

Research Article

Adaptive Artificial Intelligence Models for Enhancing Digital Inclusion and Sustainable Development in Underserved Communities

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Abstract

Technology is playing a vital role across various sectors like education, healthcare, agriculture, financial services, employment, governance, and social development. However, we still see significant digital inequalities, especially in underserved communities, particularly in rural and low-income areas. Here, challenges such as limited connectivity, high technology costs, lack of digital skills, language barriers, and inaccessible digital services hinder meaningful participation in the digital economy. This conceptual paper delves into how adaptive Artificial Intelligence (AI) models can boost digital inclusion and support sustainable development in these communities. It brings together insights from literature on artificial intelligence, digital inclusion, adaptive learning, responsible AI, and sustainable development. The paper introduces the Adaptive AI Digital Inclusion and Sustainable Development (AIDISD) framework, which is built around five key dimensions: accessibility, personalization, contextual adaptation, resource efficiency, and community empowerment. It explores potential applications in education, healthcare, agriculture, financial inclusion, employment, and public services. Additionally, the paper highlights challenges related to infrastructure, data scarcity, algorithmic bias, privacy, cybersecurity, affordability, digital literacy, and institutional capacity. The analysis emphasizes that adaptive AI should be viewed as part of a larger socio-technical strategy rather than just a standalone tech solution. For inclusive deployment, we need local participation, suitable infrastructure, responsible data governance, human oversight, and ongoing evaluation. Ultimately, the paper concludes that well-designed adaptive AI systems can foster more inclusive and sustainable digital ecosystems, provided they are affordable, locally relevant, accessible, transparent, and aligned with the Sustainable Development Goals.

Keywords

Adaptive Artificial Intelligence, Digital Inclusion, Digital Divide, Sustainable Development, Underserved Communities, Responsible AI, Digital Transformation, Sustainable Development Goals

1. Introduction

The rapid expansion of digital technologies has transformed how individuals, organisations, governments, and communities access information and participate in economic and social

activities. Digital connectivity increasingly influences access to education, healthcare, employment, financial services, markets, government services, and opportunities for innovation

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Received: 21 September 2026; **Accepted:** 8 October 2026; **Published:** 29 October 2026



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[2]. However, access to digital technologies remains highly unequal. The contemporary digital divide is not limited to whether an individual has an internet connection or a digital device; it also includes differences in affordability, quality of connectivity, digital skills, accessibility, relevant content, and the capacity to derive meaningful benefits from digital technologies [4].

The International Telecommunication Union estimates that 5.5 billion people were online in 2024, while approximately 2.6 billion remained offline. Internet use was substantially lower in low-income countries than in high-income countries, and the urban-rural divide remained significant. Globally, approximately 83% of urban residents used the Internet compared with 48% of rural residents [5]. These figures demonstrate that universal and meaningful connectivity remains an important development challenge.

Artificial Intelligence (AI) has emerged as a major technological development with applications across education, healthcare, agriculture, finance, employment, and public administration. Machine learning, natural language processing, computer vision, recommender systems, and generative AI can process information, identify patterns, generate content, and support decision-making. However, AI is not inherently inclusive. Systems trained on data that inadequately represent rural populations, marginalised languages, or low-income contexts may produce biased or irrelevant outputs [3].

Adaptive AI offers a potentially important response to this challenge. In this paper, adaptive AI refers to AI systems capable of modifying their outputs, interfaces, recommendations, or resource requirements in response to users, contexts, environments, or changing data. This capacity is particularly relevant to underserved communities because their technological conditions and needs may differ substantially from those assumed in conventional digital systems [6].

1.1. Problem Statement

Despite substantial progress in digital connectivity, many underserved communities continue to experience multiple forms of digital exclusion. Limited infrastructure, high costs, inadequate digital literacy, language barriers, disability-related accessibility constraints, and limited locally relevant digital content can prevent individuals from converting access to technology into meaningful social and economic benefits. At the same time, AI systems can introduce additional inequalities when training data inadequately represent marginalised populations. There is therefore a need to investigate how adaptive AI can be designed to respond to diverse user circumstances while contributing to inclusive and sustainable development.

1.2. Objective of the Study

The main objective of this paper is to examine how adaptive Artificial Intelligence models can contribute to digital inclusion and sustainable development in underserved communities.

The specific objectives are to:

- 1) Examine the relationship between adaptive AI and digital inclusion.
- 2) Identify potential applications of adaptive AI in underserved communities.
- 3) Analyse the contribution of adaptive AI to selected Sustainable Development Goals.
- 4) Identify technological, socioeconomic, ethical, and institutional barriers to implementation.
- 5) Propose a conceptual framework for deploying adaptive AI in an inclusive and sustainable manner.

1.3. Research Questions

- 1) How can adaptive AI models enhance digital inclusion in underserved communities?
- 2) Which sectors can benefit from adaptive AI applications?
- 3) How can adaptive AI contribute to sustainable development?
- 4) What challenges may limit the deployment of adaptive AI in underserved communities?
- 5) What principles should guide the development of inclusive and sustainable adaptive AI systems?

2. Literature Review

2.1. Digital Inclusion and the Digital Divide

Digital inclusion extends beyond physical access to devices and internet connectivity. It includes the affordability, quality, usability, accessibility, skills, confidence, and relevance required for individuals to participate meaningfully in digital society. The International Telecommunication Union demonstrates that substantial inequalities remain across income groups and between urban and rural populations [5]. The World Bank similarly argues that digital technologies can generate development benefits, but that these benefits depend on complementary factors such as skills, accountable institutions, and an enabling business environment [1].

The distinction between connectivity and meaningful participation is particularly important. A person may own a smartphone and still remain digitally excluded if internet services are unaffordable, content is unavailable in a familiar language, digital platforms are too complex, or the individual lacks the skills required to use them effectively.

2.2. Artificial Intelligence and Digital Transformation

AI is increasingly embedded in digital systems used for information retrieval, prediction, recommendation, automation, and decision support. These capabilities can increase the scale and personalisation of digital services. However, the benefits

of AI are strongly dependent on the quality and representativeness of data, computational infrastructure, institutional capacity, and governance. UNESCO emphasises that AI should be developed and deployed in ways that protect human dignity and rights and promote fairness, transparency, inclusiveness, human oversight, and environmental sustainability [8].

2.3. Adaptive Artificial Intelligence

Adaptive AI can be conceptualised as a class of AI systems that adjust their behaviour or outputs in response to changes in users, contexts, environments, or data. Adaptation may occur at the individual, community, environmental, or resource level. For example, an adaptive learning system can change content difficulty according to learner performance; a voice-based public service can adjust language and interaction complexity; and an agricultural decision-support system can incorporate local soil, weather, crop, and resource conditions.

3. Adaptive AI for Digital Inclusion

3.1. Personalised and Adaptive Learning

Adaptive learning systems can analyse learner interactions and modify content, sequence, difficulty, and feedback. In underserved settings, these systems may support learners with different levels of prior knowledge and digital literacy. Low-bandwidth delivery, local-language content, voice interfaces, and offline functionality can further improve accessibility.

3.2. Language and Communication Inclusion

Language remains a major barrier to digital participation. AI-based natural language processing can support translation, speech recognition, text-to-speech, conversational interfaces, and locally relevant content. Greater representation of low-resource languages in AI datasets and evaluation processes is therefore important for inclusive digital transformation.

3.3. Accessibility and Disability Inclusion

AI can support people with disabilities through speech recognition, automatic transcription, text-to-speech, image description, voice interfaces, and simplified interaction. These applications should be developed through inclusive design and evaluated with people who have diverse accessibility requirements [10].

4. Applications in Underserved Communities

4.1. Healthcare

Adaptive AI can support health information services, de-

cision-support tools, appointment systems, remote consultation, and health education. Systems can adjust information complexity and communication modes to users' needs. Because health applications are high-impact, clinical governance, human oversight, privacy, and validation are essential [12].

4.2. Agriculture

Agricultural AI can integrate soil characteristics, weather information, crop type, pest and disease observations, farm conditions, and farmer-provided information to produce context-specific recommendations. Such systems may support more efficient resource use and climate adaptation.

4.3. Financial Inclusion

Adaptive digital financial systems can provide personalised financial education, navigation assistance, and information about available services. However, automated financial decision-making can produce unfair outcomes when data are incomplete or biased; transparency and appropriate human review are therefore important.

4.4. Employment and Entrepreneurship

AI can support skills development, employment information, entrepreneurship education, market information, and digital business services. The usefulness of these applications depends on whether recommendations reflect local economic conditions.

4.5. Public Services

Conversational AI, voice interfaces, local-language systems, and simplified digital forms can make public services more accessible. Public-sector AI should be subject to strong transparency, privacy, accountability, and equal-treatment safeguards.

5. Adaptive AI and Sustainable Development

The United Nations 2030 Agenda identifies 17 Sustainable Development Goals (SDGs) addressing poverty, inequality, health, education, economic development, infrastructure, climate action, and other global priorities [7]. Adaptive AI can potentially support several of these goals when deployed responsibly.

SDG 1 – No Poverty: AI-enabled agricultural advice, entrepreneurship support, employment information, and financial services may expand economic opportunities.

SDG 2 – Zero Hunger: Adaptive agricultural systems can support crop planning, soil management, irrigation, pest monitoring, and climate adaptation.

SDG 3 – Good Health and Well-being: AI-supported health information and decision-support tools can extend access to information and assist health workers [11].

SDG 4 – Quality Education: Adaptive learning systems can personalise education and extend learning support where teaching resources are limited.

SDG 8 – Decent Work and Economic Growth: AI-enabled skills development, employment services, and productivity tools may support economic participation.

SDG 9 – Industry, Innovation and Infrastructure: Inclusive AI development can contribute to innovation and digital infrastructure when underserved areas are included.

SDG 10 – Reduced Inequalities: Adaptive interfaces, local-language services, and accessibility features can reduce selected barriers to digital participation.

SDG 13 – Climate Action: AI can support climate monitoring, agricultural adaptation, environmental management, and resource optimisation.

6. Proposed Adaptive AI Digital Inclusion and Sustainable Development Framework

This paper proposes the Adaptive AI Digital Inclusion and Sustainable Development (AIDISD) framework. The framework places community context at the beginning of the AI lifecycle and treats ethics, governance, privacy, security, accessibility, and human oversight as cross-cutting requirements.

Layer 1: Community Context

Socioeconomic conditions, language, digital literacy, culture, infrastructure, environmental conditions, accessibility requirements, and community priorities.

Layer 2: Data and Knowledge

Local datasets, user-generated information, environmental data, institutional data, expert knowledge, and relevant open datasets.

Layer 3: Adaptive AI Engine

Personalisation, contextual adaptation, language adaptation, resource adaptation, and continuous feedback.

Layer 4: Inclusive Digital Services

Education, healthcare, agriculture, finance, employment, and public services.

Layer 5: Sustainable Development Outcomes

Improved digital participation, service access, productivity, economic opportunities, resource efficiency, resilience, and progress toward relevant SDGs.

Conceptual pathway: Community Context → Data and Knowledge → Adaptive AI Engine → Inclusive Digital Services → Sustainable Development Outcomes.

Cross-cutting safeguards: Ethics → Governance → Privacy → Security → Accessibility → Human Oversight → Monitoring and Evaluation.

7. Challenges and Limitations

7.1. Infrastructure Constraints

Unreliable electricity, limited broadband, high data costs, and inadequate device availability can restrict the use of AI services. Lightweight models, offline functionality, and edge computing may be relevant responses.

7.2. Data Scarcity and Quality

Underserved populations are often underrepresented in datasets. Inadequate local data can reduce model accuracy and contextual relevance.

7.3. Algorithmic Bias

AI can reproduce or amplify patterns of inequality in training data. Testing across demographic, linguistic, geographic, and socioeconomic groups is therefore necessary.

7.4. Privacy and Data Protection

AI systems may process personal and community information. Responsible data collection, secure storage, controlled access, and compliance with applicable data protection requirements are essential.

7.5. Digital Literacy

Users need sufficient skills and confidence to interact with AI-enabled services. Digital literacy should therefore accompany technological deployment.

7.6. Affordability and Sustainability

The cost of devices, connectivity, computing, maintenance, and technical support may limit long-term adoption.

7.7. Community Participation

Systems designed without meaningful local participation may fail to address actual needs. Communities should participate in problem identification, design, testing, evaluation, and governance.

8. Discussion

The literature indicates that digital inclusion is a multidimensional challenge and that connectivity alone is insufficient. Adaptive AI offers a potential shift from a technology-centred model, in which users are expected to adapt to standardised systems, toward a user-centred model in which systems adjust to user and community circumstances.

This distinction is important in underserved settings. An educational platform that adapts learning difficulty, language, and delivery format may be more accessible than a standardised platform. Similarly, an agricultural system that integrates local soil and weather conditions can provide more contextually relevant support than a generic recommendation service.

Nevertheless, adaptive AI should not be treated as a standalone solution to poverty or inequality. Digital exclusion is connected to infrastructure, education, affordability, institutional capacity, and social inequality. The World Bank notes that the benefits of digital technologies depend on complementary factors and enabling institutions [9]. Consequently, adaptive AI should be implemented as part of a wider digital inclusion strategy.

9. Policy and Practical Implications

Governments

Invest in broadband, reliable electricity, digital public infrastructure, digital literacy, open and responsible data practices, and AI governance.

Educational Institutions

Develop AI systems and research programmes that incorporate local languages, contextual datasets, inclusive design,

and community-based evaluation.

Technology Developers

Build affordable, low-bandwidth, accessible, explainable, and resource-efficient systems and evaluate performance across diverse populations.

Development Organisations

Integrate adaptive AI into programmes involving education, agriculture, healthcare, livelihoods, and social protection while maintaining human oversight.

Local Communities

Participate as co-designers, knowledge contributors, evaluators, and governance stakeholders rather than only as end users.

Researchers

Conduct empirical studies that test adaptive AI in underserved settings and report outcomes across relevant demographic, geographic, linguistic, and socioeconomic groups.

10. Proposed Research Model

The proposed model treats Adaptive AI Capability as the independent variable, Digital Inclusion as the primary outcome, and Sustainable Development Outcomes as a downstream outcome.

Table 1. Proposed Research Model: Constructs, Dimensions, and Illustrative Indicators.

Construct	Dimensions	Illustrative Indicators
Adaptive AI Capability	Personalisation; contextual adaptation; language adaptation; resource adaptation; accessibility adaptation	Relevant recommendations; adaptive interfaces; local-language support; low-bandwidth operation
Digital Inclusion	Access; affordability; usability; digital skills; meaningful participation	Device/connectivity access; cost; ease of use; confidence; frequency and quality of use
Trust and Responsible AI	Transparency; reliability; privacy; fairness; human oversight	Perceived transparency; data protection; confidence; ability to seek human review
Community Participation	Consultation; co-design; feedback; local knowledge	Participation in design/testing; feedback mechanisms; local data contribution
Sustainable Development Outcomes	Economic; social; educational; health; environmental outcomes	Income opportunities; learning access; service access; productivity; resource efficiency

11. Conclusion

Adaptive Artificial Intelligence presents significant opportunities for improving digital inclusion and supporting sustainable development in underserved communities. By adjusting outputs, interfaces, recommendations, and resource requirements to diverse user and community conditions, adaptive AI can address selected barriers associated with language, literacy, accessibility, affordability, and contextual relevance.

Potential applications span education, healthcare, agriculture, financial inclusion, employment, and public services. However, the benefits of adaptive AI are not automatic. Infrastructure constraints, data scarcity, algorithmic bias, privacy risks, affordability, digital literacy gaps, and weak institutional capacity can limit impact.

The proposed AIDISD framework therefore positions adaptive AI within a broader socio-technical system in which community participation, responsible governance, human oversight, inclusive infrastructure, and continuous evaluation are

central. Future empirical research should test the framework in specific underserved communities and compare outcomes across different sectors and socioeconomic contexts.

Abbreviations

AI	Artificial Intelligence
AIDISD	Adaptive AI Digital Inclusion and Sustainable Development
ITU	International Telecommunication Union
OECD	Organisation for Economic Co-operation and Development
SDG	Sustainable Development Goal
UNESCO	United Nations Educational, Scientific and Cultural Organization
WHO	World Health Organization

Author Contributions

Joel Sadiki Charo: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Methodology, Project administration, Data curation

Conflicts of Interest

The authors declare no conflicts of interest.

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