



Combined Proceedings of the 39<sup>th</sup> iSTEAMS Bespoke Conference – July, 2025  
& iSTEAMS Emerging Technologies Conference October, 2025

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39<sup>th</sup> International Science Technology Education Arts Management  
& Social Sciences (iSTEAMS) Bespoke Conference – Accra, Ghana 2025

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## Evolution of Some Emerging Technologies and the Curiosity In Africa

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### ABSTRACT

This paper addresses the evolution, dissemination and growing curiosity surrounding selected five emerging technologies in Africa. These technologies are Artificial Intelligence (AI), Internet of Things (IoT), Blockchain Technology, Renewable Energy, and Quantum Computing. These technologies are restructuring the economies, industrial operations and social systems in Africa. The curiosity about these technologies has been driven by the continent's cumulative digital literacy, growing investment and expanding technological ecosystem in modernization hubs. However, the stride of adoption of these technologies remains irregular, due to lack of adequate infrastructural, strong regulatory and enough capacity. This paper explores these emerging technologies global and African trajectories, hypothetical foundations that illuminate their adoption, present usefulness, limitations and policy recommendations to ensure that Africa profits evenhandedly from these transformative revolutions.

**Keywords:** Evolution, Artificial Intelligence, Blockchain Technology, Regulatory, Security, Renewable Energy, Africa, Literacy, Industrial Operations, Quantum Computing

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#### Proceedings Citation Format

Anokhaoya Donatus Osiokha (2025): Evolution of Some Emerging Technologies and the Curiosity In Africa. Combined Proceedings of the 39<sup>th</sup> iSTEAMS Multidisciplinary Bespoke Conference 17<sup>th</sup>-19<sup>th</sup> July, 2025 & iSTEAMS Emerging Technologies Conference 30<sup>th</sup>-31<sup>st</sup> October, 2025. Ghana-Korean Information Resource Centre, Balme Library, University of Ghana, Accra, Ghana. Page 151-168. [www.isteams.net/ghana2025](http://www.isteams.net/ghana2025).  
[dx.doi.org/10.22624/AIMS/ACCRABESPOKE2025P18](https://doi.org/10.22624/AIMS/ACCRABESPOKE2025P18)

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### 1. INTRODUCTION

Emerging technologies focuses on the new trends of technological advancement that are redefining the global economy, improving how people now attend to issues and advanced communication transactions, modern and efficient way of production and also influence how people are governed.



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Competitiveness is what drive the globe, industries and other sectors mainly rely on new technologies to optimize processes, add value and improve productivity and solve complex challenges. The global influence of these technologies can never be over emphasized and these impacts will continue to drive public and private sectors and provide new modern and evolution, opening greeter and better opportunities of the way business are ben done, better and improved solutions to businesses challenges collectively and individuals. This article is a to review five selected emerging technologies in our world today, these are Artificial Intelligence (AI), Internet of Things (IoT), Blockchain Technology, Renewable Energy technologies and Quantum Computing.

Artificial Intelligence (AI) focuses on the automating decision-making and analysis with the aid of advancement in technologies; Internet of Things (IoT) have to do with the connections of physical devices in computerize ways and converting physical modern to digital moderns; Blockchain Technology encompasses the use of computing intelligence to redefines confidence, trust and transparency in any defined field; Renewable Energy technologies are modern targeted at reducing reliance on fossil fuels in order to solve environmental issues; and Quantum Computing is the transformation of computational speed and problem-solving capacity. With the advent and wide spread of this emerging technologies, the African continent's curiosity on these technological is on the rise. There are several innovation hubs in most African countries such as Nigeria, Egypt, South Africa and Kenya ae integrating most of these technologies into major sectors like health, agriculture, education, finance and aviation. The rapid growth of the continent's population has increased the interest in new technologies and access to internet has also create belter opportunities and fertile ground for technological innovation to strive in African. There are several challenges such as poor infrastructure, insufficient policy frameworks, lack of digital skills which limit the full unitization of these technologies.

## 2. RELATED LITERATURE

### 2.1 Definitions of Artificial Intelligence (AI)

Seral authors have given their thought and basic definitions on Artificial Intelligence. Some of these definitions are:

Artificial Intelligence It is a step-by-step process for performing repetitive actions, designing models, and solving technical problems without pre-existing concrete solutions. (de Lima-Santos and Ceron (2021). AI systems are defined in an extensive framework, with risk-based and social-good approaches, which comprises automation in the form of structured or unstructured data acquisition, content creation, moderation, and production, predictive and recommendation systems employed for decision-making, and targeting users.(European Commission, Directorate-General for Communications Networks, Content, and Technology (2021).

The process of “creating computing machines and systems that perform operations analogous to human learning and decision-making.” Castro and New (2016, p. 2) Nah et al. (2020). Artificial intelligence is portrayed as the interactions between virtual and human agents across social, cultural, political, and ethical domains to enable machine imitations of human behavior and thoughts. Nah et al. (2020). AI “refers broadly to computational systems that involve algorithms, machine learning methods, natural language processing, and other techniques that operate on behalf of an individual to improve communication outcome.” Hancock et al. (2020, p. 90).

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On a very broad account the areas of artificial intelligence are classified into sixteen categories (Becker et al. (2000), Singer et al. (2000), Chen and Van Beek (2001), Hong (2001) and Stone et al. (2001)). These are: reasoning, programming, artificial life, belief revision, data mining, distributed AI, expert systems, genetic algorithms, systems, knowledge representation, machine learning, natural language understanding, neural networks, theorem proving, constraint satisfaction, and theory of computation (Peng and Zhang (2007), Zhou et al. (2007) and Wang et al. (2007).

### 2.1.1 Applications of AI:

According to the *State of AI in Africa Report* (CIPIT, 2024), AI acceptance across the globe and African nations in particular has spread over several startups such as education, health, and financial technology. In today world, the application of Artificial intelligence cut across several areas of human endeavours as enumerated below:

- **Communication:** AI Tools like Siri, Google Assistant, and Alexa use AI for speech recognition and natural language processing in many mobile and home devices. Several websites use AI-powered chatbots to respond to customer help instantly. AI helps Gmail and other platforms detect spam, categorize messages, and even suggest smart replies.
- **Transportation and Navigation:** Apps like Google Maps and Waze use AI to analyze traffic data and suggest the fastest routes. Uber and Bolt in Nigeria use AI to search and book for a drop and match riders with drivers efficiently and calculate cost and estimated arrival times.
- **Health sector:** AI is used in health care sector in detecting and diagnosing ailments like cancer, diabetes, and heart conditions through medical imaging analysis. Smartwatches monitor heart rate, sleep patterns, and physical activity, offering AI-based health insights.
- **Education and Learning** Platforms like Coursera and Duolingo use AI to tailor learning experiences based on user progress. AI systems can evaluate assignments and quizzes, reducing teachers' workload. Tools like Google Translate use AI to instantly translate text, voice, and images.
- **Fraud Detection:** Banks use AI algorithms to detect unusual transaction patterns that may indicate fraud. AI chatbots provide 24/7 customer support and automate routine transactions. AI models analyze data trends to assist investors in making informed decisions.
- **Entertainment and Media:** Platforms like Netflix, YouTube, and Spotify use AI to suggest movies or music based on your interests. Facebook, Instagram, and TikTok use AI to curate personalized content and ads. AI creates realistic behaviors in non-player characters (NPCs) and adapts difficulty levels dynamically.
- **Smart Homes and Appliances:** AI enables devices like smart thermostats, lighting, and security cameras to learn user habits. Systems like Alexa or Google Home automate daily routines such as turning on lights or playing music.
- **Security and Surveillance:** Used in phones, airports, and security systems to identify individuals.
- **Cybersecurity:** AI detects malware, phishing attacks, and suspicious online activities in real time.
- **Agriculture:** AI-powered drones and sensors help farmers monitor soil health, crop growth, and irrigation. AI models predict pest attacks and suggest timely interventions.

### 2.1.2 Challenges and ethical considerations:

Overview of the ethical challenges facing AI has identified six types of concerns that can be traced to the operational parameters of decision-making algorithms and AI systems.

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- **Common sense reasoning:** AI systems lack the common sense reasoning that humans apply effortlessly in daily life.
- **Transfer learning:** It is difficult to create AI that can learn in one domain and apply that knowledge effectively to another.
- **Explainability and transparency:** Understanding how complex AI models arrive at their decisions is a significant challenge, which hinders trust and debugging efforts.
- **Computational power:** The immense computational resources needed to develop and run advanced general AI are a major limitation.
- **Data dependency:** AI requires vast amounts of data, but problems with data quality, privacy, and availability can limit its effectiveness.

AI systems should be auditable and traceable. There should be oversight, impact assessment, audit and due diligence mechanisms in place to avoid conflicts with human rights norms and threats to environmental wellbeing. The ethical deployment of AI systems depends on their transparency & explainability (T&E). – UNESCO - <https://www.unesco.org>

## 2.2 Internet of Things (IoT)

The IOT concept was coined by a member of the Radio Frequency Identification (RFID) development community in 1999, and it has recently become more relevant to the practical world largely because of the growth of mobile devices, embedded and ubiquitous communication, cloud computing and data analytics. IoT can be defined in three categories as below: (Sunil Patel, Keyur K Patel, Sunil M Patel Carlos Salazar, 2016,)

Internet of things is an internet of three things:

- (1). People to people
- (2) People to machine /things
- (3) Things /machine to things /machine,

Interacting through internet. Internet of Things (IoT) is a concept and a paradigm that considers pervasive presence in the environment of a variety of things/objects that through wireless and wired connections and unique addressing schemes are able to interact with each other and cooperate with other things/objects to create new applications/services and reach common goals. In this context the research and development challenges to create a smart world are enormous. A world where the real, digital and the virtual are converging to create smart environments that make energy, transport, cities and many other areas more intelligent. Hello Tractor (2023) show that IoT applications in African agriculture have enhanced mechanization, helping smallholder farmers access tractors and monitor productivity.

### 2.2.1 The fundamental characteristics of IoT

- **Interconnectivity:** With regard to the IoT, anything can be interconnected with the global information and communication infrastructure.
- **Things-related services:** The IoT is capable of providing thing-related services within the constraints of things, such as privacy protection and semantic consistency between physical things and their associated virtual things. In order to provide thing-related services within the constraints of things, both the technologies in physical world and information world will change.
- **Heterogeneity:** The devices in the IoT are heterogeneous as based on different hardware platforms and networks. They can interact with other devices or service platforms through different networks.

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- **Dynamic changes:** The state of devices change dynamically, e.g., sleeping and waking up, connected and/or disconnected as well as the context of devices including location and speed. Moreover, the number of devices can change dynamically.
- **Enormous scale:** The number of devices that need to be managed and that communicate with each other will be at least an order of magnitude larger than the devices connected to the current Internet. Even more critical will be the management of the data generated and their interpretation for application purposes. This relates to semantics of data, as well as efficient data handling.
- **Safety:** As we gain benefits from the IoT, we must not forget about safety. As both the creators and recipients of the IoT, we must design for safety. This includes the safety of our personal data and the safety of our physical well-being. Securing the endpoints, the networks, and the data moving across all of it means creating a security paradigm that will scale.
- **Connectivity:** Connectivity enables network accessibility and compatibility. Accessibility is getting on a network while compatibility provides the common ability to consume and produce data.

### 2.2.3 Challenges for IoT:

There are key challenges and implications today that need to be addressed before mass adoption of IOT can occur.

- **Privacy and Security:** As the IoT become a key element of the Future Internet and the usage of the Internet of Things for large-scale, partially mission-critical systems creates the need to address trust and security functions adequately. New challenges identified for privacy, trust and reliability includes providing trust and quality of-information in shared information models to enable re-use across many applications. Providing secure exchange of data between IoT devices and consumers of their information. Providing protection mechanisms for vulnerable devices.
- **Cost versus Usability IOT:** Uses technology to connect physical objects to the Internet. For IOT adoption to grow, the cost of components that are needed to support capabilities such as sensing, tracking and control mechanisms need to be relatively inexpensive in the coming years.
- **Interoperability:** In the traditional Internet, interoperability is the most basic core value; the first requirement of Internet connectivity is that “connected” systems be able to “talk the same language” of protocols and encodings. Different industries today use different standards to support their applications. With numerous sources of data and heterogeneous devices, the use of standard interfaces between these diverse entities becomes important. This is especially so for applications that supports cross organizational and various system boundaries. Thus the IOT systems need to handle high degree of interoperability.
- **Data Management:** Data management is a crucial aspect in the Internet of Things. When considering a world of objects interconnected and constantly exchanging all types of information, the volume of the generated data and the processes involved in the handling of those data become critical.

### 2.3 Blockchain Technology

Chainalysis (2024) reports that Nigeria and Kenya rank among the top global users of blockchain-based crypto transactions, showing deep grassroots curiosity despite regulatory uncertainties. Blockchain is a sequence of blocks, which holds a complete list of transaction records like conventional public ledger.

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Blockchain is a sequence of blocks, which holds a complete list of transaction records like conventional public ledger with a previous block hash contained in the block header, a block has only one *parent block*. It is worth noting that *uncle blocks* (children of the block's ancestors) hashes would also be stored in ethereum blockchain. The first block of a blockchain is called *genesis block* which has no parent block. We then explain the internals of blockchain in details.

**2.3.1 Block:** A block consists of the *block header* and the *block body*, the block header includes:

- Block version: indicates which set of block validation rules to follow.
- Merkle tree root hash: the hash value of all the transactions in the block.
- Timestamp: current time as seconds in universal time since January 1, 1970.
- nBits: target threshold of a valid block hash.
- Nonce: a 4-byte field, which usually starts with 0 and increases for every hash calculation.
- Parent block hash: a 256-bit hash value that points to the previous block.

The block body is composed of a transaction counter and transactions. The maximum number of transactions that a block can contain depends on the block size and the size of each transaction. Blockchain uses an asymmetric cryptography mechanism to validate the authentication of transactions. Digital signature based on asymmetric cryptography is used in an untrustworthy environment.

### 2.3.2 Digital Signature

Each user owns a pair of private key and public key. The private key that shall be kept in confidentiality is used to sign the transactions. The digital signed transactions are broadcasted throughout the whole network. The typical digital signature is involved with two phases: *signing phase* and *verification phase*. For instance, a user wants to send another user a message. (1) In the signing phase, User 1 encrypts her data with her private key and sends User two the encrypted result and original data. (2) In the verification phase, User two validates the value with User 1 public key. In that way, user 1 could easily check if the data has been tampered or not. The typical digital signature algorithm used in blockchains is the elliptic curve digital signature algorithm (ECDSA).

**2.3.3 Key Characteristics of Blockchain:** In summary, blockchain has following key characteristics.

- **Decentralization.** In conventional centralized transaction systems, each transaction needs to be validated through the central trusted agency (e.g., the central bank), inevitably resulting to the cost and the performance bottlenecks at the central servers. Contrast to the centralized mode, third party is no longer needed in blockchain. Consensus algorithms in blockchain are used to maintain data consistency in distributed network.
- **Persistency.** Transactions can be validated quickly and invalid transactions would not be admitted by honest miners. It is nearly impossible to delete or rollback transactions once they are included in the blockchain. Blocks that contain invalid transactions could be discovered immediately.
- **Anonymity:** Each user can interact with the blockchain with a generated address, which does not reveal the real identity of the user. Note that blockchain cannot guarantee the perfect privacy preservation due to the intrinsic constraint
- **Taxonomy of blockchain systems:** Current blockchain systems are categorized roughly into three types: public blockchain, private blockchain and consortium

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blockchain. In public blockchain, all records are visible to the public and everyone could take part in the consensus process. Differently, only a group of pre-selected nodes would participate in the consensus process of a consortium blockchain. As for private blockchain, only those nodes that come from one specific organization would be allowed to join the consensus process.

## 2.4 Renewable Energy

The World Bank (2023) highlights that renewable mini-grids could power up to 380 million Africans by 2030, underscoring the transformative potential of solar and wind technologies in addressing energy poverty. Renewable energy sources accounted for 29.1% of electricity generation globally in 2022, totaling 8.440TWh. The other 70.9% (20,591TWh) corresponded to fossil fuels, nuclear energy, pumped storage and other non-renewables, bringing global electricity generation from all sources to 29,031TWh in 2022. Over the past decades, the profile of renewable energy sources has significantly diversified. While hydropower\* continues to provide the bulk of electricity generation, variable renewables have steadily increased their share in the global electricity mix, growing from 1.1% of renewable generation in 2000 to 40.2% in 2022. In 2022, hydropower remained the largest source of renewable electricity, generating 4,330TWh, a modest 0.8% increase over 2021.

Wind energy follows, producing 2,098TWh, marking a 14.0% increase compared to 2021. Solar energy, the fastest-growing renewable energy source in recent years, generated 1,294TWh, a year-on-year increase of more than one quarter (25.6%). Bioenergy produced 619TWh, growing by 1.5%, while geothermal energy contributed 97TWh and marine energy was close to 1TWh. In African, Nigeria is blessed with an abundance of energy resources to meet its current and future needs for growth. Nigeria is endowed with an abundance of energy resources, including coal, natural gas, tar sands, crude oil, and generally high-quality sources. Crude oil accounts for over 90% of the nation's economic activity (Igbinovia & Krupka, 2018). With a resource estimated to be at 36 million barrels or roughly 4.9 billion tonnes of oil equivalent (toe), Nigeria was classified as the tenth largest producer of crude oil in the world in 2006 (Chris et al., 2021).

Natural gas reserves in the nation are estimated to be 5210 billion m<sup>3</sup> (187 trillion SCF) as of 2006, making them more abundant than oil. This comprises both linked and unlinked reserves, positioning Nigeria as one of the top ten nations in the world with the biggest gas reserves (Uyigue & Archibong, 2010). In addition, Nigeria has 1.52 billion tonnes of coal and lignite, as well as 4.1 billion tonnes of tar sands (Shaaban & Petinrin, 2014). Petroleum in particular continues to be the most significant source of foreign exchange earnings and government revenue in the energy subsector. Between 2002 and 2006, the GDP benefited on average by 25.24% from the petroleum industry. Nevertheless, other economic sectors are contracting despite the oil industry's success. For instance, although overall or total electricity consumption showed a marginal increase of 1.8% from 5.63GWh in 2002 to 7.47GWh in 2006, actual electricity usage decreased by 13.4% between 2002 and 2006. In Nigeria, just 40% of homes are wired into the national grid.

### 2.4.1 Importance of Renewable Energy

A more sustainable strategy for rural development, ecosystem health, energy independence, and mitigating climate change is provided by renewable energy. Renewable energy is defined by the International Energy Agency (IEA) as energy derived from natural processes that regenerate more quickly than they are consumed (Chris et al., 2021).

Reducing environmental effects is typically the driving force behind the switch from non-renewable to renewable energy (Ibanga, 2018).

Using and switching to renewable energy offers several socioeconomic and environmental advantages, including:

- i. Creation of clean energy, which emits less greenhouse gas than fossil fuels—either none at all or very little.
- ii. Energy supply diversification, which lessens reliance on imported and fossil fuels.
- iii. Fostering employment growth and economic development in the manufacturing, installation, etc.
- iv. Enhanced energy accessibility and availability leading to higher productivity, which raises GDP.

#### 2.4.2 Overview of Available Renewable Energy Sources

Renewable energy is becoming more and more popular. Renewable energy is any type of energy that comes from sunshine, either directly or indirectly, by heating the earth's surface differently and creating air movement, such as wind power. An adult individual can refill these energy sources during their lifespan. Renewable energy is widely available in Nigeria (Akuru et al., 2016). In terms of energy, Nigeria's renewable energy potential is roughly 1.5 times greater than that of its fossil fuel resources.

Nigeria's low level of access to power can be significantly improved and changed by hydro, solar, biomass, and wind energy (Shaaban & Petinrin, 2014).

- **Solar Energy Potential:** This energy source is dependent on the sun's core's nuclear fusion power. There are various methods for gathering and converting this energy. These range from sophisticated devices that directly convert sunlight into electrical energy using mirrors, boilers, or photovoltaic cells, to solar water heating using solar collectors or attic cooling with solar attic fans for home use. The fact that this energy source is insufficient to sustainably power our contemporary society is one of its main concerns. PV or thermal systems are the sources of solar electricity (Akuru & Okoro, 2008).
- **Wind Energy Potential:** This type of energy that depends on variations in surface temperature brought on by sunshine is this one. Although wind energy can be utilized to create power and pump water, it needs a large area of sky coverage to produce a meaningful amount of energy. There are additional constraints on this type of energy due to various factors that impact wind availability year-round. Grain milling and water pumping have been done for centuries using wind energy (Madhusudhan & Damodhar, 2019). Optimising the components of wind power generation and wind water pumping is a crucial prerequisite for meaningful wind energy exploitation (Musa, 2014).
- **Hydropower Prospect:** The gravitational potential of the water that sunlight lifted from the oceans is what drives this type of energy. It's possible that hydroelectric energy isn't always renewable because reservoirs ultimately fill up and need to be excavated at great expense before they can be used again. In the developed world, the majority of the sites that are suitable for hydroelectric dams are already in use (Akuru et al., 2016). Global hydropower capacity was estimated at 2810 TWh in 2004 and is expected to reach 4903 TWh by 2030, growing at a pace of 1.8% annually; nonetheless, its share of the world's energy supply will stay around 2% (Gupta, 2016; Karekezi et al., 2003). There are now several hydropower development projects underway throughout the world, with a combined capacity of

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roughly 100,000 MW. Asia makes up the largest contribution, at 84,000 MW. Other regions contribute 14,800 MW from South America, 1236 MW from North and Central America, 2211 MW from Europe, and 2403 MW from Africa (Singh et al., 2009).

- **Biomass and Bioenergy Resources:** This relates to plant-based energy. This type of energy is widely available everywhere. Among these energy sources, burning trees for warmth and cooking is the most prevalent. This method contributes significantly to air pollution in many places by releasing a large amount of carbon dioxide gases into the atmosphere. Modern biomass energy sources include the manufacture of alcohol and methane for use as fuel in cars and electric power plants. Various techniques can be employed to transform biomass into electrical energy. Direct combustion of biomass, such as woody or agricultural waste, is the most used method. Anaerobic digestion, pyrolysis, and gasification are more alternatives. Through the process of gasification, biomass is heated with less oxygen than required for complete combustion, producing a synthesis gas with a usable energy content. By quickly heating the biomass in the absence of oxygen, pyrolysis produces bio-oil. When organic matter is broken down by bacteria without oxygen, anaerobic digestion creates a renewable natural gas. Various techniques are effective with various kinds of biomass. To provide energy, woody biomass like sawdust, pellets, and chips are usually burned or gasified. The remaining corn Stover and wheat straw are either baled for burning or treated in anaerobic digestion to produce gas. Anaerobic digesters are used to transform very wet wastes, such as those from animals and humans, into a gas with a medium energy content. Furthermore, pyrolysis may be utilized to turn the majority of other biomass types into bio-oil, which can be utilized in furnaces and boilers (Akuru et al., 2016).

#### 2.4.3 Challenges of Renewable Energy Adoption in Africa

- **Financial and Investment:** Financial considerations severely limit Nigeria's ability to accept and use renewable energy. Given that Nigeria is the world's centre of poverty and has a weak manufacturing sector, the majority of the facilities, parts, and equipment needed to adopt renewable energy are not readily available in the country. Before they can be implemented, they must first be imported. Nigeria's high cost of installing and purchasing renewable energy capacity is the outcome of this. Even though Nigeria has made significant investments in renewable infrastructure, particularly in the field of solar energy, the total amount of funding obtained to far has not been able to meet the needs of the nation in terms of renewable infrastructure.
- **Infrastructural and Technological Limitation:** The absence of infrastructure and technology to facilitate the development of these energy sources is a major obstacle to the implementation and utilization of the abundant renewable energy resources found in Nigeria. For instance, Nigeria is endowed with year-round sunshine and minerals including silicate, lithium, lead, tin, zinc, and cobalt that are used to make solar panels and batteries. But other than cables, Nigeria doesn't produce solar panels, batteries, or any other part used in solar installations. Few people have the financial means to buy and install solar power as a standalone supply or backup supply because of the high cost of solar energy installation caused by the absence of infrastructure and technology for the production of these parts. Also, Nigeria currently lacks infrastructure for the exploitation of wind and tidal energy. Nigeria is not using various sources of energy to generate power as a result of the lack of this infrastructure. Therefore, regulations and investments are

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needed to solve the physical and technological gaps that are now preventing Nigeria from fully using these renewable energy sources.

- **Grid Integration Issues:** Against the existing production capacity of over 12,000MW, the Nigerian national system can currently transmit barely over 6000MW of power. This led to other power plants implementing redundancy. The difficulty of incorporating renewable energy sources, such as solar microgrids, into the national grid is another effect of this.
- **Regulation and Policy Hurdles:** Nigeria's attempt to encourage the diversification of its energy mix resulted in the creation of the Renewable Energy Master Plan (REMP), which was revised in 2011 after being approved by the government in November 2005. The United Nations Development Programme (UNDP) and the Energy Commission of Nigeria (ECN) collaborated on this plan to create a broad vision, objectives, and action plan for resolving the nation's major energy-related problems through the rapid development and utilization of renewable energy sources. With the help of an inclusive framework for the development of renewable energy policies, law, technology, human resources, infrastructure, and the market, REMP establishes clear and verifiable national targets for the short, medium, and long term. There were three sets of targets: medium-term for 2015, long-term for 2025, and short-term for 2007.

## 2.5 Quantum Computing

According to IBM Research (2024), quantum computing remains at an experimental stage globally but is attracting interest in African research institutions through collaborations with IBM, Google, and universities. Quantum computation is the field that investigates the computational power and other properties of computers based on quantum-mechanical principles. It combines two of the most important strands of 20th-century science: quantum mechanics (developed by Planck, Einstein, Bohr, Heisenberg, Schrödinger and others in the period 1900–1925) and computer science (whose birth may be dated to Turing's 1936 paper). An important objective is to find quantum algorithms that are significantly faster than any classical algorithm solving the same problem.

Quantum computation started in the early 1980s with suggestions for analog quantum computers by Yuri Manin [185] (and appendix of [186]), Richard Feynman [111, 112], and Paul Benioff [47], and reached more digital ground when in 1985 David Deutsch defined the universal quantum Turing machine [97]. See Preskill [201] for more on this early history. The following years saw only sparse activity, notably the development of the first algorithms by Deutsch and Jozsa [99] and by Simon [230], and the development of quantum complexity theory by Bernstein and Vazirani [53]. However, interest in the field increased tremendously after Peter Shor's very surprising discovery of efficient quantum algorithms for the problems of integer factorization and discrete logarithms in 1994 [228], which was inspired by Simon's work.

Since most of current classical cryptography is based on the assumption that these two problems are computationally hard, the ability to actually build and use a quantum computer would allow us to break most current classical cryptographic systems, notably the RSA system [210, 211]. In contrast, a quantum form of cryptography due to Bennett and Brassard [51] is unbreakable even for quantum computers.

### 2.5.1 Properties of quantum computing

In quantum physics, the quantum object does not exist in an entirely determined state. It looks like a particle but behaves like a wave when not being observed. This dual nature of particles leads to interesting physical phenomena. The state of any quantum object is expressed as a sum of possible participating states or a wave function. Such states are coherent due to the interference of all the participating states either in a constructive or a destructive manner. Observation of quantum objects when they interact with some larger physical system results in the extraction of information. Such observation of quantum objects is called quantum measurement.

Measurement can also result in the loss of information by disrupting the quantum state. These are some of the properties of quantum objects. Quantum objects referred here are the qubits in the case of quantum computing. The progress of any quantum system is regulated by Schrodinger's equation that tells us about the change in the wave-function of the system due to the energy environment. This environment is the system Hamiltonian which is a mathematical description of energies experiencing from all forces felt by all components of the system. To control any quantum system, there is a need to control this environment by isolating the system from the forces of the universe that cannot be controlled easily and by assigning energy within this isolated area only. A system cannot be completely isolated. However, energy and information exchanges can be minimized. This interaction with the outside environment can lead to loss of coherence and can result in "Decoherence".

The properties are the conceptual rules and mathematical manifestations that describe the behavior of the particles. Quantum computers use three fundamental properties of quantum mechanics to store, represent, and perform operations on data in such a way so that it can compute exponentially faster than any classical computer. The three properties are given as follows:

#### Superposition

Superposition in quantum mechanics states that any two quantum states can be summed up (superposed) resulting in another valid quantum state. It is a fundamental principle of quantum mechanics. Oppositely we can say that any quantum state is the sum of two or more than two other unique states. Superposition in quantum computing refers to the ability of a quantum system where quantum particle or qubit can exist in two different positions or say, in multiple states at the same time. It provides high-speed parallel processing in an unbelievable way and is very different from their classical equivalents that have binary constraints. The quantum computer system holds the information that exists in two states simultaneously.

Qubits are brought into a superposition by influencing them with the help of lasers so that it can simultaneously store 0 and 1 at the same time. In classical computing, if there are 2 bits, the total possible values after combining we get are 4, out of which only 1 value is possible at any instant. But on the other hand, if there are 2 qubits in the quantum computer. The total possible values after combination are 4 and all are possible at once. It looks like unthinkable because it is not like gravity that can be proved easily just by looking at the falling of an apple. The laws of classical physics fail here because superposition only exists in the territory of quantum particles.



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### **Entanglement**

Entanglement in quantum mechanics is a physical phenomenon where two or more quantum objects are inherently linked such that measurement of one rules the possible measurement of another. In other words, a pair or a group of particles interacts or share spatial locality such that the quantum state of each particle cannot be characterized independently of the other particle's state in the same group even when they are separated by a large distance. Entanglement is one of the important properties of quantum computing. It refers to the strong correlation existing between two quantum particles (physical properties of systems) or qubits. Qubits are linked together in a perfect instantaneous connection, even if they are isolated at any large distances such as located at the opposite ends of the Universe.

They are entangled or defined with reference to each other. The fact is that the state of one particle influences the state of the other. It creates strong communication between qubits. Once they got entangled, they will stay connected even after separated at any distance. In classical computers, if bits are doubled, computational power also gets doubled. But in the case of Entanglement, adding extra bits to a quantum computer can increase its computational power exponentially. Quantum computer uses this property in a sort of quantum daisy chain. Some examples of entanglement can be seen in nature such as electrons separated from each other at some distance inside an electron cloud are massively entangled with one another. If one electron is at both the states of spin-up and spin-down with each state having a probability of  $\frac{1}{2}$ , a similar case is with the other electron.

### **Interference**

The property of interference in quantum computers is similar to wave interference in classical physics. Wave interference happens when two waves interact with each other in the same medium. It forms a resultant wave with either their amplitudes added together when they are aligned in the same direction known as constructive interference or a resultant wave with their amplitudes canceled out when waves are in opposite direction known as destructive interference. The net wave can be bigger or smaller than the original wave depending on the type of interference. Since all subatomic particles along with light pose dual nature, i.e. particle and wave nature both.

The quantum particle may experience interference. If each particle goes through both the slits (Young's double-slit experiment) simultaneously due to superposition, they can cross its own path interfering with the path direction. The idea of interference allows us to intentionally bias the content of the qubit towards the needed state. However, it can also result in a quantum computer to combine its various computations into one making it more error-prone.

## **3. EVOLUTION, DIFFUSION, ACCEPTANCE, AND UPTAKE OF THESE TECHNOLOGIES IN AFRICA AND BEYOND**

### **3.1 Artificial Intelligence (AI)**

Globally, AI has evolved from early rule-based systems in the 1950s to modern machine learning and deep learning models. The diffusion of AI has accelerated due to advances in cloud computing, big data, and algorithms. In Africa, AI adoption is driven by startups addressing local challenges—such as health diagnosis (e.g., using AI for malaria detection) and education (adaptive learning systems).



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The growing curiosity among African youth and researchers is supported by regional AI labs and government policies in countries like Nigeria, Egypt, and South Africa. AI offers productivity gains (automated analysis, diagnostics, decision support) – but African firms capture a small share of global investment; local models and data remain limited.

### 3.2 Internet of Things (IoT)

IoT evolved from the concept of machine-to-machine (M2M) communication to interconnected smart systems that collect and exchange data in real-time. In Africa, IoT is transforming agriculture, smart cities, and logistics. Solutions like *Hello Tractor* in Nigeria and *Twiga Foods* in Kenya show how connected devices are helping farmers and logistics companies optimize resources. Curiosity and adoption are increasing, although challenges in connectivity and cost remain. Demonstrated improvements in mechanisation access, efficiency, and incomes for smallholders; PAYG and booking agents overcome digital literacy barriers. Hello Tractor reports millions of acres engaged and strong repayment/usage metrics.

### 3.3 Blockchain Technology

Blockchain emerged in 2008 with Bitcoin as a decentralized ledger technology. It has since evolved into a platform for smart contracts, supply-chain management, and digital identity. In Africa, blockchain technology is finding applications in remittances, identity verification, and agricultural finance. Nigeria, Kenya, and South Africa lead in crypto and blockchain adoption due to their youthful populations and the need for transparent financial systems. However, regulatory restrictions and public skepticism still pose barriers. Blockchain provides alternative remittance and value-store channels in contexts of weak currencies or limited banking. Nigeria's heavy crypto use demonstrates practical demand for such tools.

### 3.4 Renewable Energy

The renewable energy sector has evolved from early solar and hydro power research to today's integrated systems that combine solar, wind, and energy storage technologies. Globally, investment in clean energy has surged due to environmental concerns and policy support. In Africa, renewable energy is crucial for addressing power shortages. Countries like Kenya and Morocco are global leaders in geothermal and solar energy, respectively. The growing curiosity and adoption of renewable energy technologies demonstrate Africa's potential to leapfrog fossil-based power systems. Mini-grids identified as cost-effective for rural access in many African settings; multi-stakeholder financing commitments (WB, AfDB) indicate scalability potential.

### 3.5 Quantum Computing

Quantum computing represents the next frontier of computational power, using quantum bits (qubits) to perform complex calculations faster than classical computers. While still in its infancy globally, Africa's curiosity is visible through partnerships such as IBM's Quantum Network collaborations with universities in Nigeria, South Africa, and Morocco. Although direct adoption remains limited, growing academic engagement signals early curiosity and potential future uptake.

#### 4. THEORETICAL FRAMEWORKS APPLICABLE TO EVOLUTION, DIFFUSION, ACCEPTANCE, AND UPTAKE

Several theoretical frameworks explain the diffusion and adoption of emerging technologies:

1. **Rogers' Diffusion of Innovations Theory (1962):** Explains how technologies spread through societies based on perceived usefulness, compatibility, and complexity.
2. **Technology Acceptance Model (TAM):** Suggests that perceived usefulness and ease of use determine individual and organizational acceptance of technology.
3. **Socio-Technical Systems Theory:** Emphasizes the interaction between technology and social context, relevant for understanding Africa's infrastructural and cultural adaptation to new technologies.
4. **Unified Theory of Acceptance and Use of Technology (UTAUT):** Integrates social influence, facilitating conditions, and performance expectancy as determinants of technology adoption.
5. **Multi-Level Perspective (MLP):** Helps explain how niche innovations (e.g., renewable energy or blockchain pilots) evolve into mainstream systems within broader socio-technical landscapes.

##### 4.2 Gaps & Limitations

- **Infrastructure & Power:** Many AI and IoT deployments need reliable power and connectivity; lack of both constrains real-world use.
- **Funding & Skills:** African AI and deep-tech ecosystems face funding gaps and limited advanced research capacity.
- **Regulation & Policy Uncertainty:** Crypto regulation varies widely; drone airspace regulations and mini-grid tariffs are often underdeveloped or inconsistent, creating investor uncertainty.
- **Affordability & Business Models:** PAYG and other innovative finance models help, but many solutions still struggle to reach the poorest without subsidies or blended finance.
- **Data Governance & Trust:** AI systems require quality data; privacy, ownership and algorithmic bias concerns are major barriers to acceptance.

#### 5. FINDINGS ON USEFULNESS OF TECHNOLOGY AND TECHNOLOGY GAPS IN AFRICA AND BEYOND

Technology	Usefulness	Gaps/Limitations
AI	Enhances data-driven decisions in agriculture, healthcare, and finance.	Lack of infrastructure, funding, and AI policy frameworks.
IoT	Improves efficiency in farming, logistics, and smart cities.	Limited internet coverage and high cost of IoT devices.
Blockchain	Enables transparency and secure transactions.	Regulatory uncertainty and low public awareness.
Renewable Energy	Reduces carbon footprint and enhances rural electrification.	Financing challenges and inadequate grid integration.
Quantum Computing	Promises breakthroughs in data encryption and modeling.	Still experimental, requiring massive investment and expertise.

## 6. RECOMMENDATIONS FOR POLICY, RESEARCH, AND PRACTICE.

### 6.1 Policy Recommendations

- Governments should **develop clear regulatory frameworks** for AI, blockchain, and quantum research.
- **Invest in broadband and electricity infrastructure** to enable IoT and AI deployment.
- **Encourage public-private partnerships (PPPs)** for renewable energy projects.
- **Create clear, adaptive regulatory sandboxes** for crypto, AI applications, and drones to balance innovation with consumer/integrity protections. (Example: tailored sandbox regimes that monitor outcomes but permit pilots.)
- **Support DRE (distributed renewable energy) enabling policies** — standardized tariffs, streamlined licensing for mini-grids, and incentives for private investment. Align national electrification strategies with mini-grid scale-up.
- **Invest in digital infrastructure and rural connectivity** (backhaul, mobile internet) as a cross-cutting enabler for AI, IoT, and digital financial services.

### 6.2 Research Recommendations

- Establish **AI and Quantum Computing research centers** in collaboration with global institutions.
- Conduct **localized case studies** on the economic and social impacts of blockchain and IoT.
- Promote **open data initiatives** for AI model development and innovation.
- **Fund locally-led AI research** and data repositories to build models suited to local languages, crops, and health contexts. Promote open science and shared datasets.
- **Evaluate business models** (e.g., PAYG, aggregation services like Hello Tractor) with randomized trials and cost-effectiveness studies to identify scalable models.
- **Conduct socio-economic impact studies** of crypto adoption to inform consumer protections and macroprudential policy.

### 6.3 Practice Recommendations

- Integrate emerging technologies into **education curricula** to build local talent.
- Support **startups and innovation hubs** that apply technology to local problems.
- Encourage **regional collaboration** to share experiences, standards, and resources.
- **Adopt human-centered design** — use booking agents, vernacular interfaces, and off-line capabilities to increase uptake among non-technical users (as Hello Tractor shows).
- **Form public-private partnerships (PPP)** for drones, mini-grids and last-mile logistics to share risk and accelerate scale (Zipline partnerships with ministries are instructive).

## 7. CONCLUDING REMARKS

Emerging technologies present Africa with both immense opportunities and complex challenges. While AI, IoT, blockchain, and renewable energy are already shaping Africa's innovation landscape, quantum computing represents the next frontier of curiosity and collaboration. To sustain progress, Africa must strengthen policy support, invest in education, and build partnerships that localize global technologies to meet domestic needs. The continent's demographic advantage and rising digital enthusiasm position it well to be an active participant—not just a consumer—in the global technological revolution.



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The five technologies examined here offer substantial promise to address persistent development challenges across Africa—improving healthcare logistics, agricultural productivity, financial inclusion, and energy access. Their diffusion and acceptance depend not only on technical performance but on governance, local capacity, financing, and socio-cultural fit. Pragmatic, evidence-driven policies and partnerships can accelerate beneficial outcomes while controlling downside risks. The continent’s rapid, often youth-driven adoption of mobile-enabled solutions provides a unique opportunity to leapfrog legacy constraints – if investments in skills, infrastructure, and regulation keep pace.

## 8. FUTURE DIRECTIONS WITH THESE TECHNOLOGIES

- **AI and IoT convergence** will enable precision agriculture and smart urban planning. On-device AI for low-connectivity contexts (e.g., crop disease detection on smartphones) will expand usefulness where cloud access is limited. Combining mini-grids, IoT-enabled agriculture, and digital finance could create resilient rural economies (energy → irrigation → mechanization → markets).
- **Blockchain integration** with government services can improve transparency and reduce corruption. Evolving digital currencies (CBDCs, regulated stable coins) could formalize many current crypto flows and reduce illicit risks if well-designed.
- **Hybrid renewable systems** combining solar, wind, and storage will enhance rural energy access.
- **Quantum computing research** in universities could enable Africa to leapfrog in data science and cybersecurity.
- **Cross-border innovation networks** will encourage collaborative growth and knowledge sharing.



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