

Green Computing Approaches for Sustainable Digital Systems

Jalil Boudjadar

Associate Professor, Aarhus University, Denmark

Abstract

The rapid expansion of digital technologies has increased computational capacity, data-processing requirements, cloud infrastructure, network traffic, and electronic equipment consumption, creating significant environmental and energy-related concerns. Green computing provides an approach for reducing the environmental impact of digital systems through energy-efficient hardware, optimized software, sustainable data centers, virtualization, cloud-resource optimization, electronic-waste management, renewable energy integration, and lifecycle-oriented technology management. This study examines green computing approaches for developing sustainable digital systems, with particular emphasis on energy efficiency, resource optimization, sustainable computing infrastructure, intelligent workload management, and responsible electronic-device lifecycle practices. A qualitative descriptive and conceptual research design was adopted using secondary academic literature. The analysis explores how green computing strategies can reduce electricity consumption, carbon emissions, hardware waste, cooling requirements, and unnecessary computational resource utilization.

Virtualization and cloud computing can improve server utilization, while energy-aware scheduling can dynamically allocate computational workloads according to system requirements. Sustainable data-center practices can further improve efficiency through advanced cooling systems, server consolidation, renewable energy, and infrastructure monitoring. Green software engineering can contribute by designing applications that minimize unnecessary computation, memory utilization, data transfer, and processing demands. However, implementation remains affected by challenges including high modernization costs, legacy infrastructure, limited sustainability awareness, technical complexity, inconsistent measurement standards, and electronic-waste management difficulties. The study emphasizes integrated green computing frameworks that connect hardware efficiency, software optimization, cloud management, energy-aware computing, renewable energy, and responsible technology disposal. Such frameworks can support sustainable digital transformation while maintaining appropriate computational performance. Future research should investigate intelligent energy management, carbon-aware computing, sustainable artificial intelligence, green software engineering, low-power architectures, circular electronics, and standardized sustainability metrics for digital systems.

Keywords: Green Computing, Sustainable Digital Systems, Energy Efficiency, Green Software, Cloud Computing, Data Centers, Virtualization, Sustainable IT, Electronic Waste, Carbon-Aware Computing

1. Introduction

Digital technologies have become essential components of contemporary economic, educational, industrial, governmental, and social systems. The expansion of cloud computing, artificial intelligence, big-data analytics, Internet of Things networks, and high-performance computing has substantially increased computational requirements. Although digitalization can improve efficiency and connectivity, digital infrastructure also consumes electricity, requires hardware resources, generates heat, and contributes to electronic waste. These developments have increased interest in computing approaches that integrate environmental sustainability into technology design and management.

Green computing refers broadly to practices aimed at reducing the environmental impacts associated with computing technologies throughout their lifecycle. These practices include energy-efficient hardware, optimized software, server virtualization, efficient cooling systems, cloud-resource management, renewable energy utilization, responsible device procurement, and electronic-waste reduction. Green computing therefore extends beyond reducing electricity consumption during device operation and includes manufacturing, transportation, maintenance, reuse, recycling, and disposal considerations.

Data centers represent an important area for green computing because they operate large numbers of servers, storage systems, networking equipment, and cooling infrastructure. Virtualization can consolidate workloads and improve server utilization, while intelligent workload scheduling can reduce unnecessary computational activity. Advanced cooling systems and renewable energy can further contribute to more sustainable data-center operations. Cloud computing can also improve resource utilization when computing capacity is dynamically allocated according to demand.

Software design has an important relationship with computing sustainability. Applications that require excessive processing, memory, storage, or network communication can increase energy consumption. Green software engineering therefore focuses on developing applications that achieve required functionality with efficient computational resource utilization. Algorithm optimization, efficient data structures, workload reduction, and energy-aware programming can contribute to lower computational requirements.

Despite these opportunities, green computing implementation involves financial, technological, organizational, and operational challenges. Organizations may operate legacy infrastructure that is difficult to replace, while sustainability metrics may differ across technologies and providers. Electronic waste also creates environmental concerns when obsolete equipment is improperly managed. This study examines green computing approaches for sustainable digital systems, focusing on energy efficiency, sustainable infrastructure, software optimization, cloud computing, electronic-waste management, implementation challenges, and future research directions.

2. Objectives of the Study

2.1 Examination of Green Computing Approaches

The first objective is to examine major green computing approaches, including energy-efficient hardware, virtualization, cloud-resource optimization, sustainable data-center management, green software engineering, renewable-energy integration, and electronic-waste reduction. The study analyzes how these approaches can reduce energy consumption and improve computational resource utilization.

Particular attention is given to technologies and management practices that support sustainable operation of digital systems while maintaining appropriate performance, reliability, scalability, and availability across different computing environments.

The study also aims to examine how green computing principles can be incorporated throughout the lifecycle of digital technologies. This includes technology selection, system design, deployment, operation, maintenance, upgrading, reuse, recycling, and disposal. The objective considers how organizations can integrate environmental considerations into information-technology management rather than treating sustainability as an isolated operational activity. It further explores the relationship between efficient computing architecture, responsible resource utilization, environmental performance, and long-term digital-system sustainability.

2.2 Assessment of Energy and Resource Efficiency

The second objective is to assess the contribution of green computing approaches to energy and resource efficiency within digital systems. The study examines energy-aware workload scheduling, server consolidation, virtualization, efficient storage, optimized networking, low-power hardware, and intelligent cooling systems. These approaches can reduce unnecessary computational activity and improve utilization of available infrastructure. The analysis also considers how cloud platforms and automated resource allocation can respond to changing computational demand while limiting unnecessary consumption.

The study further evaluates the relationship between computing efficiency and broader environmental sustainability. Attention is given to electricity consumption, carbon emissions, cooling requirements, hardware utilization, resource depletion, and electronic waste. The objective is to understand how technical optimization can contribute to environmental improvements across digital infrastructure. It also considers the importance of measuring energy and resource performance using consistent indicators so that organizations can evaluate sustainability improvements and identify areas requiring further optimization.

2.3 Identification of Implementation Challenges

The third objective is to identify financial, technical, organizational, and operational challenges affecting the adoption of green computing practices. The study examines the costs of upgrading infrastructure, replacing inefficient hardware, implementing renewable-energy systems, optimizing software, and establishing sustainable data-center facilities. It also considers challenges related to legacy systems, limited technical expertise, sustainability awareness, interoperability, performance requirements, and difficulties in measuring environmental outcomes across complex digital infrastructures.

The study also aims to examine strategies that can facilitate wider adoption of sustainable computing practices. Particular attention is given to employee awareness, green IT policies, sustainability-oriented procurement, lifecycle management, standardized measurement frameworks, energy monitoring, and responsible electronic-waste practices. Understanding these factors can help organizations develop practical approaches to integrating sustainability with digital transformation. The objective therefore connects technological improvements with organizational planning and long-term environmental management within information-technology environments.

3. Review of Literature

3.1 Green Computing and Sustainable Information Technology

Murugesan (2008) examined green computing as an approach for reducing the environmental impact of computing technologies across their lifecycle. The study identified energy-efficient computing, responsible hardware use, sustainable disposal, and environmentally conscious system design as important components of green information technology. The literature emphasizes that sustainability should be considered during technology acquisition, operation, maintenance, and disposal. This lifecycle perspective provides a broader foundation for evaluating digital sustainability beyond electricity consumption alone and highlights the importance of organizational policies supporting environmentally responsible computing.

Molla et al. (2010) examined organizational approaches to green information systems and emphasized the importance of integrating sustainability into information-technology strategies. Their work indicates that green IT can involve both technical improvements and organizational practices. Energy-efficient infrastructure, responsible procurement, system optimization, and environmental management can collectively support sustainability objectives. The literature suggests that organizations require appropriate governance structures, awareness, policies, and performance measures to ensure that green computing becomes part of broader information-system management rather than remaining limited to isolated technical initiatives.

3.2 Energy-Efficient Computing and Data Centers

Barroso and Hölzle (2007) examined energy-efficient computing infrastructure and highlighted the importance of improving energy proportionality within computer systems. Their work emphasized that computing systems can consume significant energy even when utilization levels are relatively low. Improving energy proportionality and dynamically matching computational capacity with workload demand can therefore reduce unnecessary energy consumption. The literature provides a foundation for techniques such as dynamic resource allocation, server consolidation, workload management, and energy-aware computing within large-scale digital infrastructure.

Beloglazov et al. (2012) reviewed energy-efficient cloud computing and discussed approaches for reducing energy consumption through virtualization, dynamic resource allocation, and workload consolidation. Their research demonstrated the importance of managing computing resources according to demand rather than maintaining maximum capacity continuously. Virtual machines can enable workloads to be consolidated onto fewer physical servers, potentially improving utilization. The literature indicates that intelligent cloud-resource management can support energy efficiency, although resource-allocation strategies must also consider performance, service-level requirements, reliability, and computational workload variability.

3.3 Green Software and Sustainable Digital Systems

Coroama et al. (2013) examined the relationship between software and energy consumption and highlighted the importance of considering software behavior when evaluating ICT sustainability. Software determines computational workloads, memory requirements, storage activity, and network communication, all of which can influence energy use. The literature therefore indicates that improving

hardware efficiency alone may not achieve optimal sustainability. Software architecture, algorithms, application design, and workload management should also be considered when developing environmentally efficient digital systems.

Procaccianti et al. (2016) examined green software engineering and emphasized the importance of incorporating energy efficiency into software development processes. Their work identified opportunities for reducing software-related energy consumption through development practices, architectural decisions, and performance optimization. Green software engineering extends sustainability considerations into requirements, design, implementation, testing, and maintenance. The literature suggests that software developers can contribute to digital sustainability by understanding the environmental consequences of computational choices and designing applications that achieve required functionality with efficient resource utilization.

4. Research Methodology

4.1 Research Design

This study adopted a qualitative descriptive and conceptual research design to examine green computing approaches for sustainable digital systems. The research focused on identifying major technological, operational, and organizational practices associated with sustainable computing.

The conceptual approach examined relationships among energy efficiency, computing resources, software optimization, cloud infrastructure, data-center management, renewable energy, electronic waste, and digital sustainability.

4.2 Data Collection

Secondary information was collected from peer-reviewed journal articles, academic books, scholarly studies, and established literature concerning green computing and sustainable information technologies.

The data collection focused on:

- Green computing.
- Green information technology.
- Energy-efficient computing.
- Sustainable data centers.
- Cloud computing.
- Virtualization.
- Green software engineering.
- Energy-aware computing.
- Renewable energy.
- Electronic-waste management.
- Sustainable hardware.
- Resource optimization.
- Carbon-aware computing.
- Sustainable digital infrastructure.
- Lifecycle management.

4.3 Data Analysis

The collected literature was analyzed through thematic analysis. Major themes included energy efficiency, sustainable hardware, virtualization, cloud optimization, green software, data-center sustainability, renewable energy, electronic-waste management, and lifecycle-oriented computing.

The analysis also examined implementation challenges involving investment, legacy infrastructure, technical capabilities, sustainability measurement, organizational policies, and technology lifecycle management.

5. Analysis

5.1 Green Computing Technologies

Green computing incorporates multiple technological strategies for improving the environmental performance of digital systems. Energy-efficient processors and storage devices can reduce electricity requirements, while virtualization can consolidate workloads.

Cloud-resource management can dynamically allocate computational capacity, and efficient cooling systems can reduce energy required for thermal management. Renewable energy can further reduce dependence on conventional electricity sources for computing infrastructure.

Table 1: Green Computing Technologies and Applications

Technology/Approach	Application	Sustainability Contribution
Virtualization	Server consolidation	Improved utilization
Energy-Efficient Hardware	Computing systems	Reduced energy demand
Cloud Optimization	Resource allocation	Reduced idle capacity
Efficient Cooling	Data centers	Lower cooling energy
Renewable Energy	Digital infrastructure	Cleaner energy supply
Green Software	Application development	Lower computational demand
Energy-Aware Scheduling	Workload management	Energy optimization
SSD Storage	Data storage	Efficient storage operations
Power Management	Devices and servers	Reduced idle consumption
Hardware Reuse	IT lifecycle	Waste reduction

These approaches demonstrate that green computing requires coordination between hardware, software, infrastructure, and operational management. Virtualization and cloud optimization can improve resource utilization, while power-management technologies can reduce unnecessary consumption during periods of low activity.

Green software can reduce computational demand, and hardware reuse can extend equipment lifecycles. Sustainable computing therefore depends on integrated technology management rather than relying on a single energy-saving intervention.

5.2 Energy-Efficient Digital Infrastructure

Digital infrastructure consumes energy through computing, storage, networking, cooling, and supporting systems. Data-center optimization can address these components through server consolidation, workload scheduling, efficient cooling, infrastructure monitoring, and renewable-energy integration.

Organizations can also use power-management technologies to reduce energy consumption from underutilized equipment.

Table 2: Energy-Efficiency Strategies

Strategy	Target Area	Expected Contribution
Server Consolidation	Computing	Reduced physical servers
Dynamic Scaling	Cloud systems	Demand-based capacity
Workload Scheduling	Processing	Reduced unnecessary operation
Efficient Cooling	Data centers	Lower cooling demand
Power Management	Hardware	Reduced idle energy
Renewable Energy	Electricity supply	Reduced conventional energy dependence
Storage Optimization	Data systems	Efficient capacity utilization
Virtualization	Servers	Higher utilization
Infrastructure Monitoring	Operations	Energy visibility
Hardware Upgrading	Equipment	Improved efficiency

Energy-efficient infrastructure requires continuous monitoring because computing demand changes over time. Dynamic scaling can reduce unnecessary capacity during periods of lower demand, while workload scheduling can distribute computational tasks according to available resources.

Efficient cooling can further reduce supporting energy requirements. Infrastructure monitoring enables organizations to identify inefficient systems and evaluate the effectiveness of sustainability initiatives. These practices can collectively improve energy performance while maintaining required computing services.

6. Discussion

6.1 Green Computing and Energy Optimization

Green computing can support energy optimization by aligning computational capacity with actual system demand. Virtualization enables multiple workloads to share physical infrastructure, while

dynamic resource allocation can reduce unnecessary server operation. Energy-aware scheduling can distribute workloads according to available computational resources and energy conditions. These approaches can improve infrastructure utilization and reduce energy consumed by underused computing capacity.

Energy optimization should be evaluated across the entire digital infrastructure rather than focusing exclusively on processors or servers. Cooling, storage, networking, backup systems, and facility operations also contribute to energy consumption. Integrated monitoring can help organizations identify major sources of energy demand and prioritize optimization measures. Such approaches can provide a more comprehensive understanding of digital-system efficiency and support continuous sustainability improvements.

6.2 Sustainable Software and Digital System Design

Software engineering decisions can significantly influence computational resource requirements. Efficient algorithms, optimized database queries, appropriate caching, data compression, and lightweight application architectures can reduce processing and communication requirements. Green software engineering therefore provides an important complement to energy-efficient hardware. Sustainability considerations can be incorporated during requirements analysis, architecture design, coding, testing, deployment, and maintenance.

Software sustainability also requires balancing energy efficiency with functionality, security, reliability, and user experience. Excessive optimization may affect performance or maintainability if not appropriately managed. Developers should therefore evaluate energy-related improvements alongside technical requirements. Monitoring software resource consumption can provide information for identifying inefficient processes and guiding future optimization. Integrating sustainability indicators into software development can help organizations consider environmental performance as part of broader software-quality management.

6.3 Organizational Transformation and Green IT Management

Green computing requires organizational commitment because technology sustainability involves procurement, infrastructure management, software development, employee behavior, and lifecycle planning. Organizations can establish green IT policies covering energy monitoring, equipment procurement, device reuse, cloud-resource management, and electronic-waste disposal. Sustainability objectives can also be incorporated into technology planning and infrastructure investment decisions.

Organizational transformation depends on measurable sustainability objectives and appropriate performance indicators. Organizations need reliable information about energy use, equipment utilization, infrastructure efficiency, and technology lifecycle outcomes. Employee awareness and technical training can strengthen implementation because everyday technology-management decisions influence resource consumption. A coordinated governance framework can connect sustainability objectives with IT management, procurement, infrastructure operations, software development, and responsible technology disposal.

7. Challenges

7.1 Financial and Technological Challenges

Implementing green computing can require significant investment in energy-efficient hardware, infrastructure modernization, advanced cooling, renewable-energy systems, monitoring technologies, and software optimization. Organizations operating older infrastructure may face additional costs because legacy systems are not always compatible with modern energy-efficient technologies. Decision-makers may also encounter difficulties when sustainability benefits occur over longer periods while implementation expenses arise immediately.

Technological complexity can further complicate green computing initiatives. Digital infrastructure typically involves interconnected hardware, software, cloud services, networks, storage systems, and facility-management technologies. Optimizing one component may affect another component's performance or resource requirements. Organizations therefore need integrated assessment methods capable of evaluating computing performance, energy consumption, reliability, scalability, and sustainability simultaneously rather than optimizing individual components in isolation.

7.2 Measurement, E-Waste, and Organizational Challenges

Measuring the environmental performance of digital systems remains challenging because computing infrastructure involves multiple energy-consuming components and different operational conditions. Organizations may use different sustainability indicators, making direct comparisons difficult. Energy consumption can also vary according to workload, geographic location, infrastructure age, cooling requirements, and electricity sources. Standardized measurement frameworks can improve consistency and support more reliable sustainability evaluation.

Electronic waste represents another significant challenge because rapid technology development can shorten hardware replacement cycles. Improper disposal may result in environmental impacts and loss of recoverable materials. Organizations therefore need lifecycle-oriented procurement, equipment reuse, refurbishment, recycling, and responsible disposal practices. Employee awareness and organizational policies are also important because sustainable computing depends not only on infrastructure but also on everyday decisions regarding device use, upgrades, storage, printing, and technology management.

8. Future Research

Future research should investigate intelligent energy-management systems capable of dynamically optimizing computing workloads according to system demand, infrastructure conditions, and energy availability. Researchers could examine artificial intelligence, machine learning, predictive analytics, and automated workload scheduling for data centers and cloud environments. Studies should evaluate energy consumption alongside computational performance, reliability, latency, and service requirements. Carbon-aware computing models could also investigate how workloads can be coordinated with lower-carbon electricity availability while maintaining appropriate service quality.

Future studies should focus on sustainable software engineering and energy-aware application development. Research could develop standardized methods for measuring software energy consumption across programming languages, architectures, platforms, and application types.

Researchers could investigate energy-efficient algorithms, sustainable data structures, efficient database operations, lightweight architectures, and resource-aware artificial intelligence. Green software metrics could be integrated into software testing and quality assessment so that developers can evaluate environmental performance alongside conventional indicators such as speed, reliability, security, and maintainability.

Further research should examine circular approaches to computing hardware and digital infrastructure. Studies could investigate device durability, modular hardware design, repairability, refurbishment, component reuse, responsible recycling, and sustainable procurement. Researchers should also examine lifecycle environmental impacts from manufacturing through disposal and identify strategies for extending equipment lifetimes without compromising security or performance. Integrated frameworks connecting green hardware, sustainable software, renewable energy, cloud optimization, and circular lifecycle management could provide a broader foundation for sustainable digital-system development.

9. Conclusion

Green computing provides a comprehensive approach for reducing the environmental impact of digital technologies while maintaining required computational services. Energy-efficient hardware, virtualization, cloud-resource optimization, sustainable data-center practices, green software engineering, renewable energy, and responsible electronic-waste management can collectively improve the sustainability of digital systems. These approaches demonstrate that environmental considerations can be incorporated into technology design, deployment, operation, maintenance, and end-of-life management.

Energy optimization represents a central component of green computing. Virtualization and server consolidation can improve infrastructure utilization, while dynamic resource allocation can align computing capacity with demand. Efficient cooling and infrastructure monitoring can address supporting energy requirements, while renewable energy can contribute to cleaner electricity supply. However, effective optimization requires continuous measurement because energy consumption varies according to workloads, infrastructure characteristics, environmental conditions, and operational requirements.

Software also plays an important role in sustainable digital systems. Algorithm optimization, efficient data management, lightweight architectures, caching, and reduced network communication can lower unnecessary computational requirements. Green software engineering therefore complements hardware and infrastructure optimization. Sustainable software development should consider environmental performance alongside functionality, security, reliability, scalability, and maintainability throughout the software lifecycle.

Overall, sustainable digital transformation requires integrated green computing strategies that connect technological efficiency with organizational governance and lifecycle responsibility. Financial constraints, legacy infrastructure, measurement difficulties, technical complexity, and electronic-waste management remain important challenges. Future research into intelligent energy management, carbon-aware computing, sustainable artificial intelligence, green software metrics, low-power architectures, circular electronics, and standardized sustainability indicators can strengthen the development of environmentally responsible digital systems. Such integrated approaches can support continued digital

innovation while addressing the environmental demands associated with expanding computational infrastructure.

References

1. Murugesan, S. (2008). Harnessing green IT: Principles and practices. *IT Professional*, 10(1), 24–33. <https://doi.org/10.1109/MITP.2008.10>
2. Raghavan, B., & Ma, J. (2011). The energy and energy costs of computing. *ACM SIGMETRICS Performance Evaluation Review*, 39(3), 44–48. <https://doi.org/10.1145/2160803.2160809>
3. Buyya, R., Beloglazov, A., & Abawajy, J. (2010). Energy-efficient management of data center resources for cloud computing: A vision, architectural elements, and open challenges. *Proceedings of the 2010 International Conference on Parallel and Distributed Processing Techniques and Applications*, 1–12.
4. Beloglazov, A., Abawajy, J., & Buyya, R. (2012). Energy-aware resource allocation heuristics for efficient management of data centers for cloud computing. *Future Generation Computer Systems*, 28(5), 755–768. <https://doi.org/10.1016/j.future.2011.04.017>
5. Koomey, J. (2011). *Growth in data center electricity use 2005 to 2010*. Analytics Press.
6. Molla, A., Cooper, V. A., & Pittayachawan, S. (2011). The green IT readiness (G-readiness) of organizations: An exploratory analysis of a construct and instrument. *Communications of the Association for Information Systems*, 29, Article 1. <https://doi.org/10.17705/1CAIS.02901>
7. Jenkin, T. A., Webster, J., & McShane, L. (2011). An agenda for 'green' information technology and systems research. *Information and Organization*, 21(1), 17–40. <https://doi.org/10.1016/j.infoandorg.2010.09.003>
8. Watson, R. T., Boudreau, M.-C., & Chen, A. J. (2010). Information systems and environmentally sustainable development: Energy informatics and new directions for the IS community. *MIS Quarterly*, 34(1), 23–38. <https://doi.org/10.2307/20721413>
9. Murugesan, S., & Gangadharan, G. R. (Eds.). (2012). *Harnessing green IT: Principles and practices*. Wiley-IEEE Press.
10. Whitehead, B., Andrews, D., Shah, A., & Maidment, G. (2014). Assessing the environmental impact of data centres part 1: Background, energy use and metrics. *Building and Environment*, 82, 151–159. <https://doi.org/10.1016/j.buildenv.2014.08.021>
11. Avgerinou, M., Bertoldi, P., & Castellazzi, L. (2017). Trends in data centre energy consumption under the European Code of Conduct for Data Centre Energy Efficiency. *Energies*, 10(10), Article 1470. <https://doi.org/10.3390/en10101470>
12. 2030. Challenges, 6(1), 117– [1] 157. <https://doi.org/10.3390/challe6010117>
13. Freitag, C., Berners-Lee, M., Widdicks, K., Knowles, B., Blair, G., & Friday, A. (2021). The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations. *Patterns*, 2(9), Article 100340. <https://doi.org/10.1016/j.patter.2021.100340>
14. Hintemann, R., & Hinterholzer, S. (2019). Energy consumption of data centers worldwide: How will the Internet become green? *Proceedings of the 8th International Conference on Smart Cities and Green ICT Systems*, 1–8.

15. Masanet, E., Shehabi, A., Lei, N., Smith, S., & Koomey, J. (2020). Recalibrating global data center energy-use estimates. *Science*, 367(6481), 984–986. <https://doi.org/10.1126/science.aba3758>
16. Belkhir, L., & Elmeligi, A. (2018). Assessing ICT global emissions footprint: Trends to 2040 and recommendations. *Journal of Cleaner Production*, 177, 448–463. <https://doi.org/10.1016/j.jclepro.2017.12.239>
17. Freitag, C., Berners-Lee, M., Widdicks, K., Knowles, B., Blair, G., & Friday, A. (2021). The climate impact of ICT: A review of methodologies and evidence. *Proceedings of the ACM on Human-Computer Interaction*, 5(CSCW2), Article 1.
18. Forti, V., Baldé, C. P., Kuehr, R., & Bel, G. (2020). *The global e-waste monitor 2020: Quantities, flows and the circular economy potential*. United Nations University/United Nations Institute for Training and Research.
19. World Bank. (2018). *What a waste 2.0: A global snapshot of solid waste management to 2050*. World Bank. <https://doi.org/10.1596/978-1-4648-1329-0>
20. International Telecommunication Union. (2024). *Greening digital companies 2024: Monitoring emissions and energy consumption of ICT companies*. International Telecommunication Union.