A Conceptual Framework for Integrating AI, IoT, and Blockchain to Accelerate Zimbabwe's Sustainable Development: An ICT4D Perspective

Caleb Manjeese
Mathematics and Computer Science
Great Zimbabwe Universiity
Masvingo, Zimbabwe

cmanjeese@gzu.ac.zw
https://orcid.org/0000-0003-0338-7063

Abstract— **Information and Communication Technology for Development (ICT4D) is the use of technology with a developmental agenda, especially in the underserved regions and has been instrumental in sustainable development. Combined with Artificial Intelligence (AI), the Internet of Things (IoT), and Blockchain (BC), there has been a new dimension to sustainable development as new prospects are presented by the three technologies in synergy. AI has the capability to provide technicians with new ways of solving challenges efficiently. Industries like health, education and agriculture can be revolutionized as tailor made solutions boost decision making and productivity. IoT can guarantee smooth data exchange, real time monitoring and automation thereby increasing productivity and saving costs. BC is a technology that guarantees transparency, accountability and trust during transacting digitally thus making it ideal for use in governance, finance and supply chain management. A qualitative approach was used to gather opinions from a sample of ICT4D practitioners and stakeholders to gauge the perceived impact of AI, IoT, and Blockchain on sustainable development and to explore possible opportunities available with the combined technologies. In-depth interviews were conducted with experts in the field to gather detailed insights on the success factors for AI, IoT and BC, what considerations in designing a framework, and framework suitability to the integration of the three technologies. The results indicated that AI, IoT, and Blockchain have the potential to positively impact sustainable development in various aspects, including increased efficiency, improved decision-making, and enhanced innovation. For the integration framework to bring positive results, it needs to consider ICT4D and sustainable development components such as local context, capacity building, and green technology.**

Keywords- Sustainable development, Artificial intelligence, Blockchain, Internet of Things

I. BACKGROUND AND INTRODUCTION

The fourth industrial revolution (4IR) technologies have been given great attention recently in solving existing challenges. AI, IoT and BC have changed how various industries conduct their operations. Individually the technologies have power, but if operated in synergy they have great potential to outperform the power of the three operated individually. If used in sustainable development (SD) the technologies promise great achievements [1].

Blockchain is a technology that guarantees the reliability of data and trust of transaction in a multi-user environment. IoT is all the connected devices that generate continuous streams of data. The volumes of data act as a wealth of information that can be analyzed by AI to produce meaningful patterns that can be insightful to decision makers [2]. The technologies used in combination have great potential for meaningful outcomes that ca change various industries operate. To give a perspective of how these technologies can be combined together, BC is useful for providing a foundation for immutable data and security for IoT devices and AI provides the critical analysis of the data. Thus the use of blockchain can increase accountability and transparency in the use of AI. The large volumes of data that has been generated and not used for meaningful purposes can now be used as the process of using the data can be simplified [3].

The BC technology's advantage is it provides decentralized data storage and management thus reducing disadvantage of single points of failure or attack. This is useful for safeguarding data integrity and having a reliable base for AI analysis. The large amounts of data produced by IoT can both be a blessing or a curse bringing both challenges and opportunities. AI can analyze the data to discover anomalies, reveal trends or show areas of improvement within the IoT ecosystem. Blockchain could be used to provide decentralized access to AI models, this spreading data across several points rather than relying on a single point. This can improve security and privacy as people do not have to share their data across the networks. This is a great way of encouraging collaboration where contributors can build on shared data and models [2].

Fusing AI, BC and IoT can change the way of technology interactions making them smooth, personalized and anchored in trust as BC will help in trail verification thus removing misinformation. AI can be used to understand user preferences and behaviors whilst at the same time it is protecting the privacy of users and enhancing their experiences. The transparency brought by BC can bring confidence to AI driven decisions and recommendations [2].

According to Pandey and Joseph, [4], AI, blockchain, and IoT can advance sustainable development goals across various sectors. Sustainable development is a framework to growth that values meeting the current needs without risking the needs of future generations. It is a way of life that encourages prioritizing the needs of future lives in meeting current needs. For example, the three technologies can be applied in different sectors such as

- Resource Management: AI optimizes resource usage, while IoT monitors and controls resource consumption in real-time. Blockchain ensures transparent tracking of resources.
- Renewable Energy: Blockchain enables peer-to-peer energy trading, promoting renewable energy adoption. AI optimizes energy production and consumption.
- Supply Chain Transparency: Blockchain provides end-to-end tracking, ensuring accountability and transparency. AI analyzes supply chain data to identify inefficiencies.
- Sustainable Agriculture: AI-driven precision farming reduces waste and improves crop yields. Blockchain tracks products from farm to table.
- Smart Cities: AI and IoT optimize urban infrastructure, transportation, and services. Blockchain ensures secure data management.

Many ICT companies and organizations believe their sector can significantly contribute to achieving the SDGs. One example is Mats Granryd, the GSMA Director General, suggests that "Together, as an industry, we have the opportunity to drive positive change, empower communities and create a sustainable future by unlocking the power of connectivity and creating a better future for all." [5].

The use of high tech like IoT, AI, and Blockchain has the potential to push developing countries to greater heights and jump some of the normal growth stages. These technologies will bring new business models forcing organisations to be innovative as they adapt and evolve.

Information and Communication Technologies for Development (ICT4D) play a crucial role in advancing sustainable development, particularly in developing countries. ICT4D leverages technology to bridge the digital divide, enhance education, improve healthcare, support economic growth or foster environmental sustainability. Unlike mainstream ICTs, whose main goal is to create software for business purposes, ICT4D is about what should be done to support human and socio-economic development, and how to do it. Many authors contributed to the shaping of what ICT4D is today, and most of them addressed, directly or indirectly, the specific and inherent features and orientations that ICT4D projects and technologies need to fulfil [6].

There is need for an investigation of how AI, blockchain and IoT can be deployed in the context of ICT4D for sustainable development where the technologies are made available to underserved areas to achieve sustainable development. By linking ICT4D to sustainable development (SD), we can be able to harness technology to bring positive change and attain sustainable development goals. Examples of where ICT4D principles can be applied to AI, BC and IoT to support sustainable development includes: the use of chatbots by governments to respond to citizen requests and provide timely feedback 24/7, Prediction of natural disasters and calamities to save the general populace from destruction and save life and property and practicing of smart farming through machine learning (ML), such as predicting crop diseases and weather forecasting to increase farm productivity. These applications contribute to ICT4D as they bridge the digital divide as well as to sustainable development in communities. A practical example will be to create decentralized platform for farmers to share data, access AI-powered insights and receive incentives for sustainable practices. Despite all these opportunities there is less of application of the technologies and this study will propose a framework for their implementationthis document and are identified in italic type, within parentheses, following the example. Some components, such as multi-leveled equations, graphics, and tables are not prescribed, although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

A. Research Questions

1. How can AI, IoT, and blockchain technologies be integrated to address key sustainable development challenges in Zimbabwe?

2. What factors are critical for the implementation of integrated AI, IoT and BC solutions in Sustainable development and ICT4D in Zimbabwe?

3. How can AI, IoT, and blockchain integration framework improve sustainable development results in Zimbabwe?

B. Objectives

1. Propose integrated framework for AI, IoT and BC implementation to address sustainable development in Zimbabwe

2. Ascertain the key drivers and challenges for implementing integrated AI, IoT and BC in sustainable development in Zimbabwe

3. Appraise the proposed framework's chances of enhancing sustainable development results in Zimbabwe.

C. Significance

This research is important in understanding how AI, IoT and BC technologies impact the Zimbabwean landscape by exploring how integration of the technologies in sustainable development within an ICT4D context can accelerate development. These emerging tools have potential to revolutionize operations and development strategies and address national priorities such as agricultural production, healthcare service deliver, financial inclusion, climate change and mitigation, and governance and transparency. The study came up with a structured framework for leveraging emerging tools in solving real world problems. The study contributes to existing knowledge by producing a framework specific to the Zimbabwean context and helps to inform policy decisions through evidence-based research. The research is in alignment with the Zimbabwe's SDG goals, 4IR goals and would be valuable academically.

II. LITERATURE REVIEW

This section reviews existing studies theories and findings to guide the study.

A. What is Artificial Intelligence, Internet of Things and Block chain

Artificial Intelligence (AI) is the science of designing intelligent systems that can perform tasks that normally require human intelligence such as reasoning, learning, perception and problem solving. It solves problems by identifying patterns relationships. Precision agriculture, smart grids, climate modeling and sustainable supply chains

are examples of how AI can be used in sustainable development. Expected benefits include improved efficiency, enhanced decision, increased accuracy, and scalability [7].

The Internet of Things (IoT) is a network of interconnected devices and sensors and that gather and distribute data [8]. The network consists of devices, like sensors and smart gadgets, connected through the internet. These devices are always collecting and passing data around to other devices in the network, they react to situations depicted by the data and interact with other devises. Environmental monitoring, resource management, smart infrastructure, sustainable and precision agriculture, and optimized waste management are examples of IoT systems in use and the advantages they bring include improved efficiency, enhanced decision-making, increased productivity and improved public health [9], [10], [11].

Blockchain is a technology that relies on several computer science techniques such as data storage, networking encryption and consensus mechanisms to create a shared database. Consensus mechanisms are important for sharing data and maintaining its integrity through agreeing to the structure and work that can be performed no the data. Key characteristics include equal peers, transparency, tamper-resistance, secure communication, and multiparty consensus [10], [12]. Blockchain ensures transparency and fairness and it promote collaboration hence improved outcomes. [13], [14].

B. AI, IoT and BC in ICT4D and sustainable development

The Combination of AI, blockchain, and IoT can produce systems that are efficient and sustainable in areas like energy, agriculture, and supply chain management. They work by having IoT system collecting data, blockchain setting the rules and infrastructure, and AI optimizing the processes [15].

An example of how a financial institution can use AI and blockchain is to have AI powered contracts running on a blockchain platform to have automated agreements. AI monitors the conditions and will execute the contract when all requirements are met thus reducing intermediaries and saving on costs and time. This integration boosts transparency as all parties can verify the transaction on the platform, the outcome is faster processing by about 40% and 30% increase in client satisfaction. [16].

Chauhan, (2024) [8] says these technologies can address a variety of issues like conservation of resources, efficient energy use, waste management and environmental monitoring. AI-powered algorithms can optimize energy consumption, enhance resource management, and improve the efficiency of various systems. A blockchain provides a distributed system for data management thereby increasing transparency. Data becomes almost impossible to manipulate as altering records is made difficult [17].

Another example of where the technologies can be used is in supply chain management where the product route from source to consumer can be tracked and help customers make informed decisions, thereby reducing environmental impact [18]. For instance, food companies can use blockchain to share details about product origin, production, and transport, helping consumers make informed choices. Waste management can also incorporate the technologies to ensure proper disposal [19].

Blockchain can potentially be implemented in IoT scenarios like supply chain, wearables, smart cities, and homes. A Combination of AI and blockchain can enhance security of financial transactions and transparency, whilst AI is used for automating verification processes [20].

The summary of objectives of AI, Blockchain and IoT in sustainability according to [21] are listed as follows:

- Boost Energy Efficiency: Develop green tech to optimize energy use, reduce waste, and boost efficiency across sectors.
- Sustainable Resource Management: Use AI, blockchain, and IoT to enhance resource management, including water conservation, waste reduction, and sustainable agriculture.
- Monitor and Protect: Leverage tech to monitor air and water quality, conserve biodiversity, and manage ecosystems.
- Smart and Sustainable Cities: Use IoT, AI, and blockchain to create efficient transportation, grid management, and waste management systems.
- Sustainable Supply Chains: Implement blockchain to promote transparency and ethical practices in supply chains.
- Renewable Energy Transition: Accelerate adoption of renewables with AI-driven optimization and blockchain-enabled energy trading.
- Environmental Education: Integrate green tech into education to raise awareness and equip individuals for a sustainable future.
- Collaboration and Partnerships: Foster research, share best practices, and drive innovation in green tech and sustainability.
- Ethical Tech Development: Address ethics and data privacy, ensuring equitable access to green tech.
- Global SDGs Contribution: Align green tech efforts with UN SDGs to address global challenges.

The integration of AI and IoT in agriculture transforms farming into a more efficient, sustainable practice. Widespread adoption, however, has been hindered by expensive deployment and maintenance costs especially in regions with limited resource. To overcome these obstacles there is need to have cost-effective solutions, supportive policies, and knowledge sharing [8]. However it should be noted that each of these technologies has its own challenges such as the blockchain's security issues. Smart contracts can have vulnerabilities causing serious consequences thus they need continuous research to ensure privacy and security.

The design and implementation of these technologies have been witnessed in various industries and for them to be more useful there is need to have them incorporated from the grassroots which is the focus of ICT4D. In integrating AI, IoT and BC, the key ICT4D considerations for sustainable development include infrastructure readiness, digital literacy, policy alignment, inclusivity, and trust. The implementation of these technologies in agriculture, energy, healthcare, and governance in developing contexts like Zimbabwe should consider such factors [8], [22].

For the success of these technologies there is need to consider affordability and reliability of internet and electricity, as they are essential. Most of the rural populations lack basic infrastructure such as reliable internet and power supply. ICT4D interventions could be focused on investing in affordable connectivity infrastructure, and reliable but cheap power supply such as solar power.

The government is required to establish ICT4D policies to support innovation in AI, IoT and BC while guaranteeing data privacy and security. These policies should be aligned to national and international development priorities such as the UN SDGs [23], [24].

If AI, IoT and BC technologies are to be successful, there is also need for capacity building and digital literacy especially in rural areas, as ICT4D considers human capital development as central. All stakeholders need training to use AI, IoT, and blockchain tools. Failure to train the users there is a risk of exclusion and widening the digital divide and risk reducing the impact of these technologies. ICT4D calls for community empowerment, ensuring that technology adoption is participatory and inclusive [25], [26].

Inclusivity and Equity under ICT4D frameworks stress that technology must benefit marginalized groups (rural populations, women, youth). AI, IoT, and blockchain solutions should be localized i.e. they need to support local languages, cultural contexts, and affordability for them to have a meaningful impact. Equity ensures that sustainable development outcomes are shared broadly and not concentrated among elites [27]. The template is used to format your paper and style the text. All margins, column widths, line spaces, and text fonts are prescribed; please do not alter them. You may note peculiarities. For example, the head margin in this template measures proportionately more than is customary. This measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire proceedings, and not as an independent document. Please do not revise any of the current designations.

C. Frameworks for AI, Blockchain and IOT implementation

1) Block Chain Model

The most common framework is the Blockchain Maturity Model (BMM) which, as a structured framework is a set of guiding principles used to compare a proposed or instantiated blockchain solution against expected attributes or elements of a reliable solution. It helps with assessment of the product characteristics and the processes used to develop and maintain the solution. It can be applied to public, private or hybrid blockchain solutions and it is not specific to any vendor, domain, or industry. BMM can be used as a blueprint to help improve solutions by providers and demonstrate if they meet industry standards. Investors can use BMM to gauge the maturity and value of potential solutions. Acquisition professionals and customers can use it to judge solutions against common standards for fair and effective acquisitions [28].

According to Wang, Chen, and Xu, (2016) [29] the BMM has four indicators: networks, information systems, computing methodologies, and security and privacy, and to determine its maturity the five stages of the Capability Maturity Model (CMM) were adapted and these are: stage 1, initial, which is the chaotic and ad hoc status of a new service; (2) repeatable, wherein some experiences are borrowed from similar products; (3) defined, which is the stage at which a service is standard and documented; (4) managed stage, which comprises the standard metrics proposed for qualitative evaluation; and (5) optimizing, which means that the service is continuously optimized and improved. Blockchain solution should include all layers (network, protocol, application & transactions) of the solution. The goal of BMM is to have a blockchain technology solution that is trusted, transparent, reliable, immutable, distributed, and sustainable. BMM is useful, as blockchain solutions are becoming more used, but solution seekers have little experience in acquiring, implementing, or maintaining blockchain based solutions. The primary principles of blockchain are decentralization and distributed. Secondary principles of BMM are consensus, cryptography, immutability, incentive mechanism, peer-to-peer, resilience and transparency.

The Blockchain frameworks act as the trust and transparency layer, essential for governance and ethical supply chains. Another example of a framework is the Smart Circular Economy Frameworks which utilize Distributed Ledger Technology (DLT) to move away from the "extract-produce-discard" model. They emphasize traceability, smart contracts for automated compliance, and tokenization for incentivizing recycling. The main implementation focus is the Supply Chain Traceability that Ensures ethical sourcing and reducing "greenwashing" and is linked to SDG 12, and the Decentralized Energy Trading which focus on Peer-to-peer (P2P) renewable energy markets [30].

Blockchain implementation frameworks focus on providing the tools, standards, and structures that simplify adoption, ensure security, and enable scalability of blockchain solutions across industries. They emphasize transparency, decentralization, interoperability, and regulatory compliance to make blockchain practical for real-world applications and emphasize on simplification, transparency & trust, security, interoperability, regulatory compliance and industry applications [31].

2) AI Model

There are many proposed models for AI development, implementation and use and one of them is the AI ethics frameworks which can help govern interactions between humans and AI systems ensuring that proper decisions are made in their development to overcome problems such as misuse, accountability and boundaries of operation and safety. Though a n general framework can be agreed upon, the most applied approach is develop and implement on a project by project basis as each project presents a set of unique ethical challenges. In the rollout of AI capability, one should seek to establish the building blocks around AI and these can be ensured by answering four key developmental questions for ethical use of AI and these are: Am I using AI for the right reasons? can I explain the reasoning path? can I recognize and mitigate AI bias? and how secure is the data I am using? [29].

AI ethics examines the moral responsibilities of AI applications and their creators, addressing concerns like surveillance, transparency, and confidentiality [32]. The AI systems are expected to prioritize human welfare and freedom and serve humanity and the common good. All stakeholders including users, developers and all those to be impacted by its use must find ways of managing AI risks and opportunities.

Floridi and Cowls (2021) [33] recommend that AI development and deployment be guided by:

- Beneficence: Promote well-being, dignity, and planetary sustainability
- Non-maleficence: Ensure privacy, security, and cautious capability development
- Autonomy: Respect individuals' power to make decisions (or choose not to)
- Justice: Foster prosperity and solidarity
- Explicability: Enable understanding and accountability to support the other principles

The most common use of AI frameworks in sustainability primarily focused on predictive analytics and resource optimization. The SDG-AI Alignment Framework is one example of an AI model linked to SD which has demonstrated through research that AI can positively impact 79% (134 out of 169) of all SDG targets. For example, some of the frameworks utilize Machine Learning (ML) for monitoring the environment and Deep Learning for social interventions such as healthcare diagnostics in rural regions. The main focus of implementation has been in precision Agriculture i.e. optimizing water and pesticide use, and energy management which focuses on predictive maintenance for renewable energy grids to reduce waste [34], [35]. AI implementation frameworks primarily address issues of data quality, ethical governance, scalability, regulatory compliance, workforce readiness, and integration with existing systems. These frameworks ensure that AI adoption is not only technically feasible but also socially responsible, secure, and aligned with business objectives.

3) IoT Models

There are a number of IoT models that have been put forward, including the IoT reference architecture, which is a framework for designing and implementing IoT systems, including device management, data processing, and analytics. There is also an IoT security framework designed to ensure the security of IoT systems, including measures to prevent hacking, data breaches, and other security threats. Among these frameworks, there is also an IoT data management framework designed for managing IoT data, including data collection, processing, storage, and analytics [36].

The main goal of IoT frameworks is to provide the sensory layer for sustainable development, enabling real-time data collection and remote monitoring. An example of an IoT model linked to sustainable development is the IoT-Driven Pathways Framework which focuses on four domains: resource-efficient operations, energy optimization, circular economy practices (tracking product lifecycles), and Green Human Resource Management. This framework has its implementation focus as: Smart Cities which is the use sensors to manage traffic flow (SDG 11) and monitor air quality and Water Stewardship which helps IoT-enabled leak detection and soil moisture sensing (SDG 6) [37], [38].

D. Integrated Framework

The most recent implementation models (2024–2026) advocate for an integrated architecture where the three technologies work in synergy. To have an Integrated AI–IoT–Blockchain (BC) framework there is need to combine AI for decision-making, IoT for data collection in real-time, and BC is used for secure, decentralized trust Table 1. This triad is increasingly used in smart cities, healthcare, industrial automation, and digital ecosystems to enhance security, transparency, and efficiency. The AI–IoT–Blockchain framework is evolving toward edge computing integration, where AI models run closer to IoT devices, reducing latency, and blockchain ensures secure peer-to-peer trust. This has been particularly relevant for South Africa's smart city initiatives in Johannesburg, where secure IoT infrastructure is critical for traffic management, energy grids, and public safety [39].

TABLE I. INTEGRATED FRAMEWORK FOR IOT, BLOCKCHAIN AND AI

Layer	Technology	Function in Sustainable Development
Perception	IoT	Collects environmental/operational data (e.g., carbon emissions).
Trust/Logic	Blockchain	Validates data and executes Smart Contracts for resource sharing.
Intelligence	AI	Analyzes data to predict trends and optimize future resource use.

There has been a common challenge across the frameworks i.e. despite the proposal of so many frameworks, widespread implementation still faces hurdles such as interoperability problems caused by lack of standards between different IoT and Blockchain protocols, high energy consumption leaving a high carbon footprint of training large AI models and maintaining Proof-of-Work on blockchain, data privacy arising from the need to balance transparency with the security of sensitive citizen data [40].

To solve the challenges arising from the existing framework, there is need to integrate sustainable development and ICT4D in the implementation framework. Integrating sustainable development and ICT4D (Information and Communication Technologies for Development) into an AI-IoT-Blockchain framework ensures that technological innovation directly supports social equity, environmental protection, and inclusive economic growth. This alignment makes digital transformation not only efficient but also ethical and impactful for communities, especially in regions like Africa, where ICT4D is central to bridging the digital divide.

E. Conceptual Framework: IoT, AI and Blockchain Ecosystem for Sustainable Development

The proposed conceptual framework integrates the Blockchain Maturity Model, IoT Reference Architecture, and AI Ethics Framework to create a framework for the integration of IoT, AI and BC in sustainable development as shown in Figure 1. A framework integrating IoT, AI, and Blockchain for sustainable development within an ICT4D perspective is needed to ensure that these powerful technologies are deployed inclusively, ethically, and sustainably so they benefit marginalized communities, strengthen trust, and drive equitable development outcomes rather than reinforcing digital divides. The conceptual framework combines the three technologies into one functional entity with four layer and ICT4D and sustainable development being used as moderating factors.

1. Perception Layer

This level presents the IoT devices where data is collected and passed on to a blockchain level.

2. The Network Layer

Represent the blockchain services where data is stored, and transmitted to meet data requirements for users.

3. Processing and Application Layer

- applications are built on top of the blockchain and AI layers to provide Data processing, Data analytics and Decision-making capabilities

4. User Interface

Rebuilt on top of AI and blockchain to meet user requirements.

5. ICT4D component

This is a crosscutting component that ensures the development and deployment of each layer meets the requirements for usability and functionality that removes digital divide. The development of the system must consider

6. Sustainable development component It is a cross cutting component that requires the development and deployment of the other four layers to consider financial, social and environmental sustainability in the use of the technologies by consumers.

III. Methodology

The study employed a qualitative research approach to unearth the opportunities, challenges, best practices for AI,

IOT and BC in sustainable development. A qualitative approach allowed for gathering rich, contextual data through interviews with stakeholders to understand how AI, IoT and BC have been applied to sustainable development and what are the success factors for the technologies in sustainable development [41]. Together with the phenomenological design, the study explored and captured experiences, perceptions and opinions of stakeholders concerning AI, IoT and BC in sustainable development and possible integration techniques of the three technologies..

A. Population and sampling

With the number of stakeholders involved in sustainable development unknown, the study employed a purposive sample where people who have knowledge of the area will be interviewed. Sampling by saturation will be employed i.e. data collection will continue until no new data is emerging. An initial sample of ten (10) in-depth interviews was to be contacted with stakeholders who have knowledge of the area.

B. Instruments and Data Collection Procedures

The study gathered data using individual in-depth interviews with selected participants.

In-depth interviews

In-depth interviews were conducted with 13 stakeholders who have knowledge of the technologies under study, and these included academics, policy makers, civil society, regulators, IT consultants, technology organisations directors. Interviews allowed the stakeholders to explain their experiences, perceptions and opinions in the use of AI, IoT and BC in sustainable development. Interview with participants were done using online or face to face means. All the proceedings where recorded for transcribing and analysis if the participant was agreeable.

C. Ethics

The study aimed to be ethical at all stages of the research, from problem formulation to final report writing. The researcher sought out consent from respondents. During the

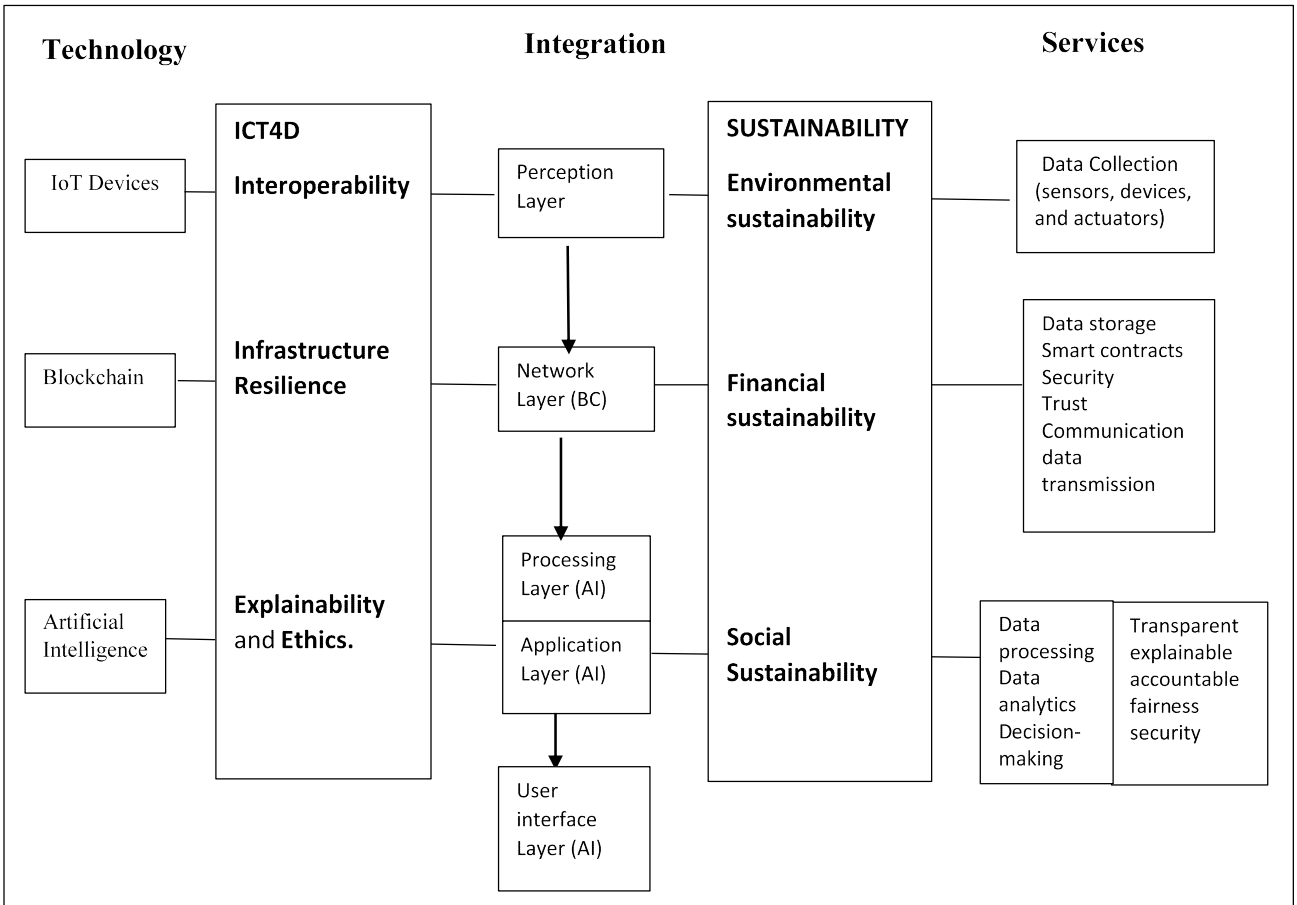

Fig. 1. AI, IoT and Blockchain Ecosystem for Sustainable Development Implementation Framework with ICT4D (Proposed)

study, respondents' anonymity was enhanced by not referring to respondents by their name, or publishing their organisations, not allowing respondents to write their names on any part of the research instruments. Respondents' identities were protected by anonymizing responses and the right to withdraw at any time was emphasized since participation was voluntary. Proper ethical clearances were sought with the relevant authorities.

D. Data analysis and presentation

The data analysis followed a grounded theory approach. After the transcription of the data, the researcher engaged in reading and re-reading the transcripts to have a complete understanding of the content. Coding was done to identify important phrases and ideas related to the research questions, permitting the organization of data into meaningful groups

[42]. After coding, the researcher grouped these codes into broader themes that capture the essence of participants' experiences, opinions, and perceptions. To ensure thoroughness, the analysis involved constant comparison, where emerging themes were continuously compared against the data to refine and validate them [43]. Data was also presented in themes.

E. Developing and Applying Codes

The 13 interviews were transcribed into scripts and loaded into Taguette Qualitative data analysis software. Codes and code categories were created based on the underlying theory and literature review, which was used to generate the conceptual model. Identifying themes, patterns and relationships involved a systematic and iterative process. The steps involved open coding, coding comparison and category development. Patterns and relationship were identified using axial coding and pattern recognition. Primary and secondary data comparisons were also conducted, in order to compare the findings of interview data analysis with findings presented in literature with the aim of uncovering differences or similarities between them. The data analysis followed a grounded

IV. RESULTS

This section presents and discusses the study's results. A thematic approach was used to present and discuss results of the study.

A. Demographic Data

All the participants held some positions of authority in their organisations or society and had some duties related to sustainable development or deployment of ICT. The distribution by office or roles shows that the participants were drawn from a wide range of fields and industries thus giving a fair coverage and expected to give a balanced picture of the perceptions, opinions and experiences. Demographic data is

shown in Table 2.

TABLE II. DEMOGRAPHIC DATA

Variable	Description	Frequency
Age	30-40 years	3
	40-50 years	6
	50-60 years	3
	60+ years	1
Gender	Male	8
	Female	5
Education	Diploma	2
	Degree	5
	Masters	5
	Doctoral	1
Office	Manager	2
	Regulator	2
	Director	2
	ICT Technician	2
	Policy maker	1
	Lecturer	1
	Traditional Leader	1
		1
		1

B. Data Coding

After the interview transcripts were entered into the Taguette qualitative data analysis (TQDA) software, the following codes were generated, as shown in Table 3

1) Integrated framework for AI, IoT and BC implementation to address sustainable development in Zimbabwe

From the interviews it is evident that the participants appreciate the potential of AI, Blockchain and IoT in bringing progress in sustainable development as they list a number of ways the technologies can be used. This is supported by the code implementation possibilities which had 23 highlights (The number of references) from the interviewees and below are the excepts to support:

Res1 "For example, AI-powered chatbots can improve healthcare access, while IoT-based sensors can monitor climate parameters."

Res1 "In agriculture, AI can be used for precision farming, while IoT can monitor crop health. In healthcare, Blockchain can secure medical records, and AI can assist in diagnosis."

Res1 "For example, AI can be used to monitor the climate and help us to model climate adaptation strategies, while IoT-based sensors can monitor water quality".

Res2 "The potential applications of AI, IoT, and Blockchain are many. In agriculture, AI can be used for precision farming, while IoT can monitor crop health"

Res4 "In agriculture, IoT sensors can optimize watering and fertilization, AI can predict pest outbreaks, and blockchain can ensure transparent supply chains."

The data showed that a number of organisations and individuals have come to realize the potential of AI, IoT and Blockchain in improving their operations or daily activities and have started to use them for competitive advantage. However, the challenge is that most of the implementations consider the use of the technologies individually. The combination of the three technologies holds greater promise than individually. The realization by the few is a starting point that promises greater things for sustainable development.

2) Appreciation of the technologies in achieving Sustainable Development

This is shown by codes awareness and interests in technology, which had 5 and 11 references from the

interviewees. The respondents showed that the Zimbabwean market is beginning to appreciate the potential of the three technologies and the benefits they can bring to their operations. However, the appreciation is not transferred into use as there is still low usage of the technologies, and this is supported by the code awareness and interests in technology:

Awareness and Growing Interests

This code shows that users are now beginning to have knowledge about the technologies and the capabilities they bring to their operations and they are seeking more information and opportunities. This is supported by the following snippets:

Res2 "Currently, awareness of these technologies is growing"

Res3 "In Zimbabwe, AI, IoT, and Blockchain are still emerging. Awareness is growing among tech-savvy farmers and organizations"

Res4 "Zimbabwe is in the early stages of adoption. Awareness is growing, especially in urban centers and academia."

Res5 "Awareness is growing among policymakers and academia"

Res6 "These technologies are gaining traction, but adoption is uneven."

Res7 "Awareness is growing among government, academia, and private sector actors", "The awareness of AI, IoT, and Blockchain is growing in Zimbabwe"

Res12 "Growing awareness among government technologists, regulators, academia, and some private sector players; interest is increasing, but widespread adoption is uneven"

The biggest challenge facing the implementation of the three technologies is awareness and interests. Though a number of respondents showed knowledge in the them, they indicated that the majority of people and organisations haven't utilized them although they appreciate their usefulness and competitive advantage.

3) Challenges and limitations of implementing AI, IoT, and blockchain

This theme showed what challenges and limitations exist in Zimbabwe in the utilization of AI, IoT, and Blockchain in sustainable development. The theme was supported by codes Low investment (11), Lack of infrastructure (32), Funding (14), Skills deficit (40), Cost and Sustainability (3), Policy and regulation (33), Data privacy (20), Security (25), Ethical considerations (13), and digital divide (11).

a) Low Investment and Lack of Infrastructure

This was referenced 32 times from the interviews showing that lack infrastructure is a challenge in the utilization of AI, IoT and Blockchain. This shows how important infrastructure is to the deployment of the technologies. The main challenge shown is the uneven distribution of required infrastructure with a noticeable gap between urban and rural areas. This limits the use of the technologies in areas of low investments. Selected interview snippets to support the code are shown below:

Res2 "Adoption remains limited due to infrastructural challenges, such as unreliable electricity and internet connectivity, as well as a skills gap"

Res3 "Major challenges include inadequate infrastructure such as power supply and internet connectivity, limited technical skills, scarce funding, and an evolving policy and regulatory environment that is not yet fully supportive of these emerging technologies."

Res4 "Major challenges include unreliable internet and power infrastructure, limited technical skills among farmers and staff, lack of funding, and an underdeveloped policy environment that supports these technologies."

TABLE I. RESULTS OF CODING

Count	code	meaning
5	Interests in Technology	Willingness to adopt the technologies
13	Developing	Technological establishment is still low
10	Low Adoption	Implementation and use of technology
11	Low Investment	Aggregate investment is insufficient to sustain the technology
32	Lack of Infrastructure	Lack of technology to run AI, Blockchain and IoT systems
40	Lack of Skills	Requisite skills to develop, use and maintain AI, IoT and Blockchain systems
16	Existing Initiatives	Existence of AI, Blockchain and IoT systems or pilots
14	Funding as challenge	Funding for development, use and Maintaining the systems
33	Policy and regulation as challenge	Requisite regulations, laws and policies for the development, use and maintenance of the systems
23	Implementation possibility	Possibility of using the systems in various sectors of Zimbabwe's economy
21	Innovation and entrepreneurship	Possibility of creating opportunities for innovative products and entrepreneurship gains
20	Data Privacy	Possibility of invasion of privacy
13	Security	Possibility of data loss leading to damage
13	Ethical Consideration	Meeting ethical standards
40	Training and Education	Need for training and possible training mechanisms to meet demand
11	Digital divide	Haves and have nots, in terms of the AI, IoT and Blockchain
29	Partnerships for growth	Possible use of partnerships to spur growth of AI, IoT and Blockchain systems
15	Local Context	Systems that meet local needs and consider local values and culture
3	Cost and sustainability	The cost of implementation and maintenance
11	Awareness	Recognizing opportunities

Res4 "Infrastructure remains uneven, with connectivity gaps in rural areas. Skills development is nascent, and investment is largely donor-driven or pilot-based."

Res5 "Infrastructure: Limited broadband access and power reliability.", "adoption is limited by infrastructure gaps, especially in rural areas"

b) Lack of Skills

This was mentioned 40 times by the interviewees as one of the challenges to the implementation of AI, IoT and BC. There are noticeable and acknowledged advantages in their use from experts but those who are supposed to use the technologies do not have the know-how. The main challenge is to have those who are able to develop, implement and maintain the systems as well as those who can use the systems are in short supply. Selected snippets to support the code are given below:

Res3 "There is a significant shortage of professionals with advanced skills in these areas", "Gap in advanced analytics, IoT engineering, and secure blockchain development; retention of talent is a concern."

Res12 "Advanced AI/machine learning expertise, data science, and AI ethics, IoT engineering, sensor networks, edge computing, and system integration, Blockchain development, smart contracts, and decentralized application design, Data governance, privacy, and cybersecurity know-how"

Res13 "AI, IoT and Blockchain experts are still few to meet Zimbabwe's needs for development."

Res10 "Shortages in advanced AI/ML capabilities, IoT system integration, and blockchain development; ongoing training and partnerships are critical"

Res9 "Zimbabwe faces significant skills gaps in AI, IoT, and Blockchain, especially in rural areas"

c) Funding

Funding is required to acquire, develop, implement and maintain the systems as well as training the users. From the discussions it shows that their lack of funding for the technologies from government with the little funding for sustainable development coming from private organisations and NGOs. This lack of funding has the potential to limit the growth of AI, IoT and BC hence limiting their success. Selected snippets are presented below:

Res2 "Low domestic investment; reliance on external grants."

Res3 "Low domestic investment; reliance on donor support"

Res13 "...scaling is hindered by funding and data readiness."

Res10 "..., inadequate funding for innovation…"

Res1 "challenges facing the adoption of AI, IoT, and Blockchain technologies in Zimbabwe are infrastructure, skills, funding, and policy and regulatory environment"

d) Policy and regulation

The participants highlighted that there is lack of sufficient policy and regulations to support the use of AI, IoT and BC in Zimbabwe. What is available mostly are drafts that are under review. The lack of such has the potential to push would be users as they are afraid of losing their investments as well as lack of protection. This code was mentioned 33 times showing how important it is to the growth and use of the technologies. Some snippets are shown below:

Res1 "The country lacks a clear policy framework for these technologies"

Res2 "The current policy and regulatory environment for AI, IoT, and Blockchain in Zimbabwe is evolving", "The government has established a task force to develop a national AI strategy"

Res3 "The current policy and regulatory environment for AI, IoT, and Blockchain in Zimbabwe is not strong and defined."

Res4 "The government through the ministry is coming up with a regulatory framework for AI use, this can be expanded to include other technologies related to AI.", "Major challenges include inadequate infrastructure such as power supply and internet connectivity, limited technical skills, scarce funding, and an evolving policy and regulatory environment that is not yet fully supportive of these emerging technologies."

Res3 "There are some regulations concerning electronic transactions and data protection, but specific frameworks for AI, IoT, and blockchain are still under development or in draft stages"

Res4 "Zimbabwe's policy environment is still developing. There are some regulations around data privacy and digital transactions, but comprehensive frameworks specific to AI, IoT, and Blockchain are limited. Standards and guidelines are in the early stages"

e) Data Privacy

This was highlighted 20 times during discussions and this shows how organisations and individuals are fearful of using the technologies for fear of losing their data or infringing data privacy regulations. It is important that the technologies should have clear policies on how to handle private data.

Res5 "Weak enforcement of data protection laws…"

Res8 "Potential risks include misuse of personal data, cybersecurity threats, and ethical concerns such as algorithmic bias or exclusion of vulnerable groups without adequate safeguards."

Res10 "… Data privacy laws are in draft forms and need strengthening."

Res11 "Risks include data privacy issues, security vulnerabilities, and ethical concerns such as misuse of AI or Blockchain systems without oversight"

Res11 "Fragmented data silos, data privacy concerns, and need for governance frameworks, addressing bias in AI, equitable access, and transparent use of citizen data."

Res12 "Protection of personal and sensitive data; risk of breaches, misuse, or surveillance concerns.", "Invest in data governance, privacy protections, and ethics guidelines for AI/IoT"

Res13 "Protecting personal data; risk of breaches or misuse.", "Keeping pace with rapid tech changes; avoiding under-or over-regulation."

f) Security

The participants showed that they have concerns in use of Ai, IoT and BC because of the security risks associated with the technologies especially with data exchange. For the technologies to be adopted widely, the suggestion is to have security measures implemented in them and have assurances that risks have been minimized. Its importance can be seen by the number of references from participants numbering 25. If the technologies are to gain wide acceptance, security risks need to be addressed.

Res1 "The potential risks and challenges associated with the adoption of AI, IoT, and Blockchain technologies in Zimbabwe include data privacy, security, and ethics. There is a need for robust regulations and standards to mitigate these risks."

Res3 "Risks include data privacy breaches, cybersecurity threats, and unethical use of AI. There is also the danger of technology dependency and exacerbation of inequality if access remains limited."

Res3 "Data privacy concerns, cybersecurity threats, and ethical issues such as data ownership."

Res4 "Security: Vulnerabilities in IoT networks."

Res8 "Establishing legal frameworks for data privacy and security is also vital.", "Risks include data misuse, cybersecurity threats, and ethical concerns such as bias and discrimination in AI systems"

Res8 "Potential risks include misuse of personal data, cybersecurity threats, and ethical concerns such as algorithmic bias or exclusion of vulnerable groups without adequate safeguards"

Res11 "Risks include data privacy issues, security vulnerabilities, and ethical concerns such as misuse of AI or Blockchain systems without oversight"

g) Ethical Consideration

The other challenge being faced by those using the technologies are the ethical considerations. How will the technologies interact with the wider community considering the cultural and values aspects of different people? There is need to make sure all concerns are addressed such as job losses and cultural beliefs. This was mentioned 13 times showing its importance, and some extracts to support this theme are shown below:

Res1 "The potential risks and challenges associated with the adoption of AI, IoT, and Blockchain technologies in Zimbabwe include data privacy, security, and ethics.",

Res2 "Ethical concerns around data privacy and security further complicate adoption."

Res3 "Need for AI ethics guidelines and accountability mechanisms."

Res5 "Ethics: Need for AI ethics frameworks and environmental safeguards."

Res6 "Need for AI ethics guidelines and algorithmic transparency."

Res8 "Risks include data misuse, cybersecurity threats, and ethical concerns such as bias and discrimination in AI systems."

Res8 "Potential risks include misuse of personal data, cybersecurity threats, and ethical concerns such as algorithmic bias or exclusion of vulnerable groups without adequate safeguards."

Res9 "Ethical concerns related to AI decision-making also need proactive management."… "Addressing bias in AI, equitable access, and transparent use of citizen data."

Res12 "Ensuring fairness and avoiding discrimination in AI systems; governance of automated decision-making."

Digital divide

The participants also articulated that the digital divide was a challenge to the wider adoption of the technologies, as most areas, especially rural areas, lacked the requisite infrastructure. This was mentioned 11 times, demonstrating how important it is. Some snippets to support are shown below:

Res1 "People are mainly aware of AI, and the other two technologies are more familiar with tech people than any other citizen."

Res2 "…danger of technology dependency and exacerbation of inequality if access remains limited"

Res3 "Skills gaps include limited technical knowledge in AI, IoT, and Blockchain among local farmers, technicians, and policymakers"

Res4 "Infrastructure remains uneven, with connectivity gaps in rural areas. Skills development is nascent, and investment is largely donor-driven or pilot-based."

Res5 "Skills are concentrated in urban universities, and investment is mostly donor-driven or pilot-based."

Res6 "These technologies are gaining traction, but adoption is uneven."

Res7 "Existing efforts include initiatives by tech hubs and government training programs, but there remains a significant need to expand these to reach more communities and build sustainable local talent pools."

Res8 "… exclusion of vulnerable groups without adequate safeguards"

h) Cost and sustainability

Though this was not directly mentioned many times and only 2 times. It can be linked to lack of infrastructure and other determinants of lack of adoption. Cost of acquisition, development, deployment and maintenance can be high for these technologies hence hindering their wider use in sustainable development.

Res12 "High upfront costs; long-term maintenance and support requirements."

Res13 "High upfront costs, maintenance, and uncertain long-term ROI; need for blended finance and sustainable business models.", "Cost and sustainability"

4) Design to ensure inclusivity, accessibility, and sustainability in Zimbabwe

This theme tries to answer the question, how can ICT4D initiatives be designed and implemented to ensure inclusivity, accessibility, and sustainability in Zimbabwe? This is answered by the codes, Innovation and entrepreneurship (21), Local Context (15), Training and Education (40) and

Partnerships for growth (29). The question has to be answered if solutions for sustainability of the projects s to be achieved.

a) Innovation and entrepreneurship

The design of AI, IoT and BC needs to take the innovation and entrepreneurship approach to allow for more players to invest in the technologies. One of the challenges is lack of funding and resources, but this can be helped by allowing innovators to come up with solutions that are cheap and can be accessed locally. If the solutions are context specific and cheap this can allow for wider adoption and fats spread. This was mentioned 21 to show its importance. Snippets to support are shown below:

Res1 "There are opportunities for innovation and entrepreneurship in AI, IoT, and Blockchain in Zimbabwe. Startups and SMEs can leverage these technologies to develop innovative solutions for local challenges. Incubators and accelerators can provide support and funding for these ventures"

Res2 "Startups and SMEs can leverage these technologies to develop innovative solutions for local environmental challenges."

Res3 "The growing digital ecosystem provides fertile ground for startups developing solutions tailored to local needs—such as mobile-based agri-tech platforms, healthcare apps for rural communities, and blockchain-based microfinance service"

Res4 "Policymakers can enact supportive legislation, establish innovation hubs, provide funding and incentives for startups, and develop standards that ensure interoperability and security. Capacity building and awareness campaigns are also vital."

Res5 "There are opportunities for startups developing affordable IoT devices for smallholder farmers, incubators supporting agritech innovations, and government or donor funding for pilot projects. These can foster local entrepreneurship and sustainable solutions."

Res6 "Growth in fintech, agritech, and healthtech using emerging technologies.", "Innovation hubs like TechVillage and Impact Hub Harare"

Res7 "The government can support adoption through clear policies, incentives for innovation, capacity-building initiatives, and the creation of a conducive environment for startups"

Res8 "There is growing interest among young innovators and startups focused on addressing city challenges with tech solutions. Incubators and accelerators in Zimbabwe are gradually providing platforms for these entrepreneurs, although funding remains a challenge"

b) Training and Education

If these initiatives are to succeed and be sustainable there is need to consider the training needs for the developers, maintainers and users. This has been shown to be important as it is mentioned 40 times in the discussions. Snippets are shown below:

Res1 "there are existing initiatives and programs that support capacity building and skills development in AI, IoT, and Blockchain in Zimbabwe, For example, universities are introducing programs on AI and data science, and there is collaboration with international partners to provide training and mentorship."

Res2 "Capacity building and skills development programs can be designed in partnership with international organizations, universities, and industry partners. These programs should focus on practical skills development and address specific industry needs."

Res3 "Many practitioners lack exposure to practical implementation, and there is limited specialized training at tertiary institutions.", "Some universities have started offering specialized courses and degree programs in emerging technologies"

Res4 "Capacity building can be enhanced through partnerships with universities, tech hubs, and development agencies. Training programs should be practical, affordable, and tailored to local contexts. Funding opportunities should focus on incubators and skills development"

Res7 "Educational institutions are starting to introduce relevant coursework, but more targeted capacity building is needed"

Res8 "Funding for training programs, internships, and mentorship is critical to developing local expertise."

Res11 "Shortages in advanced AI/ML capabilities, IoT system integration, and blockchain development; ongoing training and partnerships are critical."

Res12 "Support capacity building through public training programs, scholarships, and vendor-agnostic certification."

Res13 "Access to specialized degree programs, short courses, hands-on labs, and practical project experience; ongoing professional development for civil servants."

c) Partnerships for growth

Design of these technologies should also consider the funding mechanisms as it is important to the eventual design, context and cost of the technology. The more the funding the faster the spread and cheaper it becomes hence the more it is used. This was highlighted 29 times in discussions with participants.

Res1 "The growing digital ecosystem provides fertile ground for startups developing solutions tailored to local needs—such as mobile-based agri-tech platforms, healthcare apps for rural communities, and blockchain-based microfinance service"

Res3 "Public-private partnerships can accelerate deployment, and inclusion of ICT in national development strategies will create a conducive environment.", "Programs should involve partnerships between academia, industry, and government to develop relevant curricula, offer hands-on training, and promote research. Funding opportunities from international donors can support such initiatives.", "some universities have started offering specialized courses and degree programs in emerging technologies", "providing funding for pilot projects, creating innovation hubs, and offering training programs to build local expertise."

Res4 "Partnerships: Collaborate with global tech firms and universities., Funding: Leverage diaspora networks and donor agencies., Curriculum: Develop national competency frameworks for emerging tech."

Res5 "Identified priority areas for skills development.", "Existing Initiatives Partnerships for growth, Support technical training and public-private partnerships."

Res6 "Collaborate with universities and international agencies.", "There are some pioneering projects, but they are often pilot or donor-funded initiatives rather than scaled solutions."

Res8 "Capacity building should be collaborative, involving universities, tech hubs, and development partners.", "Existing efforts include initiatives by tech hubs and government training programs, but there remains a significant need to expand these to reach more communities and build sustainable local talent pools.", "Multi-stakeholder partnerships involving government, academia, and the private sector."

Res9 "Capacity programs should involve partnerships with universities, technology firms, and international development agencies to provide on-the-job training, workshops, and certification courses. Funding could be accessed through public-private partnerships or donor support."

Res10 "Skills are scarce, and investment mostly comes from international partners or pilot projects."

Res11 "partnerships with tech firms and educational institutions, and support for continuous learning through workshops and certifications.", "Partnerships for growth Training and Education", "Shortages in advanced AI/ML capabilities, IoT system integration, and blockchain development; ongoing training and partnerships are critical."

Res12 "Public funding and donor-funded pilots exist, with private sector interest in fin-tech, agtech, and smart services, but long-term financing mechanisms are still evolving", "government innovation funds, development partner grants, impact investors, and blended finance for pilots.", "Emerging regulatory landscape; national strategies exist for ICT and digital transformation, but sector-specific guidelines for AI, IoT, and Blockchain are still developing", "Facilitate funding through grant programs, blended finance, and public-private partnerships", "Partner with universities and research institutes to nurture local talent; establish local AI/IoT/Blockchain centers of excellence", "Public-private partnerships to fund and deliver targeted training", "Collaboration with tech companies, NGOs, development partners, and academic institutions; ensure local language and accessibility considerations",

Res13 "Public-sector seed funding and donor-supported pilots are common; long-term financing mechanisms and private sector investment are evolving.", "government innovation funds, development partner grants, venture funds, blended finance for pilots", "Promote interoperability standards and open data where feasible to unlock ecosystem collaboration.", "Partner with universities and research institutes to cultivate local talent; establish regional centers of excellence.", "Engage with tech companies, NGOs, development agencies, and academia; consider language accessibility and inclusivity."

d) Local Context

One of the design issues that can encourage uptake of the new technologies and spur sustainability is the consideration of local context. Most of foreign designed applications fail to suit local needs hence the need to have locally developed applications. This was mentioned 15 times by the participants signaling its importance. Some snippets to support this code are shown below:

Res1 "Startups and SMEs can leverage these technologies to develop innovative solutions for local environmental challenges."

Res2 "Local Context innovation and entrepreneurship", "Capacity building and skills development programs can be designed in partnership with international organizations, universities, and industry partners. These programs should focus on practical skills development and address specific industry needs."

Res2 "providing funding for pilot projects, creating innovation hubs, and offering training programs to build local expertise."

Res4 "Capacity building can be enhanced through partnerships with universities, tech hubs, and development agencies. Training programs should be practical, affordable, and tailored to local contexts. Funding opportunities should focus on incubators and skills development", "Key challenges include poor internet infrastructure, limited local expertise, insufficient funding, and an underdeveloped policy and regulatory environment that hinders innovation and risk management."

Res8 "Ensuring solutions are appropriate for rural communities and do not exacerbate inequalities."

Res12 "opportunities to localize hardware and maintenance services to support rural deployments.", "Partner with universities and research institutes to nurture local talent; establish local AI/IoT/Blockchain centers of excellence", "Ensuring solutions are context-appropriate, culturally sensitive, and beneficial to marginalized communities."

Res12 "Collaboration with tech companies, NGOs, development partners, and academic institutions; ensure local language and accessibility considerations", "Universities in Zimbabwe and regional universities offering degrees and boot camps.", "Public sector ICT capacity-building programs funded by donors and development partners.", "Private-sector training programs in data analytics, IoT deployment, and blockchain development targeted at local startups and government staff."

Res12 "Ensuring solutions are accessible to marginalized communities and do not widen gaps between urban and rural areas."

Res13 "Opportunities to localize hardware assembly, repair services, and service networks for rural deployments.", "Partner with universities and research institutes to cultivate local talent; establish regional centers of excellence.", "Ensuring solutions are culturally appropriate, accessible, and beneficial to marginalized groups."

5) Prospects of success in achieving sustainable development

This theme tries to answer the question, what are the prospects of success of these technologies in achieving sustainable development? If these technologies are

implemented, there is need to determine whether the systems will be sustained. This is represented by sub themes (codes) existing initiatives (16) and implementation possibilities (23).

a) Existing Initiatives

The participants highlighted the initiatives that are have been done by the government, NGOs and other organisations and how they are doing. It shows the possibility of coming up with full-fledged systems that are operational and acceptable in sustainable development in Zimbabwe. This was mentioned 16 times showing how possible it is to deliver working systems as the prototypes and small scale systems are used.

Res1 "Yes, there are a few initiatives and projects that leverage AI, IoT, and Blockchain for sustainable development in Zimbabwe. For example, projects like AI-powered crop disease diagnosis, and another on IoT-based water quality monitoring. We are also exploring Blockchain applications in supply chain management and identity verification.", "Our universities have been coming up with programs to promote AI use and workshops by different experts on AI use in different areas."

Res2 "Investment levels are modest but increasing, with some startups and government initiatives exploring pilot projects."

Res3 "Existing initiatives include university-led training programs and NGO-led workshops on digital agriculture. Some government initiatives aim to promote digital literacy, but more targeted efforts are needed to build expertise in these specific technologies."

Res4 "Infrastructure remains uneven, with connectivity gaps in rural areas. Skills development is nascent, and investment is largely donor-driven or pilot-based."

Res5 "AI: The National AI Strategy (2026–2030) aims to integrate AI into public services, agriculture, and education., IoT: Pilot projects in smart farming and water management are underway, supported by universities and NGOs., Blockchain: The Reserve Bank of Zimbabwe has explored blockchain for financial inclusion and digital identity.", "Identified priority areas for skills development."

Res5 "IoT: EMA has piloted IoT-based air quality sensors in Harare and Bulawayo to monitor urban pollution., AI: The Meteorological Services Department uses AI models for climate forecasting and early warning systems. Blockchain: The Ministry of Lands is exploring blockchain for land registry transparency and anti-corruption."

Res6 "Digital Skills for Africa: Supported by UNESCO and African Union.", "Existing Initiatives Training and Education, there are some pioneering projects, but they are often pilot or donor-funded initiatives rather than scaled solutions."

Res8 "For example, there are projects utilizing blockchain for financial inclusion and identity management, and IoT applications in agriculture for crop monitoring"

Res8 "Examples include pilot projects using IoT for climate-smart agriculture to monitor soil moisture and weather conditions, Blockchain initiatives for transparent land registry management, and AI-driven healthcare diagnostics tools introduced in some urban clinics. These projects aim to improve efficiency, transparency, and service delivery."

Res9 "Agriculture: IoT sensors for precision farming and AI for yield prediction., Healthcare: AI diagnostic systems and Blockchain for secure patient records., Energy: IoT-enabled smart grids and Blockchain to facilitate peer-to-peer clean energy trading", "There are some examples, like IoT sensors used in limited cases for monitoring waste bins to optimize collection schedules. Other projects, such as Blockchain for land registry, are mostly still at pilot stages. AI use is rare but emerging in traffic monitoring and public security trials."

Res11 "Early pilots exist in agriculture, health logistics, energy, and smart city trials; broader scale-up depends on data readiness, policy clarity, and investment."

Res12 "Early pilots exist in agriculture, health logistics, energy management, and urban services; scaling is hindered by funding and data readiness."

6) Implementation Possibilities

The participants explain how the three technologies can be used in conjunction in sustainable development. This is proof that the participants acknowledge the value the technology can bring and where and how to use them.

Res1 "AI, IoT, and Blockchain could significantly advance SDGs such as zero hunger (by increasing crop productivity), good health and well-being (through better resource management), quality education (via digital literacy programs), and climate action (by monitoring environmental impacts).", "In agriculture, IoT sensors can optimize watering and fertilization, AI can predict pest outbreaks, and blockchain can ensure transparent supply chains. In healthcare, these technologies can improve access to medicines or health data management. smart grids and renewable energy management can benefit from IoT."

Res4 "Agriculture: IoT-enabled irrigation systems and AI for crop yield prediction. Healthcare: Blockchain for secure patient records; AI for triage and diagnostics. Energy: Smart grids using IoT; blockchain for decentralized energy trading."

Res8 "There are notable opportunities for local startups and entrepreneurs to innovate in these fields. Incubators and accelerators could foster technology development, and funding can be mobilized through partnerships with international donors and development agencies."

Res8 "One example is the application of IoT sensors for smart waste management systems that optimize collection routes and reduce costs. Some pilot Blockchain projects exist for land records and identity management to improve transparency. AI has been tested in traffic monitoring and predictive maintenance of infrastructure in limited areas."

Res10 "Reducing urban poverty through enhanced service delivery and job creation. Improving public health through AI-based disease monitoring and IoT-enabled health data collection. Strengthening education with digital learning platforms powered by AI. Supporting climate action via IoT sensors for pollution monitoring and Blockchain for transparent resource management."

Res10 "Agriculture: Supporting urban farming with sensor data. Healthcare: Using AI to analyze health trends

and Blockchain to protect patient data. Energy: Monitoring city energy consumption via IoT to improve efficiency."

Res11 "Agriculture: IoT-enabled soil moisture and weather monitoring to optimize irrigation; AI-driven yield predictions and disease detection; blockchain-based supply chain traceability for farmers., Healthcare: Telemedicine platforms supported by AI triage, remote diagnostics, and logistics optimization for medical supplies; IoT for cold-chain temperature monitoring., Energy: Smart metering pilots, demand-response systems, and micro-grid management leveraging IoT; blockchain for peer-to-peer energy trading and transparent subsidies., Urban planning and governance: Smart water meters, flood/river sensors for early warning; AI-based anomaly detection in City Watch data; blockchain for transparent procurement and land registry records."

Res12 "Poverty reduction (SDG 1): AI-driven social protection targeting, crop insurance with IoT data, and microfinance risk assessments; transparent benefit delivery via blockchain where feasible. Health and well-being (SDG 3): AI-enabled disease surveillance, remote diagnostics, optimized drug supply chains; IoT for cold-chain monitoring; digitized health records with strong privacy protections. Quality education (SDG 4): AI tutoring systems; low-bandwidth e-learning platforms; data analytics to identify learning gaps; community digital hubs to improve access. Clean water and sanitation (SDG 6): IoT water level and quality sensors; AI for leak detection and demand forecasting; blockchain for subsidy and tariff transparency. Climate action (SDG 13) and resilient infrastructure (SDG 9/11): IoT sensors for early warning of floods, drought forecasting, and energy management; AI for climate risk mapping and adaptive planning. Sustainable cities and communities (SDG 11): Smart governance dashboards, citizen feedback analytics, and IoT-enabled asset management."

Res12 "soil moisture monitoring, pest/disease detection via computer vision, precision irrigation, yield forecasting, water savings, higher yields, reduced input costs., data integration, cost of devices, maintenance in rural areas., remote triage, logistics optimization, supply chain traceability, data-driven outbreak response., improved access, reduced stock-outs, better public health insights., data privacy, regulatory compliance, connectivity gaps., Use cases: smart meters, grid stability, demand-side management, micro-grids, blockchain-based energy trading., reliability, efficiency, €-style transparent incentives."

Res12 "Agriculture: IoT-based soil moisture and weather sensors coupled with AI for irrigation scheduling; blockchain-enabled traceability to improve market access and price transparency for smallholders., Health: AI-assisted disease surveillance and logistics optimization for vaccine and supply chains; IoT-enabled cold-chain monitoring in clinics and pharmacies."

Res13 "Technology can be used for disease surveillance and resource planning, Quality Education access, Climate Action.", "AI-assisted diagnostics in clinics with connectivity support."

V. Discussion and Recommendations

A. Discussion

The integration of AI, IoT, and Blockchain technologies has the potential to significantly contribute to sustainable development in Zimbabwe. Socio-economic challenges such as poverty, inequality, and environmental degradation can be addressed by these technologies. The power of these technologies individually are great but when combined they can be greater. Here are examples of how these technologies can be used individually in sustainable development.

- Climate modeling: AI analyzes climate data to predict patterns, helping policymakers prepare for extreme weather events.
- Energy efficiency: AI optimizes energy consumption in buildings and industries, reducing waste and carbon footprint.
- Sustainable agriculture: AI-powered precision farming improves crop yields, reduces water usage, and promotes eco-friendly practices.
- IoT enables real-time monitoring and management of resources, promoting sustainability. Examples:
- Smart grids: IoT optimizes energy distribution, reducing waste and improving renewable energy integration.
- Water management: Used for Optimizing water usage, quality monitoring, IoT sensors detect leaks, monitor quality, and optimize water usage.
- Waste management: optimizing waste collection and reducing associated waste disposal costs and impact to environment.
- Blockchain ensures transparency, accountability, and security in sustainable development initiatives. Examples:
- Carbon credits: Blockchain tracks carbon credits, ensuring transparency and preventing fraud.
- Supply chain transparency: Blockchain tracks sustainable sourcing, promoting responsible practices.
- Renewable energy trading: Blockchain enables peer-to-peer energy trading, promoting renewable energy adoption.

B. Integrated Solutions

- The results have shown that it is possible to integrate the three technologies and achieve greater results for example in:
- Smart farming: the technologies can allow for precision farming thus improving yields and reducing waste.
- Smart cities: IOT sensor can be used to collect data whilst AI provides analysis on water, waste management in urban areas for optimization thus improving citizen's life.
- Sustainable supply chain: Blockchain and IoT can be used in tracking goods from source to final destination, thus ensuring the authenticity of goods and reducing counterfeits, whilst AI is used for

optimization of logistics and supply chain management.

Integrating the Ai, IOT and BC in sustainable development brings a number of advantages over using them individually: The use of AI to analyze IoT data in real time allows swift decision-making and action.

The installation of automated processes can be improved by having IoT and AI systems thus reducing manual errors and increasing productivity.

Resource optimization can be improved as blockchain and IoT can track the supply chain whist AI optimize resource allocation thus reducing waste and improve on sustainability

There is increase in transparency, accountability and trust as blockchain ensures transparent and tamper proof transactions.

Compliance and transparency is improved by real-time tracking of transactions using IoT and Blockchain thus improving on monitoring and reporting as well as providing data trails.

Data security can be increased by use of blockchain providing decentralized data storage thus reducing cyber risks. Data encryption can also be improved by use of BC and AI thus protecting sensitive information. Access control can be ensured by use of BC.

AI can be used to analyze data from IoT and BC to provide actionable insights thus decision making becomes data-driven. This can allow for pro-active planning leading to better and informed policies to promote sustainable development.

Resource usage optimization reduces waste and environmental impact thus achieving sustainable development through the use of AI and IoT. The use of AI and IoT makes it easier for renewable energy integration by optimizing renewable energy generation and distribution. AI and IoT can be used to drive derive climate models to help communities to prepare for extreme weather conditions.

Sustainable development initiatives can greatly benefit by integrating AI, IoT, and Blockchain, to achieve greater impact, efficiency, and sustainability.

C. *Recommendations*

For the success and sustainability of AI, IoT and BC in SD there is need address the financial, technical and social aspects of technology as well governance issues. To leverage these technologies for sustainable development in Zimbabwe, here are the recommendations:

1. Development of a national ICT4D strategy is key to achieving SD. The integration of AI, IoT, and Blockchain into existing development plans and policies should be prioritized and government should remove donor dependency as it risks the long term sustainability of the initiatives or the focus from the donor may not suit the local needs and demands. Other sources of funding should be explored such as Public-Private Partnerships (PPP), reallocated government funds, and service usage charges to guarantee the continuation of the projects.

2. Training and capacity building in terms of development, deployment and maintenance is required. There is need to train local experts and communities to ensure they develop, implement, and maintain technologies to meet local standards and needs. Technical sustainability is threatened by high staff turnover and a lack of digital literacy.

3. Projects can be developed as pilot projects i.e. they can be done on a small scale until refined. AI, IoT, and Blockchain projects can be launched in specific sectors, such as agriculture, healthcare, and education and expanded when fully tested.

4. The government must foster partnerships with stakeholders such as international organizations, private sector, and NGOs to unlock funding, expertise, and resources.

5. Inclusive stakeholder participation is a requirement that is fundamental to sustainability as top-down approaches often exclude the end-users thus causing rejection and ultimate failure. Grassroots participation of citizens and local communities ensure the systems are user-friendly and relevant. Also there is need to ensure equal representation of all actors to cater for diversity

D. *Limitations and Further research*

The number of research respondents and the methodology used may limit the generalizability of the results, there is need to expand the scope of the research to include the expected users of the technologies as well to cater for suitability of the technologies to their environments.

Further research is required to test the framework and its applicability to the integration of AI, IoT and BC to sustainable development. Lab work is required to come up with a practical model of implementation to have tangible results on the integration of the three technologies. Research is also needed to test how the framework will fit with implementation of pilot projects in specific sectors (e.g., agriculture, healthcare)

VI. Conclusion

The integration of AI, IoT, and blockchain technologies holds significant potential for driving sustainable development in Zimbabwe. By leveraging these technologies, Zimbabwe can address pressing challenges in areas such as energy, agriculture, supply chain management, and waste reduction. The convergence of these technologies can enable efficient, sustainable, and inclusive systems, ultimately contributing to the country's economic growth and improvement of living standards. By embracing these technologies and following these recommendations, Zimbabwe can harness the potential of AI, IoT, and blockchain to drive sustainable development and achieve its development goals. The framework shows it is possible to integrate the technologies in SD and achieve greater results such as efficiency, security, transparency and trust.

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