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Towards Data Centre Sustainability: An Assessment of Sustainable ICT Infrastructure Practices in Zimbabwean Public University Data Centers

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Abstract

This study presents a comprehensive assessment of sustainable information and communications technology (SICT) infrastructure practices within the data centers of Zimbabwean public universities. A census was conducted on 241 technical personnel from the ICT departments of 13 public universities, supplemented by 12 in-depth interviews with ICT directors and managers as key informants. The findings reveal a mixed picture regarding the adoption of sustainable data center practices. Positive indicators include the widespread use of server virtualization and database consolidation to optimize resource utilisation. However, several critical gaps were identified. There was a notable absence of server equipment energy usage monitoring, energy efficiency considerations in equipment procurement, and continuous power audits. Furthermore, the data centers largely lacked natural air cooling, automated temperature control systems, and integration of renewable energy sources such as solar and wind power. The universities have taken steps towards data center rationalisation and cloud adoption, but budget funding constraints and non-availability of slack financial resources have hindered the full implementation of sustainable data centre initiatives. Notably, there is a lack of guiding policies and life-cycle management practices for sustainable ICT infrastructure maintenance. The research results highlight the need for a more holistic and systematic approach to promoting sustainability in Zimbabwean public university data centers in promotion of ICT for Sustainable Development (ICT4SD). The research findings provide valuable insights to inform the development of targeted interventions, potential in cross institution collaborations and Sustainable ICT policy

frameworks that can enable these universities to transition towards more environmentally responsible and energy-efficient data center operations.

Keywords: Sustainable ICT, Data Center, Practices, ICT4SD

Introduction

The modern Zimbabwe university has been significantly transformed by the proliferation of digital technologies for teaching, learning, research, administration, innovations, community service and industrialization as enshrined in the Zimbabwe's Education 5.0 doctrine. The during and post COVID-19 pandemic era triggered exponential growth and reliance on digital technologies which are data-intensive, internet network dependent applications, have led to a significant expansion of university data center infrastructure across various sectors, including higher education institutions (HEIs) (Maphosa, 2022; Andrews et al., 2021). These digitally enabled processes have led to exponential growth of data, computers, and distribution networks, placing unprecedented demands on the underlying information and communications technology (ICT). Central to the massive digital transformation of universities lie the university data centers. According to the World Bank (2023a), data center infrastructure, encompassing data centers and cloud computing solutions, forms the foundational backbone that enables a wide range of essential services in the digital age. The data centers house the critical electronic and electrical networking equipment Wi-Fi and Local Area Networks (LANs), computing, processing, storage resources that enable Education 5.0 academic, research, and administrative operations (Andrews et al., 2021). However, the environmental impact of these data centers has emerged as a pressing concern, as universities grapple with the dual challenge of meeting ever-evolving escalating computational needs while minimizing their environmental impact and carbon footprint (Masanet et al., 2020).

Over the last twenty years, the primary global concern has been centered around environmental sustainability and the issue of climate change. Zimbabwean public universities, as key contributors to the nation's education and research ecosystem, play a crucial role in addressing this challenge. The increasing global concern revolves around energy consumption, the procurement and utilisation of ICT equipment in server rooms/data centers, the cooling methods employed in server rooms, and the management of their end-of-life processes. Data centers are estimated to account for 1% to 3% of the world's total electricity consumption and contribute significantly to greenhouse gas emissions (Masanet et al., 2020). The substantial energy consumption, heat production, and carbon emissions of data centers have underscored the importance of adopting sustainable practices within data centers (Jiang, 2024).

The realm of "*Sustainable ICT*" encompasses a wide range of topics, spanning from alternative energy generation and electricity consumption methods, and the utilization of eco-friendly, recyclable materials to the integration of sustainable digital services (Pazowski, 2015; Molla, 2013). Sustainable data center practices encompass a range of strategies and technologies, including the use of energy-efficient hardware such as blade server implementation, virtualization, server consolidation /rationalization, cooling systems, energy consumption monitoring and cloud computing, deployment of renewable energy sources, and the adoption of comprehensive life-cycle management approaches (Salim, 2020).

In the context of Zimbabwean public universities, the transition towards sustainable data center practices is crucial for several reasons. These institutions play a pivotal role in driving the nation's research, innovation and industrialization agenda, and ensuring the environmental sustainability of their data centers is essential for their long-term viability and impact and attainment of United Nations Sustainable Development Goals (Maphosa, 2022; Žalėnienė & Pereira, 2021; Mhteistd, 2020). Sustainable data center practices can contribute to the universities' broader sustainability initiatives and serve as transformation agent models for other organizations within broader business spectrum in Zimbabwe.

Problem Statement

The rapid expansion of data centers in Zimbabwean public universities has raised concerns about their environmental sustainability, but a lack of research on sustainable data center practices in developing countries like Zimbabwe has created a significant knowledge gap. This gap hinders the development of custom, targeted interventions and policy frameworks to enable these higher education institutions to transition towards more environmentally responsible and energy-efficient data center operations. To address this critical issue, this study aims to conduct a comprehensive assessment of sustainable ICT infrastructure practices within the data centers of Zimbabwean public universities, contributing to the growing body of knowledge on sustainable data center management in developing country contexts.

Delimitations

The scope of this study is delimited to the data centers of public universities in Zimbabwe. While Zimbabwe has other private universities and small to medium enterprise technology sectors, such as government or commercial data centers, may also grapple with sustainability challenges, this research focuses exclusively on the public higher education institutions embracing the Education 5.0 doctrine. Additionally, the study examines the current state of sustainable practices, rather than projecting or modeling future scenarios.

Limitations

While this study provides valuable insights into the state of sustainable ICT practices in Zimbabwean university server room/data centers, various limitations are rampant in this study. The research does not carry out on-site data center energy audits, which could potentially offer a more nuanced, realistic and up-to-date understanding of the challenges and opportunities faced by these public universities. Moreover, the analysis is zeroes in on more specific sustainability dimensions of energy efficiency, renewable energy, and procurement circular economy principles, without exploring broader university, socio-economic factors that could influence the adoption of sustainable data center practices in the Zimbabwean public higher university context. Finally, the cross-sectional nature of this research study provides a snapshot in time, rather than a long term (longitudinal) perspective that could reveal trends, and the evolving nature of Sustainable ICT data center practices and management in Zimbabwe.

Literature Review

In the 21st century data centers play a central role to support the operations and development of novel ICTs in public universities (Maphosa, 2022). As these institutions increasingly rely on digital infrastructure for teaching and learning, community service, research, innovations and creation of start-up and spin-off companies for industrialization, the need for sustainability in

ICT data center practices becomes paramount as enshrined in Zimbabwe's Education 5.0 doctrine. This literature review explores the various dimensions of sustainable data center practices, focusing on the expansion of computing and connectivity, sustainable design, end-of-life management, powering data centers, power monitoring, cooling solutions, and equipment purchasing within Zimbabwean public university data centers. The objective is to assess current practices and identify strategies for enhancing sustainability in these critical infrastructures.

The Expansion of Computing and Connectivity

Data centers play a pivotal role in supporting the expansion of computing and connectivity in public universities, serving as vital infrastructural hubs for various academic activities. These centers provide the necessary computing power, storage capacity, and network connectivity to facilitate teaching, learning, and research endeavors. With the exponential growth of digital resources and online learning platforms, data centers enable universities to deliver educational content and resources to a wider audience, transcending geographical boundaries (Maphosa, 2022; Mbunge et al., 2020). They enable seamless access to online libraries, research databases, and collaborative platforms, fostering a vibrant academic environment. Additionally, data centers support the development of innovative solutions and the creation of new industries by providing the necessary computational resources for data analysis, modeling, and simulations. They also strengthen community outreach efforts by hosting various online initiatives, webinars, and distance learning programs, thereby extending educational opportunities to individuals who may not have access to traditional classrooms. Overall, data centers serve as the backbone of technological advancements within public universities, catalyzing transformative changes in teaching methodologies, research capabilities, and community engagement.

The Data Centre

A data center can be defined as a centralized facility that houses a large number of computer servers, storage systems, networking equipment, and other critical components necessary for the processing, storage, and distribution of data. It serves as the core infrastructure that supports the information technology operations of an organization or institution. Security systems, including firewalls, intrusion detection systems, and access controls, are implemented in data centers to safeguard the data and infrastructure from unauthorized access and cyber threats. Below are the various data center dimensions:

Green Data Center Dimensions (Source : World Bank , 2023)

Data centers encompass various dimensions, including physical infrastructure-building design, Sustainable ICT, Sustainable energy consumption, Sustainable cooling systems, E-Waste Management and procurement of data center ICT equipment. Each dimension plays a critical role in the overall performance and sustainability of the facility(World Bank , 2023). Understanding these dimensions is essential for developing strategies to enhance the sustainability of data centers in public universities.

Sustainable ICT (SICT)

Sustainable ICT refers to the integration of eco-friendly practices in the design, operation, and disposal of IT infrastructure (Murugesan, 2008). SICT's involves the minimizing of data center technical equipment energy consumption, life cycle management using e-waste reduction techniques, environmentally friendly purchase conditions and decisions, promoting the implementation and use of renewable energy sources. For Zimbabwean public universities, sustainable ICT practices are crucial in managing limited resources while supporting extensive digital services.

Sustainable Design

The deliberate implementing of sustainable design principles in data centers entails employing cutting-edge cooling methods, energy-conserving hardware, renewable energy and water, ultimately influencing energy usage and well-thought-out layouts to minimize energy consumption resulting in significant power saving and lowered environmental footprint (World Bank, 2023b; Ogiemwonyi et al., 2020).

End of Life Management

Whitehead and colleagues (2015) advocated for the integration of Life Cycle Assessment (LCA), a concept closely linked to End of Life (EoL) management. LCA guides EoL management practices, encompassing the monitoring, utilization, disposal, and recycling of outdated ICT equipment to responsibly handle e-waste, thus reducing environmental impact.

Data Centre Power Monitoring

The expanding size, complexity, and energy density of data centers driven by rising needs for storage, networking, and computation have evolved into a global energy challenge (Oro et al., 2015). The equipment consumes energy hence the need for power monitoring to identifying energy usage patterns, opportunities for efficiency improvements and cost minimization.

Sustainable Cooling

ICT equipment within data centers generates substantial heat, necessitating refrigeration solutions for maintaining optimal operating conditions. Two methods are employed to cool IT equipment: air-cooled and liquid-cooled systems. Typically, air cooling, facilitated by Computer Room Air Conditioning (CRAC) units or Computer Room Air Handle (CRAH) units, is conventionally utilized to regulate temperature and humidity, maintaining the IT room environment within operational parameters (Jiang, 2024; Oro et al., 2015).

Sustainable Powering

Data Centers consume power extensively (Bieser and Kunbaz, 2018; Oró et al.,2015). Sustainably powering a data center involves the use of renewable sources of energy, such as

hydro, solar and wind power, to meet the energy needs and decreasing the need for fossil power sources.

Data Centre Equipment Purchasing
Environmentally conscious purchase decisions include selecting servers, storage devices, and networking equipment with high energy efficiency ratings and take back options. Sustainable procurement practices ensure that data centers are equipped with technology that supports long-term sustainability goals.

Theories of Technology Adoption
The proposed research on sustainable ICT infrastructure practices in Zimbabwean public university data centers can be informed by several theoretical frameworks, among the chosen ones is the *Technology-Organization-Environment (TOE)* framework by Tornatzky and Fleischer's (1990).This TOE framework suggests that the adoption of sustainable data center practices in Zimbabwean public universities may be influenced by technological factors (e.g., availability of energy-efficient hardware, virtualization capabilities), organizational factors (e.g., management support, financial resources, technical expertise), and environmental factors (e.g., regulatory pressures, industry norms, competitive landscape).
The Diffusion of Innovation (DOI) theory by Rogers (1995). This DOI thoery can be applied to examine the factors that facilitate or hinder the diffusion of sustainable data center practices among Zimbabwean public universities, such as the perceived relative advantage, compatibility, complexity, trialability, and observability of these practices.
The Upper Echelons Theory developed by Donald C. Hambrick and Phyllis A. Mason in 1984, in the context of this research, the Upper Echelons Theory provides insights into how the perceptions of ICT Directors/ Top ICT Managers as decision-makers shape the adoption of sustainable data center practices.
The Institutional Theory by John W. Meyer and Brian Rowan in 1977 focuses on the role of social, cultural, and regulatory pressures in shaping public university ICT department data center practices. This theory can be used to understand how the institutional environment, including higher and tertiary education, innovation, science and technology development ministry support, government ICT and environmental policies, higher education ICT norms, and professional group expectations, influences the adoption of sustainable data center practices in Zimbabwean public universities.

Research Questions
To guide this research on Zimbabwe public university data center sustainability, the researchers formulated several research questions that align with our research objectives.

a) How are sustainable ICT data center practices currently implemented in Zimbabwean public universities?
b) What are the key drivers that influence the adoption of sustainable data center practices in the context of Zimbabwean public universities?
c) How do ICT directors perceive sustainable data center practices in Zimbabwean public universities?
d) What are the recommended interventions that can facilitate the transition of Zimbabwean public universities towards more sustainable data center operations?

Research Objectives

The overarching aim of this study is to conduct a comprehensive assessment of sustainable information and communications technology (ICT) infrastructure practices within the data centers of Zimbabwean public universities. To achieve this, the following research sub-objectives were formulated:

a) To examine the current state of implementation of Sustainable ICT data center practices in Zimbabwean public universities.
b) To identify the key drivers that influence the adoption of sustainable data center practices in the Zimbabwean public university context.
c) To explore the perceptions of ICT directors towards sustainable data center practices.
d) To provide recommendations to inform the development of targeted interventions that can enable Zimbabwean public universities to transition towards more sustainable data center operations.

Research Methodology

The investigation design of this study was influenced by the World Bank's dimensions of a data center, encompassing physical infrastructure design, sustainable ICT practices, energy consumption, cooling systems, e-waste management, and procurement of ICT equipment. The mixed-methods approach included a quantitative inquiry using an online distributed questionnaire, employing a census approach with ICT 241 Departments' technical personnel, as well as in-depth qualitative interviews with 12 ICT Directors serving as key informants in public university ICT Departments. The questionnaire provided a structured framework for gathering quantitative data, allowing for the analysis of trends and patterns among all technical personnel involved in the ICT Departments, constituting a census approach. This approach aimed to capture a comprehensive overview of the practices within the data centers. Subsequently, in-depth interviews were conducted with ICT Directors, serving as key informants. These interviews aimed to delve deeper into the perspectives, experiences, and insights of the individuals responsible for the strategic decision-making and management of the data centers.

Pilot Study

A pilot study was conducted in public universities to gather preliminary data on the investigated dimensions of data centers. The study involved 31 ICT technical personnel who were selected as participants. This pilot study aimed to test the research instruments, assess the feasibility of data collection methods, and identify any potential challenges or improvements before scaling up the investigation. The 31 ICT technical personnel were chosen from various public universities (ZOU (12), MSU (13) and CUT (6))) to ensure diversity in terms of data center sizes, infrastructures, and practices. These individuals are familiar with operations of data centers within their respective public Universities. During the pilot study, the research instruments (questionnaire and interview protocols) were administered to the ICT Department Technical Personnel as participants.

Data Analysis Plan

The data analysis plan for the research on Zimbabwe Public Universities data center sustainable ICT practices involved several key steps. Firstly, the data was thoroughly checked, cleaned and prepared by addressing missing values, outliers, and inconsistencies. Using SPSS version 27 and Amos 22 descriptive statistics were then generated to summarize key variables

and understand the data's distribution. Comparative analysis across public universities was performed to assess differences and similarities in sustainable ICT practices using appropriate statistical tests and graphs. Correlations and multiple-variate analysis/regression analysis were conducted to investigate relationships between variables and identify factors influencing sustainable ICT practices. Qualitative analysis was carried out using Atlas.ti version 9 following deductive thematic analysis to extract meaningful insights and perspectives using constructs from literature review.

Data Analysis and Results Presentation

This study scrutinised the sustainable ICT practices prevalent in data centers within Zimbabwean public universities, shedding light on the transformative capacity of environmentally conscious infrastructure within the contemporary digital landscape.

Server Virtualisation

The high level of agreement among the majority of respondents (214 out of 241) regarding server virtualization in the context of public universities in Zimbabwe suggests a strong trend towards the implementation of virtualization technologies within these academic institutions. This collective positive attitude towards virtualization signifies a growing recognition of its benefits and potential to enhance the efficiency, flexibility, and sustainability of data centers in the higher education sector.

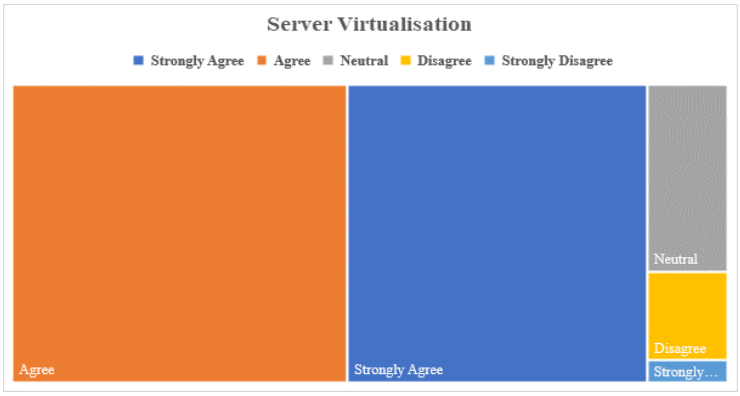

Figure 1 : Public University perceptions on Server Virtualisation

The aforementioned results have been substantiated by qualitative interview excerpts in which ICT Directors shared perspectives live on the implementation of virtualization, as detailed below:

"At the moment we have got six server instances sitting on virtualized platforms "… ICT Director 3

"We got a multi campus setup so each campus has five virtualized. We hope by we would have seven say by year end." ICT Director 4

"All of our servers are on virtualized environments." ICT Director 7

"We have, 12 servers. Of the 12 that we have, 5 are bare metal servers, they are physically on the ground and the other 7 are on cloud. ICT Director 11

Data Centre Power usage Monitoring

The results on data center power monitoring reveal a mixed response among respondents, with a minority expressing positivity, a significant portion showing neutrality, and the majority expressing disagreement. These findings suggest non implementation of power monitoring strategies within Zimbabwe universities data center environments.

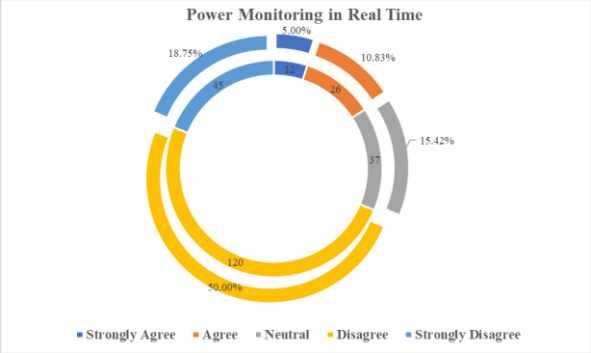

Figure 2: Public University perceptions on Data Centre Power Consumption Monitoring

Energy Efficiency Considerations

These results indicate a varied range of perspectives among respondents regarding the importance of energy efficiency in setting up data center equipment within Zimbabwean public university data centers, with a notable portion remaining neutral and a significant divergence in opinions towards the significance of energy efficiency practices in this context.

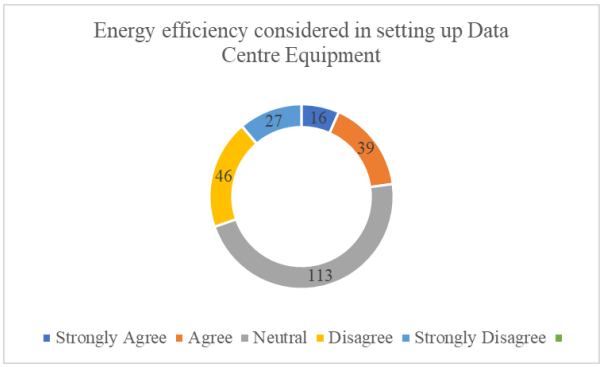

Figure 3: Public University perceptions on Energy efficiency considerations

Power Efficiency Audits For Power Supply Optimization

A combined total of 60 respondents (20 Strongly Agree and 40 Agree) showed agreement with the concept of power efficiency audits for power supply optimization. This suggests a significant portion of respondents acknowledging the importance of conducting audits to optimize power supply efficiency. A total of 150 respondents expressed disagreement with the idea of power efficiency audits for power supply optimization meaning universities are not monitoring DC equipment for power efficiency.

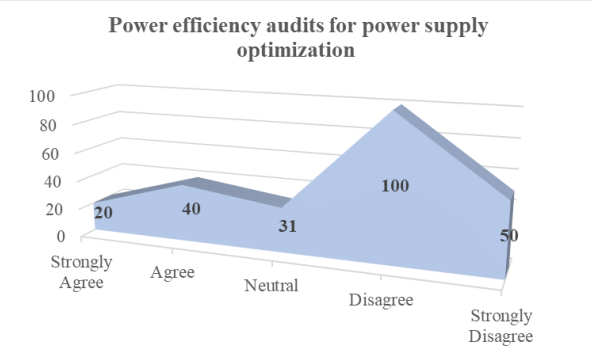

Figure 4: Public University perceptions on Power efficiency audits for power supply optimization

Solar Energy Powering

Fifty-seven respondents concurred on the adoption of solar energy within public universities, 21 remained neutral, and 163 exhibited a negative standpoint. The significant volume of dissenting views suggests that the majority of data centers in Zimbabwean public universities have yet to incorporate solar power solutions.

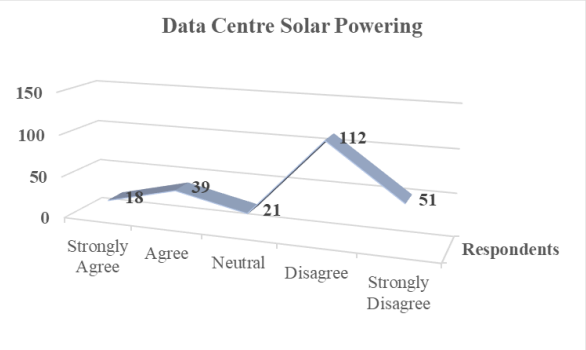

Figure 5: Public University perceptions on Solar Power

Equipment Life Span Monitoring

A minority of 44 respondents indicated agreement with the concept of universities engaging in equipment lifespan monitoring and subsequent replacement upon reaching end-of-life, whereas the majority expressed disagreement. This dissent underscores potential non-implementation of such protocols within the realm of equipment management.

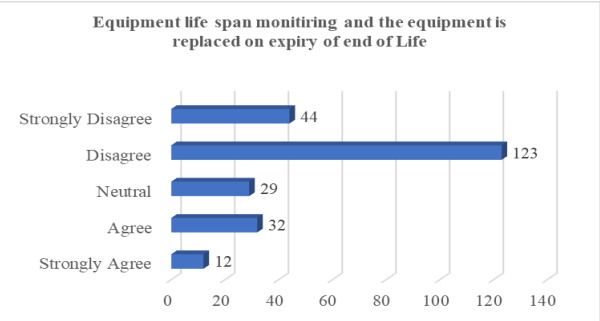

Figure 6: Public University perceptions on Equipment Life span monitoring

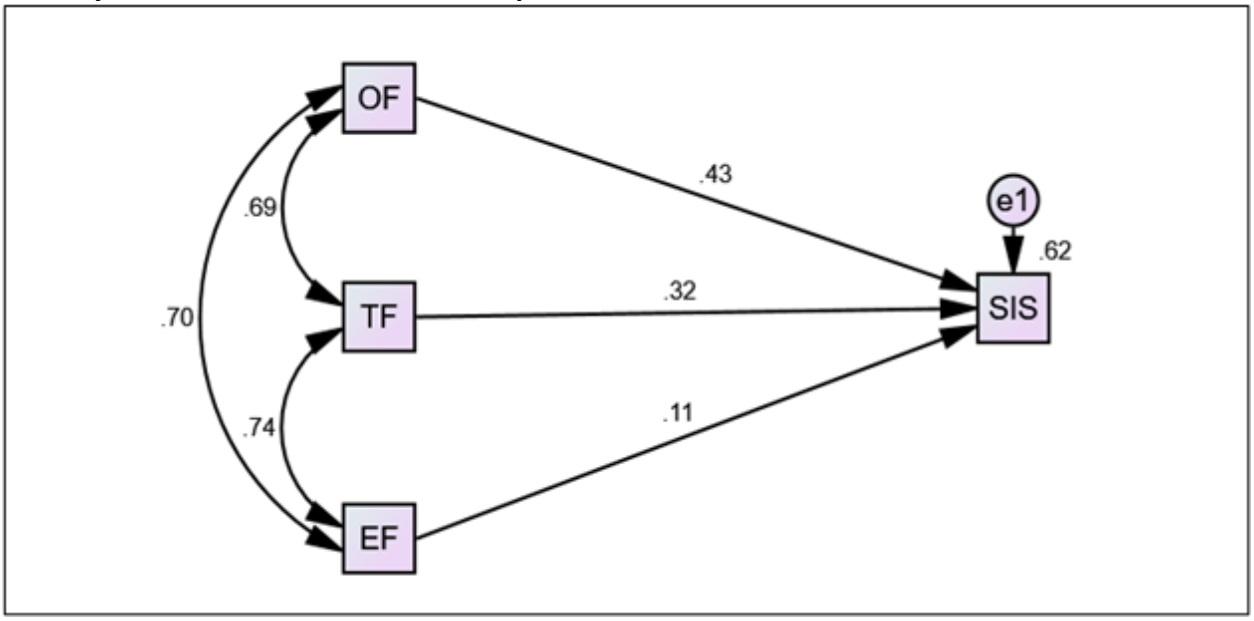

Figure 7: Factors that explain the nature of Data Center Sustainable ICT Infrastructure Practice adoption

The research employed Confirmatory Factor Analysis (CFA), deemed more suitable for examining Data Centre practices, where a conceptual framework based on existing theories such as Technology-Organization-Environment (TOE) and Diffusion of Innovation (DOI) was utilized. A Structural Equation Model was conducted using AMOS to investigate the relationships between organizational factors, technological factors, environmental factors, ICT policy, and data center practice adoption. The study found that Organizational Factors (including employee awareness, sustainable ICT services budget, communication level, staff technical skills, slack resource availability, and management support) and Technological Factors (observability, triability, ease of use, compatibility, perceived usefulness) significantly influence sustainable information and communication technology service practices, while the impact of Environmental Factors (government support, regulatory pressure, customer pressure, competitive pressure) was not statistically significant. The hypothesized relationships were supported for Organizational and Technological factors but not for Environmental factors according to the analysis results.

Findings and Conclusions

The study's findings provide valuable insights into the current state of sustainable ICT infrastructure practices in Zimbabwean public university data centers. These findings highlight the need for targeted interventions, financial support, policy frameworks, and a holistic approach to drive sustainable practices in data centers. More specifically there is:

a) Mixed picture of adoption

The positive indicators - the research found a widespread use of server virtualization and database consolidation among Zimbabwean public university data centers. These practices contribute to optimizing resource utilization and reducing hardware requirements.

Critical gaps - However, the study also identified significant gaps in sustainable data center practices. There was a lack of energy usage monitoring, energy efficiency considerations in equipment procurement, and continuous power audits.

b) Limited Adoption of Sustainable Data Center Practices

The research revealed a limited adoption of sustainable data center practices in Zimbabwean public universities. Specifically, there was an absence of natural air-cooling systems, automated temperature control systems, and integration of renewable energy sources such as solar and wind power.

c) Challenges in Implementing Sustainable Initiatives

Despite some progress, the study identified challenges in fully implementing sustainable initiatives in data centers. Funding constraints were a significant barrier, limiting the ability of universities to invest in infrastructure upgrades and sustainable technologies. While the Ministry of Higher Education funded solarization projects at some universities, this benefit was not extended to others. Consequently, the implementation of renewable energy in data centers remains partial, as many universities struggle to fund recurrent expenditures, let alone capital intensive projects like server room renewable power supply.

d) Lack of Guiding Policies and Life-Cycle Management

The research revealed a notable lack of institutional policies and guidelines for sustainable ICT infrastructure maintenance and life-cycle management practices. Without clear guidelines, it becomes challenging to ensure consistent and effective implementation of sustainable initiatives. The development of guiding policies can provide a framework for sustainable practices and facilitate their integration into data center operations.

e) Need For a Holistic and Systematic Approach

The findings emphasize the need for a more comprehensive and coordinated approach to promoting sustainability in Zimbabwean public university data centers. This includes addressing technical gaps, establishing guiding policies, and considering the entire life cycle of data center infrastructure.

Recommendations

These practices aim to curtail energy usage, enhance efficiency, minimize e-waste, and mitigate environmental impact. Data centers support mission-critical ICT digital technologies and administrative systems (for teaching and research), can serve as testbeds for sustainable ICT initiatives that can be replicated across other sectors. Chief among these studies recommendations is:

Governments play a vital role in creating an enabling environment for green data centers through policies, incentives, and regulations (Hossain et al., 2020). The government of Zimbabwe through Ministry of ICT and governments parastatals (POTRAZ) should establish green building standards, incentivize the use of renewable energy sources, regulate the use of cooling systems, and support efficient e-waste management practices. This guide targets a wide range of practitioners, from policymakers to data center technicians, offering principles applicable to policymaking, regulation, as well as development, operation, and procurement of data center infrastructure (World Bank , 2023b; Hossain et al., 2022).

Developing and implementing university policies and guidelines specific to sustainable data center management is crucial to provide a framework for implementing and monitoring sustainable ICT practices.

Enhancing institutional capacity and skills development through training programs and workshops will empower ICT technical staff to adopt and implement sustainable ICT practices effectively.
Fostering cross-institutional collaboration and knowledge sharing platforms will facilitate the exchange of best practices and lessons learned among data center professionals in other universities and industry.
Regular monitoring and evaluation of the impact of sustainable data center practices will allow for continuous improvement and the identification of areas that require further attention.

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