service to traditional data centres without several backups to mitigate any power loss. The need for backups increases the cost of running data centres. The operational flexibility of Bitcoin mining data centres makes them ideal for operating in such challenging environments. Bitcoin mining data centres can open up opportunities for skilled jobs to develop and maintain digital infrastructure, which will be important skills going into the future. Investing in data centre infrastructure and skills is important to building a digital ecosystem that will support innovation and growth. Promoting investments by bitcoin mining data centres on mini grids can help countries build out electricity infrastructure in rural areas, which, over the long term can expand to connect to the main power grid, when this is economically feasible.

Recommendations and conclusion

Recommendations

To foster the development of mini-grids and Bitcoin mining data centres, countries should adopt the following policy measures:

- Protect the investments of mini-grid developers by providing clear and transparent plans for grid expansion and introducing legal protections or adequate compensation for mini-grid developers in case of grid encroachment, which may undermine their profitability and viability by offering lower tariffs to consumers.
- Introduce clear and streamlined policies and guidelines for Bitcoin mining data centres that would enable them to obtain the necessary licences and permits to collocate at public utilities or mini-grid sites, and ensure compliance with environmental and social standards.
- Extend tax incentives on machinery and equipment provided to renewable energy grid developers to Bitcoin mining data centres that have long-term partnerships with mini-grid developers, and facilitate access to finance and credit for both parties.
- Promote and support skills development in local training institutions to enable local talent to participate in the development of the mini-grid and data centre industries, and create employment and income opportunities for rural communities.
- Improve the business environment and reduce the administrative and regulatory barriers that affect starting and running a business, including business registration, accessing electricity, enforcing contracts and resolving insolvency.

These policy measures would help to create a conducive and supportive environment for mini-grids and Bitcoin mining data centres, and enhance their contribution to rural electrification, economic development, and climate change mitigation.

Conclusion

The highest potential for Bitcoin mining in Africa lies in mini-grids because this would reduce any pressure on the main grid, which is already highly constrained in most African countries. The few exceptions are North African countries, which have achieved nearly universal access to electricity but have governments that are the least friendly to cryptocurrencies and Bitcoin mining. Further, these countries rely on fossil fuels to power their electricity, which might not appeal to Bitcoin miners looking for renewable energy-generated electricity. Opportunities for tapping into stranded energy on the main grid still exist in countries that have not reached universal access but have excess capacity, which has no way of reaching end users in the short to medium term due to underdeveloped transmission and distribution networks. This allows countries to monetize stranded energy, improve their investments' financial performance, and increase their ability to pay off investment loans.

The use cases from Kenya and Nigeria have demonstrated the positive impact of Bitcoin mining data centres in improving the financial sustainability of hydro-powered mini-grids. At the same time, Uganda has similarly shown a successful pilot from Bitcoin mining on solar PV mini-grids. These cases provide some insights into potential partnerships that mini-gird developers can consider as they plan their investment in rural areas where anchor tenants and productive electricity users are scarce. However, due to the price sensitivity of Bitcoin mining, mini-grid developers will have to provide globally competitive prices that will attract Bitcoin miners and they should also advocate for policy and regulation that is friendly to Bitcoin mining to reduce concerns of regulatory uncertainty. Further, Bitcoin mining is volatile because it is sensitive to the price of electricity, the price of Bitcoin itself, and other factors such as mining difficulty and block subsidies.

Therefore, these factors will determine if Bitcoin mining operations remain profitable and if Bitcoin mining data centres can continue operations. In bear markets and due to the Bitcoin halving events, a significant percentage of Bitcoin mining centres fold up, which is a key risk for mini-grid developers relying on them as anchor tenants. Therefore, a good understanding of the Bitcoin miners' data centres' business model and strategy for riding bear markets and events such as the halving are important factors for mini-grid developers to consider when deciding on medium- to long-term partnerships. Alternatively, mini-grid developers can also build their own Bitcoin mining data centres to streamline operations and manage costs.

While Bitcoin mining is not the ultimate solution for addressing the challenges associated with expanding electricity access in Africa, it does provide an opportunity to ease challenges faced by mini-grids at the forefront of providing access to electricity in underserved rural communities most affected by energy poverty.

[14]

Unblock Global Bitcoin mining data centre, Argentina

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