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Emerging Trends in Natural Language Processing and Related Technologies – Diffusion, Acceptance and Uptake

Ibe Chukwudi

Graduate Programme in Artificial Intelligence
Africa Centre Of Excellence on Technology Enhanced Learning (ACETEL)
National Open University of Nigeria, Abuja, Nigeria
E-mail: chukwudi.ibe@yahoo.com
Phone: +2347032518862

ABSTRACT

This paper examines five emerging technologies – voice assistants and natural language processing, robotics and automation, autonomous vehicles, renewable energy, and blockchain technology—analyzing their evolution, diffusion, acceptance, and uptake in Africa compared to global trends. The study explores technology adoption frameworks, identifies critical gaps and opportunities, and provides actionable recommendations for policy, research, and practice. Findings reveal significant disparities between Africa and developed regions, including infrastructure deficits (43% electricity access, 37% internet penetration), economic constraints (solar costs 3-7x higher), and capacity limitations. However, the analysis highlights unique opportunities for leapfrogging traditional infrastructure, particularly in renewable energy and mobile-based financial services. The paper concludes with strategic directions emphasizing inclusive innovation, linguistic diversity, appropriate technology design, and sustainable development pathways for African contexts.

Keywords: Emerging Technologies, Africa, Artificial Intelligence, Edge Computing, Energy, Cyber Security, Networks, Policies, Research, IoT

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1. INTRODUCTION

Emerging technologies are fundamentally reshaping global economies and societies. Technologies including voice assistants powered by natural language processing (NLP), robotics and automation, autonomous vehicles, renewable energy systems, and blockchain demonstrate transformative potential across sectors. While adoption trajectories in developed nations are well-documented, Africa's technology landscape presents distinct

challenges and opportunities characterized by infrastructure constraints, economic limitations, yet remarkable innovation through leapfrogging traditional development stages.

This paper analyzes the evolution, diffusion, and uptake of five key technologies, examining global progress alongside African-specific manifestations. The study identifies persistent technology gaps—including the digital divide affecting 600 million Africans without electricity access and limited internet connectivity at 37% penetration—while illuminating leapfrogging instances where African nations bypass intermediate stages to adopt advanced solutions directly. Through established adoption frameworks, this research provides evidence-based recommendations for harnessing these technologies toward inclusive and sustainable African development.

2. VOICE ASSISTANTS AND NATURAL LANGUAGE PROCESSING

Voice assistants powered by NLP have evolved rapidly since Siri's 2011 introduction, with over 4 billion devices globally by 2024. These technologies enable machines to understand, interpret, and respond to human speech through machine learning algorithms. In developed markets, voice assistants integrate seamlessly into smart homes, vehicles, and mobile devices [2]. African diffusion faces substantial barriers. Most NLP systems optimize for English, Spanish, and Mandarin, offering limited support for African languages like Swahili, Yoruba, or Hausa, creating a digital linguistic divide [3]. However, mobile phone penetration exceeding 80% in many African countries, combined with emerging efforts by Google to incorporate African languages and local startups developing region-specific NLP solutions, provides foundation for adoption.

- **Applications and Usefulness:** Voice technology offers significant potential for populations with low literacy rates or visual impairments. Healthcare applications facilitate patient-provider communication and medical record management. Educational implementations support language learning and information access. Small businesses can streamline customer service and transaction processing through voice interfaces.
- **Critical Limitations:** Language support remains the primary barrier, with inadequate African language representation in training datasets. Internet connectivity constraints limit cloud-based functionality. Cultural nuances and dialectal variations compound challenges. Privacy frameworks inadequately address voice data collection concerns. Hardware requirements limit accessibility for lower-income populations.
- **Recommendations:** Governments should prioritize indigenous language technology within national AI strategies, following Nigeria's model of collaborating with academia and private sector to build multilingual models in five local languages [4]. Policies should mandate African language support in public services and major platforms. Research must focus on comprehensive datasets addressing dialectal variation, code-switching, and domain-specific language use, leveraging transfer learning and low-resource NLP techniques. Technology companies should prioritize African language support, with startups like Botlhale AI demonstrating viable business models. Community-driven data collection engaging native speakers can accelerate dataset expansion while creating employment.



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3. ROBOTICS, AUTOMATION

Robotics technologies have transformed global manufacturing, healthcare, agriculture, and services, with AI-powered sophisticated systems accelerating productivity. The COVID-19 pandemic further accelerated automation adoption [5]. Africa's engagement remains nascent but growing, with South Africa leading in industrial robot adoption for automotive and mining sectors. Rwanda and Kenya experiment with drones for medical supply delivery, demonstrating context-appropriate innovations.

- **Applications:** Agricultural robots could enhance productivity and reduce post-harvest losses addressing food security. Healthcare robotics support surgical procedures and remote area supply delivery. Mining and manufacturing benefit from efficiency gains. Service robots address specific labor shortages.
- **Barriers:** High initial investment costs create significant barriers for small and medium enterprises dominating African economies. Limited maintenance expertise reduces sustainability. Electricity reliability constrains deployment. Most critically, automation raises employment concerns where job creation is paramount and informal labor predominates. Import dependency creates foreign exchange pressures and limits local innovation ecosystems.
- **Strategic Direction:** Africa's robotics future likely emphasizes selective automation targeting specific bottlenecks rather than wholesale manufacturing automation. Agricultural robots addressing labor-intensive tasks like weeding or harvesting can enhance food security without massive displacement. Drone technology for medical delivery will likely expand beyond Rwanda and Ghana implementations. Future automation should emphasize appropriate technology principles—solutions designed for African contexts rather than

4. AUTONOMOUS VEHICLES

Autonomous vehicle technology has progressed from science fiction to real-world testing, with companies like Tesla, Waymo, and Cruise investing billions. In Africa, adoption faces substantial obstacles including poor road infrastructure, inconsistent traffic regulations, and informal transportation systems prevalence. However, pilot programs emerge in South Africa, with discussions in Lagos and Nairobi around automated public transportation. Potential Benefits: Autonomous vehicles could dramatically improve road safety in Africa, where traffic accidents cause significant mortality and economic losses. Automated public transportation could enhance urban mobility efficiency. Optimized routing reduces fuel consumption and emissions.

- **Critical Challenges:** Infrastructure deficits represent primary barriers—poor roads, inadequate signage, unpredictable traffic patterns challenge autonomous sensors and algorithms. Systems trained on developed country data show limited African applicability. Mixed traffic environments including pedestrians, cyclists, animals, and informal vehicles create complexity current systems struggle to navigate. Regulatory frameworks are largely absent. High costs exceed most consumer and government reach.
- **Recommendations:** Governments should develop comprehensive regulatory frameworks anticipating rather than reacting to technology deployment. Research should focus on adaptations for African road conditions, developing systems navigating unpaved roads, interpreting inconsistent markings, and responding to mixed traffic. Industry should emphasize semi-autonomous features (Level 2/2+ automation) providing immediate safety value—adaptive cruise control, lane-keeping assistance, automated braking—rather than pursuing full autonomy near-term.



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5. RENEWABLE ENERGY

Renewable energy technologies—solar, wind, hydro, geothermal—have experienced exponential global growth as climate concerns intensify. Solar photovoltaic costs declined over 90% since 2010, making renewables increasingly competitive with fossil fuels [8]. Africa presents a paradox: abundant renewable resources yet severe energy poverty affecting approximately 600 million people lacking electricity access. However, adoption accelerates across the continent. East Africa leads in geothermal energy, with Kenya generating over 40% electricity from geothermal sources. Solar home systems and mini-grids proliferate in rural areas, enabling communities to bypass traditional grid infrastructure. Morocco invests heavily in large-scale solar projects.

Decentralized renewable energy aligns well with Africa's dispersed population patterns, offering leapfrogging opportunities.

- **Transformative Potential:** Renewable energy addresses Africa's most pressing developmental challenge: energy access. Solar home systems provide off-grid community electricity enabling evening study, small business operation, and improved quality of life. Mini-grids support community-level economic activities. Large-scale projects reduce fossil fuel import dependence, improving energy security and reducing emissions. Renewable energy creates local installation and maintenance employment.
- **Persistent Challenges:** Despite declining costs, initial investment requirements challenge poor households and communities. Battery storage addressing solar and wind intermittency remains expensive. Technical capacity for installation, maintenance, and repair is insufficient. Financing mechanisms are underdeveloped with limited affordable credit access. Grid integration challenges arise where renewable sources connect to existing infrastructure. Quality control issues undermine market credibility. Policy and regulatory frameworks often favor traditional energy sources.
- **Future Directions:** Renewable energy represents Africa's most immediately transformative emerging technology. Future directions include continued cost reductions, improved storage technologies, and smart grid development. Decentralized systems will proliferate, supported by innovative financing including pay-as-you-go models and community ownership structures. AI integration can optimize generation, distribution, and consumption. Blockchain-enabled peer-to-peer energy trading could empower communities to sell excess generation. Electric vehicle adoption powered by renewable electricity could transform transportation. Green hydrogen production presents industrial development and energy export opportunities.
- **Strategic Recommendations:** Governments should adopt comprehensive renewable energy strategies with clear targets, timelines, and implementation mechanisms, following Senegal's proactive solar and wind policies and Ethiopia's hydroelectric focus. Technical research should optimize technologies for African conditions— solar panels accounting for dust, extreme temperatures, humidity. Energy storage research is critical for managing intermittency. Project developers should prioritize community engagement and benefit sharing through consultation, transparent communication, local employment, and revenue sharing. Companies should leverage mobile money integration for payment collection, following M-KOPA's success serving 5 million customers through digital micropayments [10].

6. BLOCKCHAIN TECHNOLOGY

Blockchain technology, emerging with Bitcoin in 2009, has evolved beyond cryptocurrency to encompass supply chain management, healthcare, finance, and governance applications. The distributed ledger system offers transparency, security, and decentralization. In Africa, adoption gains momentum particularly in financial services, with mobile money systems like M-Pesa preparing populations for digital financial innovation. Several African countries explore central bank digital currencies. Blockchain pilots for land registry systems in Ghana and Rwanda address longstanding property rights challenges.

- **Applications and Opportunities:** Blockchain offers solutions to several African challenges. In land administration, immutable records could reduce disputes and corruption. Financial inclusion advances through blockchain-enabled remittances and microfinance. Supply chain transparency combats fraud in agriculture and mineral exports, potentially increasing export revenues. Digital identity systems could extend formal identification to marginalized populations. Smart contracts reduce transaction costs and enhance business trust.
- **Technology Gaps:** Technical complexity limits understanding among users and policymakers. Energy consumption, particularly for proof-of-work systems, conflicts with energy scarcity. Regulatory uncertainty creates risks for businesses and investors. Limited internet connectivity constrains applications requiring consistent network access. Interoperability between different blockchain systems remains challenging. Scalability affects transaction processing speeds. Association with cryptocurrency volatility and illicit activities creates skepticism.
- **Strategic Recommendations:** African governments should develop pan-African blockchain strategies aligned with the African Union's digital strategy. Regional harmonization facilitates cross-border applications and reduces fragmentation. Regulatory frameworks should balance innovation enablement with consumer protection, following Mauritius and Kenya's regulatory sandbox approaches. Nigeria's National Blockchain Policy provides comprehensive framework addressing opportunities, challenges, and governance. Research should identify high-impact use cases for African development contexts, evaluating effectiveness in land registration, agricultural supply chains, financial inclusion, identity management, and healthcare records. Blockchain developers should focus on solving real problems—financial exclusion, supply chain opacity, land tenure insecurity—where blockchain offers clear advantages over alternatives.

7. CROSS-CUTTING CHALLENGES AND CONCLUSION

The analysis of these five technologies reveals interconnected challenges constraining African adoption. Infrastructure deficits emerge as cross-cutting constraints: only 43% of Africans have reliable electricity access, less than 1% of global data center capacity exists in Africa despite 18% of world population, and internet penetration reaches just 37%. These gaps affect all technology domains from voice assistants requiring connectivity to renewable energy systems needing grid infrastructure.

The digital divide manifests in access and capacity—skills gaps, limited digital literacy, and insufficient technical expertise constrain adoption. Educational systems remain underdeveloped relative to technical demands, perpetuating capacity deficits. Economic constraints compound challenges: hardware, software, data, and connectivity costs make technologies prohibitively expensive.



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Capital costs for solar are 3-7 times higher in Africa than developed countries, smartphones cost up to 95% of monthly income for the poorest 20%, and fixed broadband averages 14.8% of GNI compared to ITU's 2% benchmark. Regulatory frameworks lag technological developments. Absence of clear legal and policy frameworks creates uncertainty inhibiting investment and innovation. While progress is evident—Nigeria's National Blockchain Policy, South Africa's autonomous vehicle planning, multiple countries' AI strategies—implementation often remains incomplete. Equity considerations are paramount. Without proactive interventions, technology adoption risks exacerbating urban-rural divides, income disparities, and gender gaps. Universal access requires deliberate efforts ensuring affordability, geographic reach beyond urban centers, linguistic inclusion, and capacity building for marginalized populations.

Despite challenges, Africa demonstrates remarkable innovation potential through leapfrogging, particularly in mobile money, decentralized renewable energy, and context-appropriate drone applications. Success requires coordinated efforts across policy, research, and practice domains, emphasizing inclusive innovation, sustainable development, and solutions designed specifically for African contexts rather than wholesale technology imports from developed economies.

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