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From Static Audits to Dynamic Intelligence: Operationalizing Sustainable Computing in Local Governments as a Precursor to Smart-City Energy Analytics

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ABSTRACT

The digital transformation of public services, while enhancing administrative efficiency, imposes a critical environmental externality on urban energy grids and material lifecycles a contradiction that directly threatens the net-zero ambitions of smart cities. Despite global sustainability pledges, empirical, granular data on the computing-energy nexus within Local Government Units (LGUs) remain conspicuously absent, particularly in rapidly digitizing developing regions. This mixed-methods study addresses this empirical lacuna through a diagnostic audit of Information and communication technology (ICT) infrastructure and operational behaviors within the LGU of Odiongan, Romblon. Leveraging face-to-face surveys (n=15 departmental representatives) conducted in May 2023 and triangulated with thematic policy analysis, we uncover a severe implementation gap: while 100% of offices utilize grid-powered desktop/laptop infrastructure, 85.7% lack consistent power-management discipline, 88.9% resort to improper e-waste disposal, and 80.0% have never conducted a carbon-footprint assessment. Paradoxically, we find nascent cloud adoption and formal sustainability policies, indicating institutional readiness for structured governance. To bridge this divide, we propose a novel Sustainable ICT Performance Framework a layered architecture integrating energy metering protocols, life-cycle procurement standards, and annual reporting dashboards. Crucially, this framework provides the empirical baseline and logical blueprint for future AI-driven predictive energy audits and real-time IoT sensor integration, transforming passive municipal compliance into active, data-driven urban energy intelligence.

1. Introduction

Climate change mitigation requires institutions to measure and reduce greenhouse gas emissions from everyday operations. The Intergovernmental Panel on Climate Change emphasizes the need for rapid and sustained emissions reductions across sectors, while organizational carbon accounting provides a basis for identifying emission sources and setting reduction priorities [1, 10, 11]. Public

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institutions are part of this transition because office facilities, transportation, procurement, information systems, and waste-management practices all influence their environmental performance. Information and communication technology (ICT) can support efficient public services, paperless transactions, remote coordination, environmental monitoring, and evidence-based decision-making. However, digital technologies also consume electricity, require resource-intensive manufacturing, and generate electronic waste. Global estimates show that ICT-sector energy use and emissions require systematic measurement, efficiency standards, and life-cycle management [2, 3, 15].

1.1 Environmental Impacts of Computing Practices

Green computing refers to the environmentally responsible acquisition, operation, maintenance, and disposal of computing resources. It includes energy-efficient hardware, optimized power settings, equipment sharing, preventive maintenance, software and data management, responsible procurement, and secure end-of-life handling. In public administration, successful Green IT requires governance, measurable indicators, staff participation, and alignment between institutional objectives and ICT decisions [4]. Digital transformation has a dual sustainability effect. It may reduce travel, paper consumption, and administrative delays, but poorly managed devices, redundant data, unnecessary storage, and frequent replacement can increase electricity demand and material consumption [5, 6]. Sustainable ICT therefore requires both technical improvements and organizational behavior change.

1.2 Energy Efficiency, Equipment Life Cycle, and E-Waste

Computers, monitors, printers, servers, network equipment, cooling systems, and uninterruptible power supplies consume energy during active and idle periods. Power-management settings, shutdown protocols, energy-efficient purchasing, and monitoring can reduce unnecessary electricity use. ENERGY STAR specifications and related standards provide practical performance criteria for office computers and equipment [18]. The environmental impact of computing also extends beyond operational electricity. Device manufacturing requires minerals, energy, water, and global supply chains, while premature replacement contributes to electronic waste. Global E-waste Monitor 2024 reported that 62 billion kilograms of e-waste were generated worldwide in 2022 and only 22.3% was formally collected and recycled, highlighting the need for asset inventories, repair, reuse, and environmentally sound disposal [7].

1.3 Digital Government and Low-Carbon Local Governance

Local government units are well positioned to demonstrate sustainable operations because they procure equipment, manage public facilities, deliver digital services, and influence community practices. Research across 51 countries found that e-government development can contribute to lower carbon-emission intensity through improvements in administrative and economic efficiency [8]. The benefit, however, depends on how digital infrastructure is acquired, operated, maintained, and retired. In the Philippines, Republic Act No. 11285 institutionalizes energy efficiency and conservation and identifies responsibilities for government entities [12]. Administrative Order No.

15, issued in 2024, further directed the accelerated implementation of the Government Energy Management Program in government offices [13]. Integrating ICT equipment into energy plans and inventories can help local governments meet these policy expectations while reducing operating costs.

1.4 Framework of the Study

The study applies an input-process-output framework. Inputs include the condition and availability of computing infrastructure, energy-use routines, equipment life-cycle practices, staff awareness, digital-work arrangements, and existing institutional policies. The process consists of survey administration, descriptive analysis, thematic interpretation, data-quality review, and assessment against Green IT and carbon-management principles. The intended output is a sustainable ICT framework translating identified gaps into governance, procurement, operations, training, monitoring, and e-waste actions.

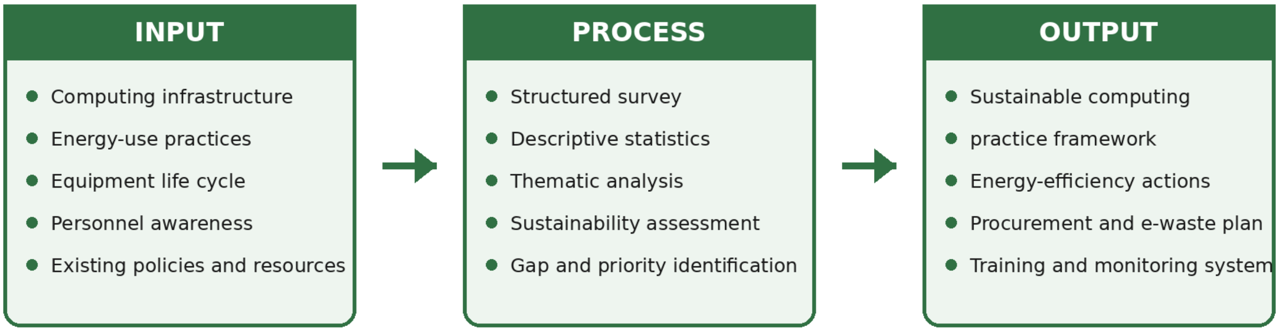

Fig. 1. Conceptual framework of the assessment of computing practices for low-carbon local governance

1.5 Research Gap and Significance

Many carbon-footprint studies focus on national ICT sectors, data centers, private companies, or large institutions. Philippine institutional evidence has shown that purchased electricity can be a major component of an organization's footprint, demonstrating the importance of energy records and standardized inventories [9]. Limited research, however, documents day-to-day computing practices in small local governments, particularly in island provinces where procurement, technical support, repair services, and accredited e-waste disposal may be constrained.

This study provides a localized diagnostic assessment for the LGU of Odiongan. Its findings can inform equipment planning, energy-efficiency measures, staff development, e-waste procedures, and future greenhouse-gas inventories. The study supports SDG 7, SDG 9, SDG 12, SDG 13, and SDG 16 by connecting digital government with energy responsibility, circular resource use, climate action, and accountable public administration.

1.6 Objectives of the Study

This study aimed to assess the computing practices of the Local Government Unit of Odiongan as a basis for sustainable practices. Specifically, it sought to:

- describe the hardware and software technologies used by the represented LGU offices;
- assess power-management, energy-consumption, and office energy-efficiency practices;
- examine software management, cloud use, data security, and remote-work practices;
- evaluate equipment disposal, paper and electronic-waste management, procurement, policy, training, and monitoring practices; and
- propose a sustainable ICT framework for reducing the environmental footprint of LGU computing operations.

2. Methodology

2.1 Research Design

The study used a mixed-methods descriptive research design combining quantitative survey results and qualitative interpretation. The quantitative component summarized the frequency of reported computing practices, while the qualitative component interpreted recurring operational concerns and proposed improvement measures. Mixed methods were appropriate because the study sought both numerical descriptions and an institutional understanding of how practices, policies, and awareness interact [19].

2.2 Research Locale and Participants

The research was conducted in the Municipality of Odiongan, Province of Romblon, Philippines. Odiongan is a first-class municipality with multiple administrative and service offices that use computers, printers, scanners, network devices, and related equipment for public-service delivery. Fifteen representatives from different LGU offices and units participated in the survey. Respondents were selected based on accessibility and familiarity with office computing practices. The assessment is therefore treated as an institutional diagnostic rather than a statistically representative survey of all municipal employees.

2.3 Research Instrument

Data were collected through a structured questionnaire containing multiple-choice, checklist, and open-ended items. The instrument covered hardware and software technologies, equipment power management, electricity sources and consumption, software updates, data security, remote work, equipment and paper disposal, office energy efficiency, carbon-reduction policies, training, energy audits, e-waste management, sustainable procurement, energy conservation, and green-building practices. Open-ended responses supported the interpretation of institutional challenges and recommended actions.

2.4 Data Collection Procedure

The survey was administered face-to-face on 9–10 May 2023. Respondents were informed of the purpose of the study and the voluntary nature of participation. Completed questionnaires were organized by assessment dimension, and the resulting statistical outputs were reviewed with the assistance of a university statistician.

2.5 Data Analysis

Quantitative responses were analyzed using frequencies and percentages. For this journal revision, valid response counts were reconstructed from the sum of the frequencies shown in the archived tables. Percentages were recalculated using the valid response count for each single-response item. For checklist or multiple-response items, percentages represent the proportion of all recorded selections. Qualitative findings were examined through thematic analysis to identify recurrent gaps and implementation priorities [20].

2.6 Data Quality and Reporting Conventions

The archived statistical tables contained several inconsistencies in totals, labels, and duplicated content. These were addressed conservatively without inventing data. Where frequencies did not equal the stated total, the valid count was derived from the listed frequencies and missing responses were noted. The software-update item recorded 16 selections despite a study sample of 15; the figures are retained as archived but marked for verification against the raw dataset. The archived Table 25 duplicated the green-building table even though its narrative referred to carbon-footprint tracking; consequently, no separate carbon-tracking percentage is reported. These limitations should be resolved using the original dataset before final publication.

2.7 Ethical Considerations

Permission to conduct the study was secured from the municipal government. Respondents provided informed consent, and their confidentiality and anonymity were protected. Results are presented at the institutional level and are intended for research and organizational improvement.

3. Results

3.1 ICT Hardware and Software Profile

The represented offices relied on common office-computing technologies. Desktop computers, laptops, and printers were each reported 15 times, while scanners were reported 14 times and servers twice. The hardware profile indicates broad access to end-user devices but limited server infrastructure. Office productivity software represented 37.5% of all recorded software selections, followed by communication and collaboration software at 30.0% and operating systems at 22.5%. Accounting and database applications each represented only 5.0% of the selections (Table 1).

Table 1

Hardware and Software Technologies Reported by the LGU Offices

Category	Technology	Frequency	% of selections
Hardware	Desktop computers	15	24.6
Hardware	Laptops	15	24.6

Hardware	Printers	15	24.6
Hardware	Scanners	14	23.0
Hardware	Servers	2	3.3
Software	Office productivity software	15	37.5
Software	Communication and collaboration software	12	30.0
Software	Operating system	9	22.5
Software	Accounting software	2	5.0
Software	Database software	2	5.0

Note. Multiple responses were permitted. Hardware percentages are based on 61 selections; software percentages are based on 40 selections.

3.2 Power Management and Energy-Use Practices

Power-management practices were inconsistent. Among 14 valid responses, 85.7% indicated that hardware was only sometimes turned off when not in use, while only 7.1% reported always doing so (Table 2). Respondents nevertheless reported the use of power-saving and sleep modes, suggesting that energy-saving features were available but not consistently reinforced through daily shutdown behavior. All respondents identified grid electricity as the primary energy source, making purchased electricity the main operational pathway through which computing contributes to emissions. One-third of respondents could not identify hardware energy consumption, demonstrating limited energy visibility.

Table 2

Power-Management and Hardware Energy-Use Practices

Indicator	Response	Frequency	Valid %
Turn off equipment when not in use	Always	1	7.1
Turn off equipment when not in use	Sometimes	12	85.7
Turn off equipment when not in use	Rarely	1	7.1
Energy-saving feature	Power-saving mode	14	56.0
Energy-saving feature	Sleep mode	10	40.0
Energy-saving feature	Other	1	4.0
Primary energy source	Electricity from the grid	15	100.0
Reported hardware energy use	500–1,000 kWh	10	66.7
Reported hardware energy use	Do not know	5	33.3

Note. One response was missing from the equipment shutdown item. Energy-saving features were a multiple-response item with 25 selections; the percentages shown for that item are percentages of selections.

3.3 Software, Cloud, Data-Security, and Remote-Work Practices

Digital-work capacity was comparatively strong. Cloud-based applications were reported by 85.7% of 14 valid respondents. Regular data backup represented 76.5% of 17 recorded data-security selections, while provision of laptops or other equipment represented 84.6% of valid remote-work responses. These practices support continuity, collaboration, and reduced travel. However, software updating was generally infrequent: 81.3% of the archived responses indicated updates once a year or less, and 6.3% indicated no software updates. Infrequent updating may increase security, compatibility, and efficiency risks (Table 3).

Table 3

Software Management, Cloud Use, Data Security, and Remote Work

Indicator	Response	Frequency	Valid %
Software application updates	Every six months	2	12.5
Software application updates	Once a year or less	13	81.3
Software application updates	No software updates	1	6.3
Cloud-based applications	Yes	12	85.7
Cloud-based applications	No	2	14.3
Data security	Regular data backups	13	76.5
Data security	Other method	4	23.5
Remote work	Provide laptops or other equipment	11	84.6
Remote work	Flexible schedule	1	7.7
Remote work	Video conferencing/collaboration tools	1	7.7

Note. The archived software-update output contains 16 selections for 15 participants and requires verification using raw dataset. Data security was treated as a multiple-response item with 17 selections. Cloud use had 14 valid responses; remote work had 13 valid responses.

3.4 Equipment Life Cycle and Waste Management

The waste-management results were mixed. Paper recycling was widely reported, with 86.7% of 15 respondents indicating that paper waste was recycled. Similarly, 83.3% of 12 valid respondents reported presence of electronic-waste management. However, among nine valid responses describing actual hardware disposal, 88.9% stated that equipment was thrown away and only 11.1% reported recycling (Table 4). This contradiction suggests that respondents may recognize or report an e-waste initiative without consistently applying a documented, traceable disposal process to obsolete devices.

Table 4

Equipment Disposal and Waste-Management Practices

Indicator	Response	Frequency	Valid %
Disposal of hardware equipment	Throw it away	8	88.9
Disposal of hardware equipment	Recycle it	1	11.1
Electronic-waste management	Yes	10	83.3
Electronic-waste management	No	2	16.7
Paper-waste management	Recycle it	13	86.7
Paper-waste management	Use for notes and memos	2	13.3

Note. Hardware disposal had nine valid responses; electronic-waste management had 12 valid responses; paper-waste management had 15 valid responses.

3.5 Office Energy Efficiency, Policy, Training, and Measurement

The largest operational weaknesses involved office energy efficiency and organizational capability. Only 11.1% of nine valid respondents reported energy-efficient lighting, and only 13.3% of 15 respondents reported energy-efficient air-conditioning. Eighty percent stated that no energy audit or carbon-footprint assessment had been conducted, while 76.9% of 13 valid respondents reported no sustainable-computing training. In contrast, 78.6% of 14 valid respondents reported a carbon-footprint reduction policy (Table 5). The coexistence of formal policy and limited auditing, training, and efficient equipment indicates that policy implementation was not yet sufficiently supported by measurement and capacity development.

Table 5

Office Energy Efficiency and Institutional Capacity

Indicator	Response	Frequency	Valid %
Energy-efficient lighting	No	8	88.9
Energy-efficient lighting	Yes	1	11.1
Energy-efficient air-conditioning	No	13	86.7
Energy-efficient air-conditioning	Yes	2	13.3
Carbon-footprint reduction policy	Yes	11	78.6
Carbon-footprint reduction policy	No	3	21.4
Sustainable-computing training	No training	10	76.9
Sustainable-computing training	Every month	1	7.7
Sustainable-computing training	Every six months	1	7.7
Sustainable-computing training	Once a year	1	7.7
Energy audit/carbon assessment	No	12	80.0
Energy audit/carbon assessment	Yes	3	20.0

Note. Lighting had nine valid responses; the carbon-policy item had 14; the training item had 13; air-conditioning and energy-audit items had 15.

3.6 Sustainable Procurement, Mobility, and Conservation Practices

Respondents reported several positive institutional practices. A technology-procurement sustainability policy represented 92.9% of 14 valid procurement responses, while 85.7% reported sustainability criteria in technology procurement. Energy-conservation policies were reported by 92.9% of 14 valid respondents, and green-building practices by 86.7% of all respondents. Twelve respondents also indicated that the LGU promotes public transportation or carpooling by providing information (Table 7).

Table 6

Sustainable Procurement, Mobility, Energy Conservation, and Green-Building Practices

Indicator	Response	Frequency	Valid %
Public transportation/carpooling	Provide information	12	100.0
Technology procurement practice	Sustainability policy	13	92.9
Technology procurement practice	Evaluate vendor sustainability	1	7.1
Procurement sustainability criteria	Sustainability policy	12	85.7
Procurement sustainability criteria	Consider energy efficiency/carbon	1	7.1
Procurement sustainability criteria	No sustainability criteria	1	7.1
Energy conservation among staff	Energy-conservation policy	13	92.9
Energy conservation among staff	No initiative	1	7.1
Green-building practices	Yes	13	86.7
Green-building practices	No	2	13.3

Note. Public-transport promotion had 12 valid responses. Procurement and energy-conservation items had 14 valid responses. Green-building practices had 15 valid responses. The original label "implementation of renewable energy solutions" was corrected because the response options referred to technology procurement rather than renewable energy.

Nevertheless, very few responses specifically identified vendor sustainability evaluation or direct consideration of the energy efficiency and carbon footprint of purchased technology. This suggests that broad policy language may not yet be translated into detailed procurement specifications and vendor-screening procedures.

3.7 Integrated Assessment of Strengths and Priority Gaps

Taken together, the results show that the LGU had basic digital infrastructure and several reported sustainability policies, but implementation, monitoring, and behavior were uneven. The most important pattern is not a complete absence of sustainability activity; rather, it is a gap between stated institutional intentions and everyday operational evidence. Policies were reported by a large majority, yet most respondents reported no energy audit, no regular training, limited efficient lighting and air-conditioning, inconsistent shutdown behavior, and problematic hardware disposal (Table 7).

Table 7

Integrated Interpretation of Major Strengths and Gaps

Type	Evidence	Interpretation	Priority response
Strength	Cloud applications: 85.7%	Supports digital service continuity and collaboration	Maintain with data-retention and energy controls
Strength	Paper recycling: 86.7%	Established resource-recovery behavior	Document procedures and track volumes
Strength	Policies: 78.6%–92.9%	Provides a governance foundation	Translate policy into responsibilities and indicators
Gap	Only 7.1% always turned off unused hardware	Idle energy use is likely avoidable	Adopt automatic sleep/shutdown standards
Gap	33.3% did not know equipment energy consumption	Energy performance cannot be managed without records	Create an ICT energy baseline
Gap	80.0% reported no energy audit/carbon assessment	No verified baseline for reduction targets	Conduct annual energy and emissions assessments
Gap	76.9% reported no sustainable-computing training	Policies may not influence employee behavior	Require annual staff orientation
Gap	88.9% of valid disposal responses threw hardware away	Environmental, data-security, and compliance risks	Use secure reuse and accredited e-waste channels
Gap	Efficient lighting 11.1%; air-conditioning 13.3%	Facility energy demand may remain unnecessarily high	Phase in efficient lighting and high-efficiency cooling

3.8 Proposed Sustainable ICT Framework

Based on the results, the study proposes a framework that connects governance, measurement, energy-efficient operations, life-cycle procurement, circular equipment management, staff capability, and transparent reporting. The framework prioritizes low-cost operational controls while building the records needed for future greenhouse-gas inventories and investment decisions (Table 8).

Table 8

Proposed Sustainable ICT Action Plan for the LGU of Odiongan

Framework area	Priority actions	Suggested indicators	Timeline
Baseline and governance	Create a complete ICT asset inventory; designate responsible offices; integrate ICT into the energy-management plan	Inventory coverage; responsible persons designated; approved annual plan	0–6 months
Energy measurement	Conduct an energy audit; record electricity use and device operating hours; estimate Scope 2 emissions	Audit completed; monthly kWh record; annual emissions baseline	0–12 months
Power management	Standardize automatic sleep, monitor-off, and shutdown settings; post end-of-day checklists	% devices configured; spot-check compliance; estimated kWh saved	0–6 months
Efficient facilities and ICT	Prioritize efficient lighting, air-conditioning, computers, monitors, printers, and shared devices	% efficient units; procurement compliance; energy intensity	1–3 years
Software and data management	Establish update schedules, secure backups, storage-retention rules, and cloud-use guidelines	Update compliance; backup success; storage reduced	0–12 months
Life-cycle procurement	Use total-cost, energy, durability, repairability, warranty, and vendor take-back criteria	% procurements using sustainability criteria; average device life	0–12 months
Reuse and e-waste	Sanitize data; repair or redeploy usable devices; use documented accredited disposal channels	% devices reused/repaired; disposal certificates; zero informal disposal	0–12 months
Training and behavior	Provide annual sustainable-computing and energy-conservation training with office champions	Training completion; knowledge checks; shutdown compliance	Every year
Mobility and reporting	Support online collaboration, carpool/public-transport information, and annual sustainability reporting	Remote meetings; mobility initiatives; annual report issued	Every year

4. Discussion

The study demonstrates that the environmental performance of digital government depends on operational discipline and institutional capacity as much as on technology availability. The LGU possessed common office hardware, cloud applications, backup practices, and remote-work equipment, indicating that digital tools were already embedded in service delivery. These capabilities can reduce paper consumption, unnecessary travel, and administrative delays. However, digitalization produces environmental benefits only when energy use, equipment life cycles, data storage, and waste are actively governed [5, 6].

The inconsistent shutdown behavior, total dependence on grid electricity, limited knowledge of energy consumption, and absence of an audit among most respondents show that the LGU lacked a reliable ICT-energy baseline. This finding is consistent with Green IT research in public administration, which emphasizes that environmental alignment requires indicators, asset information, energy-saving rules, and continuous evaluation rather than isolated technology purchases [4]. Because purchased electricity can be a dominant institutional emissions source, a baseline based on electricity records, device inventories, and operating hours is essential [9, 11].

The results also reveal an important policy–practice gap. Respondents frequently reported sustainability, procurement, conservation, e-waste, and green-building policies, yet operational evidence showed little training, limited energy audits, low penetration of efficient lighting and air-conditioning, and disposal of obsolete hardware through throwing it away. This may reflect differences in respondents' interpretation of "policy," uneven implementation across offices, or policies that are not supported by procedures, budgets, records, and accountability. For a resource-constrained local government, the most practical starting points are low-cost measures: asset inventories, power-management settings, shutdown protocols, preventive maintenance, shared-device optimization, and staff orientation. These measures can generate operational savings while establishing the records needed for more advanced carbon accounting. Equipment life-cycle management is equally important. Extending the useful life of serviceable devices can reduce premature procurement and embodied emissions, while secure reuse and accredited disposal can reduce e-waste risks [7].

The proposed framework is also relevant to Philippine public-sector energy obligations. Republic Act No. 11285 established a national policy of energy efficiency and conservation, while the Government Energy Management Program provides implementation guidance for government entities [12, 13]. Integrating ICT equipment into energy plans can help LGUs demonstrate compliance and generate evidence for budget decisions.

The study has limitations. The participant group was small and purposively drawn from office representatives, so the findings should not be generalized to all employees or other municipalities. Several archived statistical outputs also contained inconsistent totals and labels. Before final publication, the raw dataset should be checked to confirm the software-update item and any item-level discrepancies. Future research should triangulate survey responses with electricity bills, device inventories, procurement records, and e-waste documentation and may calculate Scope 1, Scope 2, and selected Scope 3 emissions for the LGU.

5. Conclusions

The Local Government Unit of Odiongan has a functional digital environment and several reported sustainability initiatives, but its computing practices are not yet supported by consistent measurement, implementation, and accountability. The strongest operational concerns were inconsistent shutdown behavior, limited awareness of energy consumption, absence of energy audits, lack of sustainable-computing training, low use of efficient lighting and air-conditioning, and unsafe or undocumented hardware disposal. These findings indicate that the main challenge is not simply technology availability but the institutionalization of sustainable routines across offices.

The presence of cloud applications, regular backups, paper recycling, remote-work support, procurement policies, energy-conservation policies, and reported e-waste and green-building initiatives provides a strong starting point. The LGU should consolidate these efforts through a formal sustainable ICT framework based on an asset and energy baseline, automatic power management, efficient procurement, equipment life-cycle planning, secure reuse and accredited e-waste disposal, annual staff training, and transparent monitoring. These measures can reduce avoidable energy use and operating costs while strengthening public accountability and contributions to climate action and responsible consumption. In future studies, some recent artificial intelligence tools can be adopted [21-29].

Author Contributions

Conceptualization, Z.N.F., W.M.Q.F., and D.D.L.; methodology, Z.N.F., W.M.Q.F., and D.D.L.; investigation, Z.N.F. and W.M.Q.F.; data curation, Z.N.F. and W.M.Q.F.; formal analysis, Z.N.F., W.M.Q.F., and D.D.L.; writing—original draft preparation, Z.N.F., W.M.Q.F., and D.D.L.; writing—review and editing, D.D.L.; visualization, D.D.L.; supervision, D.D.L.; project administration, Z.N.F. and D.D.L. All authors have read and agreed to the submitted version of the manuscript.

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Data Availability Statement

The raw survey data and original statistical outputs are available from the corresponding author upon reasonable request and subject to permission from the participating local government unit.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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