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**Emerging Frontiers in Science and Technology: Edge Computing,
Quantum Systems, Energy Storage, Space Exploration and Additive
Manufacturing.**

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ABSTRACT

New technologies are changing how the world produces energy, processes data, builds infrastructure, and explores space. This paper examines five of them including advanced energy storage, quantum computing, 3D printing, edge computing, and space exploration technologies. It looks at how each supports sustainability, reduces costs, improves reliability, and adapts to different environments. The study focuses on their evolution and diffusion globally and in Africa, the theoretical frameworks that explain their uptake, and findings from recent literature on their usefulness and limitations. It also offers recommendations for policy, research, and practice. The review finds that while global progress is strong, Africa still faces challenges with infrastructure, investment, and technical skills. Yet the continent holds major potential in materials, market size, and innovation if supported by sound industrial policy and research partnerships.

Keywords: Emerging Trends, Frameworks, Edge Computing, Africa, Quantum Computing, Associated Technologies

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1. INTRODUCTION

Technology drives global development. It shapes how people generate power, communicate, design products, and explore the universe. The past two decades have seen rapid progress in energy storage, computing, manufacturing, and space systems. These technologies are not isolated. They reinforce one another. Reliable storage enables renewable energy grids. Quantum computing speeds up research in materials and logistics. 3D printing brings local manufacturing closer to consumers.



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Edge computing improves data handling and smart infrastructure. Space systems provide global connectivity and climate monitoring. For Africa, these technologies offer a chance to leapfrog stages of industrial development. The continent's population is young, its renewable potential is high, and its digital adoption is growing fast. But success depends on more than technology access. It requires adaptation to local conditions, investment in skills, and consistent policy support. This paper reviews the state of these technologies and their relevance for sustainable development. It builds on current research, global and regional reports, and case studies that highlight opportunities and gaps.

2. TRENDING ADVANCES

2.1 Advanced Energy Storage

Energy storage supports renewable power systems by balancing variable generation and ensuring grid stability. Studies by the International Renewable Energy Agency (IRENA, 2024) show that battery costs have dropped sharply, improving access for both grid and off-grid applications. Tarascon and Armand (2001) emphasize that lithium-ion chemistry remains dominant because of its high energy density, though concerns about material supply and end-of-life recycling persist. Oyewo, Aghahosseini, and Breyer (2022) highlight storage as critical to Africa's renewable expansion.

Evolution, Diffusion, and Uptake

Storage technologies have evolved from large hydro and thermal systems to advanced batteries and hybrid storage. Adoption in Africa is growing through solar mini-grids in Kenya, Nigeria, and South Africa. Global markets continue to expand due to electric mobility and industrial decarbonization. Africa still imports most systems, even though it holds lithium and graphite reserves and has not yet developed large-scale gigafactories.

Findings and Gaps

Storage improves reliability and supports economic growth but remains expensive in many African settings. The main limitations are high capital cost, limited local manufacturing, and short system life due to harsh environmental conditions. Many lithium-ion systems deliver 3,000 to 5,000 cycles, while flow batteries can exceed 10,000. Longer cycle life lowers total ownership cost, yet maintenance practices and temperature control remain weak.

Recommendations

Governments should support regional cell manufacturing, enforce recycling standards, and fund research on thermal, and flow storage suited to local climates. Training technicians to manage and maintain these systems will improve performance and durability.

2.2 Quantum Computing

Quantum computing uses qubits to process data in ways that classical systems cannot (Arute et al., 2019). Preskill (2021) describe it as a developing field with strong potential for optimization, encryption, and material design.

Evolution, Diffusion, and Uptake

Global investment has accelerated. Google and IBM have built prototypes that perform specific calculations faster than supercomputers. Africa's role is early stage. Rwanda's Quantum Leap Africa initiative trains researchers in quantum algorithms. Cloud-based access now allows African scientists to experiment without owning quantum hardware.

Findings and Gaps



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Quantum computing is powerful but unstable. Qubit coherence times remain short, often in microseconds, limiting system reliability (Google Quantum AI & Collaborators, 2025). Costs are high, and environmental requirements are extreme. For Africa, the challenge is more concentrated on readiness, given that few institutions have the capacity to engage beyond training activities.

Recommendations

Governments and universities should prioritize software, simulation, and cryptography research instead of focusing on hardware. Collaboration with global quantum technology centres will help African researchers build knowledge before hardware becomes affordable.

2.3 3D Printing

3D printing, also called additive manufacturing, fabricates parts layer by layer from digital designs (Gibson, Rosen, & Stucker, 2021). Studies highlight its material efficiency, reduced waste, and flexibility for custom products (Ford & Despeisse, 2016).

Evolution, Diffusion, and Uptake

Global use has moved from prototyping to mass production. In Africa, uptake is visible in healthcare, and micro scale manufacturing. A few use cases have been reviewed, Prothea, a company in Kenya, uses 3D scanning and printing to produce prosthetic legs at significantly lower cost (Prothea Kenya, 2025). The University of Johannesburg in South Africa used a 3D printer to complete South Africa's first 3D printed building (CyBe Construction, 2025).

Findings and Gaps

Additive manufacturing improves material efficiency because it uses only the quantity of material required to form the part, unlike subtractive methods that remove excess material. This efficiency shortens supply chains and reduces environmental impact, although high equipment and material costs still limit wider use. Research shows that metal additive-manufactured parts may approach the durability of conventionally machined metal components, provided post-processing and quality control are rigorous (Yi et al., 2023). In contrast, polymer-based 3D-printed parts face greater risks of thermal distortion, low crystallinity, and build-orientation weaknesses which are based on the material's thermal history (Lee et al., 2021). Furthermore, Africa lacks supply chains for filaments and metals, and power stability limits continuous operation.

Recommendations

Develop training centres and shared fabrication labs. Support local material production and open-source design networks. Introduce safety and quality standards for construction and medical applications.

2.4 Edge Computing

Edge computing processes data near its source instead of relying on distant cloud centres. It improves latency and reduces bandwidth use (Shi, Cao, Zhang, Li, & Xu, 2016). Mahmud, Kotagiri, and Buyya (2018) view it as vital for sustainable digital infrastructure.



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Evolution, Diffusion, and Uptake

Mobile devices and IoT systems are prompting local edge infrastructure deployments in Africa. For example, AWS and Orange are introducing Wavelength zones in Morocco and Senegal to provide low-latency compute and storage services locally (AWS, 2024; Reuters, 2024)

Findings and Gaps

Edge systems lower latency and energy use when properly designed, but they face high setup costs and cybersecurity risks. Hardware in Africa often fails due to heat, dust, and poor power quality. Skills shortages and data governance gaps persist.

Recommendations

Encourage renewable-powered micro data centres, update data protection laws, and build local capacity for edge maintenance and software deployment.

2.5 Space Exploration

Space exploration once depended on large national programs but now includes private and regional players. Pelton (2021) and OECD (2022) describe this shift as the rise of the commercial “New Space” sector.

Evolution, Diffusion, and Uptake

Launch costs to low-Earth orbit have fallen from roughly US\$18,000 per kilogram in the late twentieth-century era to as low as US\$2,000–US\$3,000 per kilogram for recent reusable-launch vehicles. Jones, H. W. (2017). Africa participates through the African Union’s Space Strategy (2023) and national satellite programs in Nigeria, South Africa, and Egypt.

Findings and Gaps

Space activity supports environmental monitoring, navigation, and communication. African programs rely heavily on foreign launch services and imported components. Lack of manufacturing and private investment limits growth. Debris management and satellite lifespan remain global concerns.

Recommendations

Build regional cooperation for satellite data sharing, support small satellite assembly and testing within Africa, and promote clean propulsion research. Invest in education and local fabrication for long-term autonomy.

3. CONCLUDING REMARKS

These technologies are redefining global production, communication, and innovation systems. Each contributes to sustainability, efficiency, and inclusiveness when embedded within coherent development strategies. For Africa, they represent viable pathways toward industrialization, technological sovereignty, and improved social outcomes. Yet adoption remains fragmented and often externally directed, reflecting structural dependence on imported expertise and infrastructure. The continent’s progress will depend on how effectively governments, private actors, and academic institutions coordinate investment in education, research, and regional infrastructure. With abundant resources, a youthful workforce, and expanding digital capacity,



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Africa possesses the fundamentals for leadership in renewable energy, advanced manufacturing, data systems, and space applications. Sustained policy consistency, institutional collaboration, and a focus on context-appropriate innovation will determine whether these opportunities translate into long-term competitiveness and self-reliant growth.

4. OUTLOOK

Future work must focus on integration. Advanced storage can stabilize renewable grids that power edge systems and data centers. Quantum computing will enhance material discovery and optimization across sectors. 3D printing can localize production of components for energy and space applications. Edge computing will support automation and artificial intelligence. Space technology will link these systems globally. Africa's development strategy should connect these fields through cross-sector research, joint industrial programs, and sustainable investment frameworks. Building local capacity, protecting the environment, and ensuring equitable access will define the next phase of technological evolution.

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