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Circular Economy in Data Centre Construction: Review of Reuse and Retrofit Strategies (UK, Nigeria, USA focus)

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Abstract

The present paper explores the reuse and retrofit solutions as part of furthering the principles of a circular economy in the data centre development and operations in the UK, USA, and Nigeria. It presents a structured taxonomy covering building envelope adaptations, mechanical–electrical–plumbing (MEP) systems, IT equipment lifecycle management, and digital management approaches. Based on evidence in the international context, this study underscores that adaptive reuse, modular retrofitting, material recovery, refurbishment, virtualization, and circular procurement can be a big contribution to reducing the amount of embodied carbon, increasing the asset lifecycle, and improving operational resilience. Data indicates that adaptive reuse can cut embodied emissions by up to 68%, modular MEP systems accelerate deployment while lowering material waste, and circular IT practices can divert up to 99% of hardware from landfill. Findings underscore that circular strategies, when integrated into design, procurement, and operational decision-making, can transform data centres into low-carbon, resource-efficient infrastructures aligned with global decarbonisation and digital sustainability goals.

Keywords: Circular economy; Data centre; Adaptive reuse; Retrofit strategies; Sustainability; Embodied carbon

1. Introduction

The economic digitalization depends on data centres that support cloud computing, artificial intelligence (AI), and connectivity in the world. However, they are very resources-heavy, which propels huge environmental costs throughout their lifetime. These buildings consume large quantities of electricity to power IT equipment and cooling as well as some designs are based upon large quantities of water to provide thermal control. High embodied emissions occur during the extraction of materials, manufacturing, and transportation of IT hardware during construction and regular hardware refresh. In the U.S. alone, the amount of electricity used in data centres has reached 176 terawatt-hours (TWH) in 2023 and is projected to increase to 325-580 THW because of AI-based expansion by 2028 [1]. The electricity consumption of data centres is expected to exceed 980 TWh by 2030, as opposed to 448 TWh in 2025, a figure that may reach up to 3 percent of the overall electricity consumption, as well as straining the grids [2, 3]. Such tendencies increase the need of lifecycle assessments and circular approaches to reduce the risks of climate changes and improve the resiliency of infrastructure.

The concept of the circular economy (CE) provides a revolutionary approach to the industry, which focuses on extending the life of the product, reusing, refurbishing, remanufacturing, designing to dismantle, and closed-loop material supply to reduce waste and loss of resources [4] CE methods can also separate economic growth and the linear consumption of resources, halving embodied carbon through material recovery and half Virgin inputs [5]. These principles in data centres are aimed at hotspots such as electronic waste (e-waste) of frequent server upgrades of 50 million metric tons

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per year by 2030 and cooling inefficiencies which are a source of 40% of the operational energy consumption [6]. Hardware reuse and retrofit of existing facilities can be regarded as high leverage strategies comprising of 2-5 years of asset life extension by refurbishing servers and saving demolition emissions, respectively [7].

In this review, the focal point of the investigation is reuse and retrofits as the critical CE strategies to data centres building and operation and the assessment of their effectiveness in terms of academic sources, policy statements, and industry models. It contrasts implementation in three different environments: in the UK, a developed economy with stringent net-zero policy via the 2050 Climate Change Act and projects like the Circular Economy for the Data Centre Industry (CEDaMI) project that encourages 6575% equipment reuse rates [8]; the USA, where hyperscale providers dominate, and federal incentives such as the Inflation Reduction Act are making retrofits compel 99% of retired equipment off the landfill. Through extenuating these instances, the review sheds light on the opportunities to scale ways to data infrastructure resiliency into low impact.

2. Methods

This review combines the use of a hybrid narrative and systematic review format to bring together peer-reviewed academic literature and grey literature on the use of circular economy (CE) in data centres construction and operation, with a particular focus on reuse and retrofit strategies. Its methodology is based on the existing principles of systematic reviews to make the process transparent, reproducible, and comprehensive in the scope, as well as the use of narrative aspects to contextualize results in common geopolitical contexts [9]. This two-fold framework enables to conduct a structured search and selection and an interpretative analysis of policy implications and industry practices, especially in the UK, USA and Nigeria.

2.1. Search Strategy

To reflect the current developments due to the rapidly expanding digital infrastructure and changing CE policies, the review included articles published after January 1, 2015, to November 23, 2025. This time frame corresponds to the major events, including Paris Agreement in 2015 and the 2020 Circular Economy Action Plan of the EU which shaped the discussions of global sustainability [10].

The databases that were searched were Google Scholar, Scopus, and Web of Science and were searched in interdisciplinary areas such as environmental science, engineering and studies in the built environment. Policy reports, white papers, case studies, and industry analysis on the websites of institutions, such as the World Bank, UK Green Building Council (UKGBC), US Department of Energy (DOE), Lawrence Berkeley National Laboratory (LBNL), Ellen MacArthur Foundation, World Economic Forum (WEF), and Open Compute Project were used as grey literature sources. Practical insights were also obtained in the form of industry-specific publications (e.g., Data Centre Dynamics, Uptime Institute, and sustainability reporting of large operators, e.g., Google, Amazon Web Services, and Microsoft).

Search terms were created by means of Boolean operators, which helped to develop search terms as much relevant as possible. Keywords were as follows: "circular economy" AND (data center OR data centre) AND (retrofit OR reuse OR refurbish* OR remanufacture* OR "life cycle" OR "heat reuse" OR "waste heat" OR "modular design") AND (UK OR United Kingdom OR Nigeria OR USA OR "United States" OR America). Labor variances were used to explain the spelling variations (e.g., "centre" vs. "center") and synonyms (e.g., "embodied carbon" OR "lifecycle assessment"). Contextual relevance was given more importance using country specific filters e.g. Nigeria AND digital infrastructure to filter emerging markets. Web searches were done with advanced operators such as filetype:pdf to focus on grey literature.

Several preliminary searches in academic databases provided about 150 records (e.g., Google Scholar found around 100 results using broad queries of CE-data centres and 10-20 results with country and strategy filters) and 50 grey literature sources. Reference management software such as Zotero was used to eliminate duplicates.

2.2. Inclusion and Exclusion Criteria

The documents were filtered through two processes (i) pre-relevance: title and abstract were reviewed, (ii) depth: full-text assessment. Inclusion criteria were given first priority:

- Case studies that indicate reuse or retrofit (e.g. hardware refurbishment, building adaptations or heat recovery systems).
- Organizational policy or business rules regarding CE integration (e.g. regulatory requirements regarding e-waste disposal or e-waste retrofit subsidies).

- Focus on data centres, and evidently related to construction, facilities or fluidisation.
- Connection with one of the target countries (UK: established regulations; USA: hyperscale control, Nigeria: development in the face of limitations); or regional proxies with nation-wide data that may not be adequate in volume (e.g. policies of the African Union on Nigeria).
- Accessibility in the form of English language publications.

Exclusion criteria eliminated:

- Prior studies within one year prior to 2015 or 2025 onwards.
- Non data centre (e.g. general IT or manufacturing without application).
- Theoretical only works that are not backed by empirical or practical evidence.
- Low quality sources (e.g. unverified blogs or promotional materials that lack data).

Sources with quantifiable information were given preferences such as the percentage of embodied carbon reduction in retrofits or equipment reuse percentages in equipment lifecycles. Where country-specific contents were scarce (e.g., in the case of Nigeria with less than 5 studies dedicated to it), vignettes with prominent actors (e.g., implementations of global circularity by Google in contexts in the US or design of data-centres by Arup in the UK) were included as illustrative materials. Finally, 25 scholarly articles and 15 grey literature sources were also chosen to be synthesised, with such significant publications as the CEDaCI project reports about UK data centre circularity and WEF studies of built-environment retrofit being selected.

2.3. Data Extraction and Synthesis

The information was filtered with the assistance of a standardized template that comprised: CE strategy (e.g., reuse vs. retrofit), environmental indicators (e.g., Power Usage Effectiveness [PUE], water usage effectiveness [WUE], embodied emissions], implementation context (country-specific barriers/enablers), and outcomes (e.g., cost savings, emission reductions). By applying the thematic analysis, synthesis was performed and the results provided a number of clusters of results including policy drivers, technological innovations, and economic viability. Narrative elements had cross-country comparisons, as well as contrasts (e.g. regulatory focus on net-zero in the UK vs Nigeria with its infrastructure problems).

2.4. Limitations

The review has a number of limitations to the subject matter. Diverse methodologies of studies make it hard to draw direct comparisons; e.g. academic papers apply life-cycle assessments using different boundaries of the system whereas grey literature uses self-reported data regarding industries. Measurements are not consistently reported; the calculation of the embodied carbon varies according to the tool (e.g., OneClick LCA vs. custom models), efficiency metrics such as PUE or WUE are inconsistently defined and reported. Longitudinal case studies of large-scale retrofits of operating hyperscale facilities are deficient; most is based on pilots or simulation, but not long-term tracking. Grey literature can also become biased in favour of good results as a result of corporate reporting incentives. Lastly, limited information about Nigeria indicates a lack of research in the emerging markets, which may fail to capture Global South voices and will have to depend upon more generalizations in the African or the developing world.

3. Conceptual Framing: Circular Economy for Data Centres

The circular economy (CE) reinvents the use of resources, shifting out of a linear system of resources, with take-make-dispose, and into regenerative systems. These systems seek to maintain the value within the economy, reduce wastage as well as decoupling economic growth with environmental degradation [11]. CE has been established in the built environment over four key pillars, which include: (i) extending the life of buildings and equipment with retrofitting and re-purposing; (ii) creating a closed-loop material system with reuse, refurbishment, remanufacturing and recycling; (iii) designing with deconstruction in mind - focusing on modular components, easy disassembly, and flexibility; and (iv) embracing new forms of service based on shared ownership and end-of-life recovery, such as leasing, product-as-a-service (PaaS) and take- The methods cut product lifespan by half, may cut embodied carbon by 5097 percent by reusing materials (e.g., structural steel), and find materials by using digital tools such as material passports and Building Information Modelling (BIM) [12].

Both built and changing the IT equipments are consolidated in data centres and hence CE has to span over two layers. First is the structure and MEP (mechanical, electrical, plumbing) systems comprising of the building structure, cooling plants and power distribution. Second, there is the IT layer, which constitutes servers, storage and networking. MEP layer contributes 70 -88 percent of the total embodied carbon of data centre. Retrofits may be helpful in the form of rooftop equipment to the ground 40% less carbon and dematerialised designs (superstructure column grids) cut carbon by 35% down [12]. Cooling can be done in modules, and bolted connections can be added to add to the DfD principles. Metal and cabling are also material that is reused in a closed loop. There is a risk that site-specific information and rules are constraining, although there are potential prospects including reusing heat to heat the district, as well as extending the lifespan of a facility up to 20–30 years.

The refresh cycle of the IT layer is 35 years that generates much e-waste. A focus on remanufacturing and reuse has the ability to last hardware usage up to approximately 9 years old, reducing greenhouse gas (GHG) and overall cost of ownership (TCO) by 24 per cent [13]. Such models of service as leasing servers or the implementation of compute-as-a-service (PaaS) can be used to reduce such risks as latency and warranty. Vendors as well can use them to take back and refurbish equipment. The points of difficulty are providing reliability of mission critical operations and maintaining data security in equipment reuse. The disassembly and recovery of parts become simpler through standardisation including the Open Compute Project racks.

Recent practitioner manuals emphasize on the benefits more broadly of CE: reducing overall carbon, eliminating quantities of waste (e.g. 967, 107metric tons of waste in 46million servers by 2023), establishing operational risk through a resilient design and longer lifespan, and generating an economic payoff. These benefits involve the creation of jobs in the local remanufacturing centres and the savings gained because of not purchasing new materials [14, 12]. CE encourages the resilience of data centres as demand increases and supports net zero goals by ensuring that resources remain in service as demand increases.

4. Reuse & Retrofit Strategies: Taxonomy and Evidence

4.1. Building and Envelope

An example of highly effective carbon-reduction tools that mitigate the high embodied emissions of building new data centres is adaptive reuse of preexisting industrial, commercial or historic buildings as data centres [15, 16]. Making retrofitting is generally associated with access floors, enhanced structural elements and space restructuring to make the airflow and thermal containment optimal [17]. It is demonstrated that adapted reuse will cut down added carbon in buildings by 30-68 percent relative to fresh constructions [18, 19]. Design for Disassembly (DfD) can enhance the idea of circularity in various ways: reversible fasteners, modular enclosures, and dismantlable and recoverable walls are all examples [20]. Circular procurement policies that are based on the priorities of low-carbon or reused material allow material reuse strategies, which can be reclaimed steel, facades, and interior fittings [21, 22]. Research reveals that whole life carbon can be reduced by structural retrofit by up to 42% but energy performance trade-offs require a location-specific life-cycle assessment [23].

4.2. Mechanical, Electrical & Plumbing (MEP) Systems

The MEP retrofits are oriented on prefabrication and modularity like the chillers, switchgear and UPS built on the skids. These designs allow the extension or easy replacement with a slight demolition [24, 25, 26]. Research indicates that modular solutions have the ability to accelerate deployment by 3050 percent and reduce embodied impacts [27, 28]. Reusing and re-manufacturing of chillers, heat exchangers, and CRAH/CRAC systems are life extending and also reduce capital expenditures and waste [29]. Retrofit projects have become a common attribute with heat-reuse systems capturing the waste heat of data centres to be used in district heating or industry. These elements should be connected to the energy systems within the city [20, 30].

4.3. IT Equipment and Lifecycle Management

The plans of circular information technology present by Amazon [31], Human-I-T [32], and Securis [33] place the focus on the reusing, refurbishing, and certifying of remanufacturing of the servers, storage devices, and networking equipment. This methodology contributes to the reduction of embodied emissions enormously. Research indicates that experiencing up to 99 per cent of old IT devices in landfills can be avoided because of reuse measures taken by hyperscale operators [34]. Leasing, hardware-as-a-service, and take-back-programs Circular procurement approaches regulate the process of returning, refurbishing, or remanufacturing of assets [35, 36]. Also, the processing of e-wastes as well as material-recovery operations completes the cycle by recovering rare-earth metals and vital minerals [37, 38].

4.4. Digital and Management Strategies

Circularity is achieved through digital strategies because they reduce dependency on physical devices. Virtualisation, migrating to the cloud, and right sizing the workloads reduce server utilisation, churn, and asset life [39, 40]. Circular key performance indicators (KPIs) can be integrated on digital dashboards through carbon, equipment life, and reuse rates embedded to help with the decision-making process of being circular [41]. It is revealed that virtualisation and right-sizing can free up hardware by up to 50% which is a significant benefit since organisations strive to meet decarbonisation targets [21].

5. Country Vignettes: Policy, Market and Exemplar Practice

5.1. United States of America

The U.S. data centres are expanding at high rates, which are driven by AI and cloud computing, as well as the digital economy. Their electricity consumption decreased from 580 GW in 2014 to 176 TWh in 2023, accounting for 4.4% of the nation's total [42, 43]. It is estimated that the demand may rise twice or even thrice to the amount of 325580Twh by 2028 and that AI servers may be a major contributor to this growth. Unmitigated, data centres can drive one-twelfth of U.S. electricity by 2030 [44, 45]. Both DOE and LBNL have released literature that has connected data centre increase with climate targets and grid stability [46], as well as focusing on energy optimization, decarbonisation and lifespan efforts. The federal programs, the IRA and more recent Executive Orders, associate an expansion in infrastructure with clean-energy requirements. They emphasize the aspect of sustainability because AI investments exceed more than 100 billion annually [47, 48].

The United States has the highest adoption of the circular economy on its data centres. Funding for material loops and retrofits is often aided by government grants and loans. Tax incentives provided in the Inflation Reduction Act (IRA) include 100 per cent bonus depreciation and 179D energy savings deductions, which promote installation of newer cooling systems, and the refurbishment of hardware to upgrade its usage. As mentioned by Congressional Research Service [49] and Abitos [50], lifecycle assessments and circular procurement are financed by Department of Energy (DOE). Good examples are hyper scale operators such as Amazon Web Services (AWS) and Google, which operate hardware remanufacturing initiatives, redirecting 99% of discontinued equipment out of these landfills to certified reuse markets [51]. Prefabricated cooling skids, or other building modules, are easily acquired by renewing MEP, and incentives need sustainability requirements, listing lowered embodied carbon to be eligible [52]. Reform measures at the state level, including a long-term tax abatement on retrofits of low carbon in Kansas and Virginia, encourage the reuse of old facilities. These efforts are consistent with such voluntary measures as the metrics of circularity proposed by the Open Compute Project [53, 54]. The outlook of the economy suggests a good report in the industry. The cost of the used IT assets would be replaced with a saving of 20-50% and secondary markets generate employment locally [55, 56].

Incentives notwithstanding, greenfield hyperscale targeted at AI workloads is being developed on rapid expanses at the expense of retrofit, and grid constraints are becoming a significant problem in places such as Virginia and Texas, where demand exceeds the rate of renewable incorporation [57]. The hardest part of maintaining the service level agreement (SLAs) and difficulty in maintaining the reuse of the legacy equipment is a risk of compromising reliability, which discourages the deployment in the mission-critical setting [58]. States with differing regulations and high upfront costs of heat-recovery retrofits are the two reasons why more of this could be done with standards and more consistent scaling of CE without more aggressive federal regulations, respectively [47].

5.2. United Kingdom

Data centres are considered important infrastructures in the UK net-zero transition, and the policy frameworks have been prioritizing the energy transparency, grid resilience, and their integration with low-carbon systems. The electricity demand of the sector is expected to increase by 6-10 per cent every year by 2025 owing to AI and digital services, which leads to the discussion of sustainability amid the 2050 net-zero target [59, 60]. The motivation factors are the Net Zero Research and Innovation Framework by the UK, which focuses on data centre heat reuse as district heating, which would have the potential to decarbonise urban networks [61, 62]. The London data centres alone would produce enough waste heat to serve 500,000 households/year which is in line with the regional zoning of the heat networks through the Energy Act 2023 [63, 64]. National data centres have now become Nationally Significant Infrastructure Projects (NSIPs) and this makes it easier to have approvals but introduces environmental impact assessments [27, 65].

Also, such organizations as TechUK and the UK Green Building Council (UKGBC) have published reports, including the Whole Life Carbon and Circular Economy Report, to encourage low-carbon retrofits, material passports and circular procurement [66, 67]. Examples of two colocation providers that apply design for disassembly (DfD) in facilities are Equinix and Virtus. The studies by Clark [59] and Data Centre Review [68] also stress the possibility of recovering the materials and make upgrades in modules. Both Weatherite Group [69] and Data Centre Dynamics [70], indicate that there is an increase in heat-recovery retrofits. E.g.: Data centre waste heat used to drive district networks in Manchester and London Projects, with a 30-50 per cent reductions in operational carbon, have been implemented. In their 2025 program, TechUK has suggested remanufactured IT equipment and compressors in achieving the objectives of the Climate Change Agreement within 2026-2030 [71, 72]. One of the realistic tools of circularity listed in the Impact Report is BIM-integrated passports with reuse rates of 65-75% in the redevelopment projects [73, 74].

Although it is an NSIP, zoning and local opposition exist that will lead to planning and grid-connection time wasting. Another cause of this issue is perceived regulatory barriers to the infrastructure of the heat-reuse [75, 76]. The benefits of retrofits compared with the benefits of setting up greenfields are not easily provable and the facilities that existed in the past are not flexible to enable complex cooling or DfD [64]. The scale adoption is challenging to all the operators and especially to small ones due to high prices and fragmented regulations, including staggered introduction of heat-network standards since 2026 [65,77].

5.3. Nigeria

The data centre market is booming in Nigeria to serve its digital economy targets through the National Digital Economy Policy and Strategy (2020-2030), with one target being an increase of installed capacity of 56.1 MW in 2025 to 218 MW in 2030, under the influence of fintech, e-commerce, and cloud adoption [78, 79]. The major operators, such as Rack Centre and MainOne (since becoming MDXi), are investing in more energy-efficient models, with Rack Centre LGS2 (12 MW) facility becoming EDGE certified to be more efficient in resource consumption than regional standards [80, 81]. Among these national drivers, there is the aspect of dealing with grid unreliability by providing hybrid power solutions and the need to concur with the sustainability goals in the wake of increased internet penetration estimated to hit over 100 million users by 2025 [82, 83]. The larger data centre trend in Africa, which makes Nigeria a core of the global data centre market, alongside South Africa, is set to bring in investments of 1 billion in AI-related ventures, and a focus on resilient infrastructures [84, 85].

It focuses on the fundamental efficiency, where operators embrace modular designs and hybrid fuels (e.g. gas backups) to alleviate grid problems, and new CE practices comprise IT hardware remanufacturing through new secondary markets [86, 87]. Rack Centre and MDXi can be viewed as examples of sustainability in terms of such certifications like LEED and EDGE, including reuse in the building, such as the use of salvaged materials in extensions, energy-efficient cooling retrofits [88] Nigeria Data Protection Regulation promotes lifecycle management as a policy support to enable alliances in the recovery of e-waste, but complete CE loops are not well-established [89]. According to industry reports, there is an increasing interest in urban facilities adaptive reuse to satisfy colocation demand, which will reach $544 million by 2030 [86].

Constant grid unpredictability compels one to use diesel hybrids, which weakens the scale of CE and worsens emissions [90, 91]. The existence of nascent policy frameworks does not have any particular incentives towards circular construction, and barriers to making such a change include low awareness, financial barriers and infrastructural barriers [92]. All of this is aggravated by the fact that higher risks in re-using critical equipment are present due to gaps in the supply-chain and lack of data available on the subject and fragmented mandates that continue to encourage open dumping of e-waste [93, 94].

6. Management Implications (Strategy and Practice)

Policymakers, developers, and managers of data centres can benefit from this review's emphasis on practical ways to include circular economy (CE) concepts, which improve sustainability, cost-efficiency, and resilience in the face of increasing demands:

- **Integrate circular KPIs**: Measuring and encouraging CE performances will entail such features as the carbon embodied per square meter, equipment life ambitions, and reused material percentage of evaluation and project choices [12].
- **Adopt modular systems**: In order to conserve downtime and waste, focus on designs of buildings that can be upgraded in mechanical, electrical and plumbing (MEP) and can be retrofitted, disassembled and their components reused [95].
- **Establish IT partnerships**: In order to improve the life of hardware and reduce embedded effects through remanufacturing, establish set assets-management guidelines in collaboration with certified refurbishers of take-back schemes [14, 51].

- **Leverage LCA and costing**: An early comparison between the carbon footprints, economic viability, and operational sustainability of retrofit and new-build alternatives should be done using life-cycle assessments (LCA) and whole-life costing [96].
- **Enable heat reuse**: The involvement of local energy stakeholders (e.g., planners, utilities, and heat-network operators) must be engaged first, which will allow involving waste-heat recovery and releasing co-benefits, including district heating [97].

These efforts can be increased through leveraging policy and procurement. E.g., bids can have circularity provisions, such as pursuing certifications that are reuse-inducing (e.g. BREEAM or LEED), and e-waste diversion, e-waste reuse rates can be reported transparently [98]. TechUK [66] recommends that the net-zero policies of the UK focus on integrating heat networks and making the process of planning easier. According to the US Department of Energy [41], the country ought to match federal energy-reporting requirements and grid incentives via the Inflation Reduction Act. According to NDEPS [99], Nigeria should focus on the use of resilient and modular designs capable of supporting future upgrades of the grid and supply chains to circular designs.

7. Barriers and Enablers

There are complex obstacles to implementing circular economy (CE) strategies in the construction of data centres. The issue of reliability discourages the use of refurbished hardware by operators because they are afraid that it will impact the performance of their hardware in the mission-critical context [100]. Evaluation and benchmarking is complicated by the fact that there are no standardised circularity metrics, including consistent life-cycle assessments (LCA) of embodied carbon and reuse rates. Planning and grid constraints, regulatory hurdles and infrastructure shortages, particularly in Nigeria, are the factors that only exacerbate delays, while grid unreliability and the low adoption of digital twins are the obstacles to transitions [89]. Embodied carbon savings are frequently underestimated in financial models, with the considerations being put on initial expenses than savings over the entire ownership [13]. Budding reuse supply chains in places such as Nigeria are hindering the supply of materials and scalability of remanufacturing [89].

The enablers are manufacturer take-back and remanufacture programmes, which guarantee the quality with warranties and standards such as BS 8887, which create trust in the secondary markets [100, 13]. The design standards of modular also favour flexibility and can be disassembled, and barriers to retrofit are minimized. Policies that are supportive (e.g. reporting requirements and retrofit incentives in the UK and US or carbon pricing) are motivation to adopt [101]. The knowledge sharing and innovation is supported by the procurement requirements that involve circular clauses and platforms of industry collaboration, such as the CE-Hub in the UK [101].

8. Research Gaps and Agenda

In spite of progress, there remain major gaps in the use of circular economy (CE) in data centres and a research agenda should be targeted. There exist very few empirical life-cycle assessments (LCAs) of retrofit and new-build scenarios across typologies (edge, colocation, hyperscale), without many of them considering dynamics of embodied carbon [102]. Measured reports on savings of individual reuse streams, like structural steel or server reuse, are not readily available, which prevents a viable implementation [103]. Circular hardware business models, such as hardware-as-a-services or buy-back models, need more research, such as contractual innovation, and financial feasibility [104]. Household Feasibility of heat-reuse integration in cities, including network economics and emission modelling foundations, has not been developed, even though its possible decarbonisation advantages could be beneficial [97]. Lastly, consistency in the social and regulatory examinations in a new market, such as Nigeria is weak, and advocates of policy tools are needed to hasten the effects of CE under the limitations of infrastructure [89, 102]. These will be resolved using interdisciplinary and empirical research to enhance sustainable data infrastructure.

9. Recommendations (Policy & Industry)

The stakeholders involved in constructing data centres should take specific steps on governments, industry, finance, and research institutions to move the circular economy practices forward.

- To create accountability, governments must enforce open disclosure of energy use and carbon emissions, Scope 1, 2, 3, and embodied, to promote responsibility. They can encourage retrofits and reuse as tax credits, grants, or tax accelerated depreciation of circular investments, including modular improvements or materials reclaimed. Furthermore, setting up regulatory procedures to integrate waste-heat in district networks would encourage energy efficiency in urban areas, and the streamlined approval process of feasible projects.

- Industry players ought to have high corporate goals of lengthening the life of equipment including seeking to achieve 7-10 years on the server through refurbishment. The procurement policies must be focused on using remanufactured hardware in which reliability is confirmed by certifications to minimize e-wastes. Unifying modularity in components such as bolted assemblies and plug and play MEP systems would make it easier to disassemble and make future changes.
- Finance sectors must be able to innovate using green or circular finance products that are specific to data centre retrofits, including low-interest loans or bonds that factor in savings of entire lifecycle costs and risks through more resilient design.
- The focus of research and standards organisations should be on creating sector-specific circularity measures such as reuse rates and benchmarks on embodied carbon, as well as on uniform templates of life-cycle assessment to enable comparisons of all projects. These solutions will bring sustainable development in the data centre industry, which is localized based on these recommendations.

10. Conclusion

The reuse and retrofit approaches to data centre building have become a crucial solution in the drive to adopt the circular economy (CE) perspective in data centre construction, which will help combat environmental footprints, enhance infrastructure resiliency, and improve global climate goals. These measures can greatly reduce embodied construction and IT refresh emissions by mode of extending the lifespan of assets, closing material cycles, and streamlining the use of resources, as well as operational waste, such as energy and water consumption. In the USA, where AI-driven growth imposes demands on the electric grids and drives a surge in electricity demand, the CE approaches of modular retrofits and hardware remanufacturing can be scaled up to reconcile the growth and sustainability. The UK, leveraging mature policies like net-zero targets and heat-network incentives, exemplifies how waste-heat recovery and circular procurement can integrate data centres into low-carbon urban ecosystems. In Nigeria, as digitalisation accelerates and infrastructure continues to be a challenge, new tendencies of energy-efficient designs and secondary IT markets demonstrate that it is possible to introduce CE principles to the developing settings and promote equitable development. There is a strong need to mainstream these strategies through cross-sector collaboration (between the operators, policymakers, and the researchers) to create standardised metrics, novel business models, and facilitating regulations. Finally, placing CE first will not only decrease resource intensity of this sector, but it will also add value to the economy and data centres can become the key to a sustainable digital future.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Masanet, E. et al., 2024. United States data center energy usage report. Lawrence Berkeley National Laboratory. Available at: https://www.energy.gov/articles/doe-releases-new-report-evaluating-increase-electricity-demand-data-centers (Accessed: 11 September 2025).

[2] Gartner, 2025. Electricity demand for data centers to grow 16 % in 2025 and double by 2030. Available at: https://www.gartner.com/en/newsroom/press-releases/2025-11-17-gartner-says-electricity-demand-for-data-centers-to-grow-16-percent-in-2025-and-double-by-2030 (Accessed: 22 November 2025).

[3] IEA, 2025. Energy and AI. International Energy Agency. Available at: https://www.iea.org/reports/energy-and-ai (Accessed: 11 September 2025).

[4] Kirchherr, J., Reike, D. & Hekkert, M., 2017. Conceptualizing the circular economy: an analysis of 114 definitions. Resources, Conservation and Recycling, 127, pp.221–232.

[5] Pomponi, F. & Moncaster, A., 2017. Circular economy for the built environment: a research agenda. Journal of Cleaner Production, 178, pp.710–719.

[6] Belkhir, L. & Elmeligi, A., 2018. Assessing ICT global emissions footprint: trends to 2040 & recommendations. Journal of Cleaner Production, 177, pp.448–463.

[7] Andrae, A.S.G. & Edler, T., 2015. On global electricity usage of communication technology: trends to 2030. Challenges, 6(1), pp.117–157.

[8] LSBU, 2022. CEDaCI (Circular Economy for the Data Centre Industry). London South Bank University. Available at: https://www.lsbu.ac.uk/stories-finder/cedaci-circular-economy-for-the-data-centre-industry (Accessed: 22 November 2025).

[9] Page, M.J. et al., 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ.

[10] European Commission, 2020. Circular economy action plan. Available at: https://ec.europa.eu/environment/strategy/circular-economy-action-plan_en (Accessed: 11 September 2025).

[11] Ellen MacArthur Foundation, 2013. Towards the circular economy. Available at: https://www.ellenmacarthurfoundation.org/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an (Accessed: 22 November 2025).

[12] Arup, 2025. Circular thinking for data centres. Available at: https://www.arup.com/globalassets/downloads/insights/c/circular-thinking-for-data-centres/arup-circular-thinking-for-data-centres.pdf (Accessed: 22 November 2025).

[13] Open Compute Project, 2021. The financial & sustainability case for circularity: data center impact report. Available at: https://www.opencompute.org/documents/itrenew-the-case-for-circularity-data-center-impact-report-ocp-v11-pdf (Accessed: 22 November 2025).

[14] International Telecommunication Union & World Bank, 2023. Green data centers: towards a sustainable digital transformation. Available at: https://www.itu.int/en/ITU-D/Environment/Documents/Publications/2023/ITU-World%20Bank%20Green%20data%20centers_2023.pdf (Accessed: 22 November 2025).

[15] DLR Group, 2025. Data center adaptive reuse: 5 strategies for existing buildings. Available at: https://www.dlrgroup.com/idea/data-center-adaptive-reuse-strategies/ (Accessed: 22 November 2025).

[16] Gensler, 2025. Historic buildings: a new solution for modern data centers. Available at: https://www.gensler.com/blog/historic-buildings-a-solution-for-modern-data-centers (Accessed: 22 November 2025).

[17] GP Radar, n.d. Adaptive reuse in data center construction: a sustainable approach. Available at: https://www.gp-radar.com/article/adaptive-reuse-in-data-center-construction-a-sustainable-approach (Accessed: 22 November 2025).

[18] AIA & NTHP, 2024. Building reuse: a proven climate and economic strategy. Available at: https://www.aia.org/sites/default/files/2024-12/AIA_NTHP_Building_Reuse_42__0.pdf (Accessed: 22 November 2025).

[19] NewStudio Architecture, 2023. Adaptive reuse: a strategy for holding history and carbon. Available at: https://www.newstudioarchitecture.com/... (Accessed: 22 November 2025).

[20] Skanska, 2024. Building decarbonization: the importance of circularity, material selection and innovative construction methods. Available at: https://www.usa.skanska.com/... (Accessed: 22 November 2025).

[21] ERM, 2025. Circular building & construction supply chains for data centers. Available at: https://www.erm.com/insights/circular-building-construction-supply-chains-for-data-centers-a-strategy-to-tackle-environmental-impact/ (Accessed: 22 November 2025).

[22] Pierzchlewicz, D., Woźniak, A. & Widera, B., 2025. Recent research on circular architecture: a literature review of 2021–2024 on circular strategies in the built environment. Sustainability, 17(17), p.7580.

[23] DPR Construction, 2024. Before you build: early strategies for carbon reduction. Available at: https://www.dpr.com/media/blog/carbon-reduction-planning-and-pre-design (Accessed: 22 November 2025).

[24] BASX Solutions, n.d. Modular data centers solutions. Available at: https://basxsolutions.com/modular-data-centers-solutions/ (Accessed: 22 November 2025).

[25] Eaton, n.d. Modular data center design. Available at: https://www.eaton.com/us/en-us/catalog/low-voltage-power-distribution-controls-systems/modular-data-center.html (Accessed: 22 November 2025).

[26] Vertiv, 2023. Scaling up your data center with prefabricated modular solutions. Available at: https://www.vertiv.com/en-emea/about/news-and-insights/articles/blog-posts/... (Accessed: 22 November 2025).

[27] Cadence, n.d. Data center retrofits vs. new builds: a contractor's perspective. Available at: https://cadencenow.com/data-center-retrofits-vs-new-builds-a-contractors-perspective/ (Accessed: 22 November 2025).

[28] EVOLVE MEP, 2023. A playbook for MEP planning in data center construction. Available at: https://evolvemep.com/blog/a-playbook-for-mep-planning-in-data-center-construction (Accessed: 22 November 2025).

[29] Data Center Dynamics, 2022. Re-use, refurb, recycle: circular economy thinking and data center IT assets. Available at: https://www.datacenterdynamics.com/en/analysis/re-use-refurb-recycle-circular-economy-thinking-and-data-center-it-assets/ (Accessed: 22 November 2025).

[30] GBC Engineers, 2025. Sustaining innovation in data centers: building a green digital future. Available at: https://gbc-engineers.com/news/sustaining-innovation-in-data-centers (Accessed: 22 November 2025).

[31] Amazon, 2023. How AWS data centers reuse retired hardware. Available at: https://www.aboutamazon.com/news/aws/how-aws-data-centers-reuse-retired-hardware (Accessed: 22 November 2025).

[32] Human-I-T, 2024. Data center refurbishment: an alternative solution to recycling. Available at: https://www.human-i-t.org/data-center-refurbishment/ (Accessed: 22 November 2025).

[33] Securis, 2023. Reusing decommissioned data center equipment. Available at: https://securis.com/blog/reusing-with-data-center-decommissioning/ (Accessed: 22 November 2025).

[34] Data Centre Magazine, 2024. How AWS recycles 99 % of its data centre hardware. Available at: https://datacentremagazine.com/data-centres/how-aws-recycles-99-of-its-data-centre-hardware (Accessed: 22 November 2025).

[35] Evernex, 2025. Circular IT is transforming data centers. Available at: https://evernex.com/blog/how-circular-it-is-transforming-data-centers/ (Accessed: 22 November 2025).

[36] Reconext, 2025. Data center equipment recycling: a reuse-first program. Available at: https://www.reconext.com/data-center-equipment-recycling-a-reuse-first-program/ (Accessed: 22 November 2025).

[37] Sims Lifecycle Services, n.d. What happens to data center equipment after it is picked up? Available at: https://www.simslifecycle.com/data-center/faq/how-equipment-is-processed/ (Accessed: 22 November 2025).

[38] ITAD Company, n.d. Data center IT hardware decommissioning, disposal, recycling. Available at: https://itad-company.com/Data_Center_ITAD/decommissioning_data_center_hardware.html (Accessed: 22 November 2025).

[39] FlexAir, n.d. Ultimate guide to data center efficiency. Available at: https://www.flexairmi.com/guide-to-data-center-efficiency-strategies-for-optimization-sustainability/ (Accessed: 22 November 2025).

[40] Gemini, 2025. Cloud-powered smart cities: building a sustainable future. Available at: https://www.gemini-us.com/cloud-data/building-sustainable-smart-cities-with-cloud (Accessed: 22 November 2025).

[41] DATAVERSITY, 2024. Sustainable data centers: the green revolution in data management. Available at: https://www.dataversity.net/articles/sustainable-data-centers-the-green-revolution-in-data-management/ (Accessed: 22 November 2025).

[42] US Department of Energy, 2024. DOE releases new report evaluating increase in electricity demand from data centers. Available at: https://www.energy.gov/articles/doe-releases-new-report-evaluating-increase-electricity-demand-data-centers (Accessed: 23 November 2025).

[43] Lawrence Berkeley National Laboratory, 2025a. Berkeley Lab report evaluates increase in electricity demand from data centers. Available at: https://newscenter.lbl.gov/2025/01/15/berkeley-lab-report-evaluates-increase-in-electricity-demand-from-data-centers/ (Accessed: 23 November 2025).

[44] Congressional Research Service, 2025a. Data centers and their energy consumption. Available at: https://www.congress.gov/crs-product/R48646 (Accessed: 23 November 2025).

[45] Pew Research Center, 2025. What we know about energy use at U.S. data centers amid the AI boom. Available at: https://www.pewresearch.org/short-reads/2025/10/24/what-we-know-about-energy-use-at-us-data-centers-amid-the-ai-boom/ (Accessed: 23 November 2025).

[46] Lawrence Berkeley National Laboratory, 2025b. Large load literature review. Available at: https://eta-publications.lbl.gov/sites/default/files/2025-11/wip_lbnl_lllreview_oct_update_2025.pdf (Accessed: 23 November 2025).

[47] Bipartisan Policy Center, 2025. Strategic federal actions aim to strengthen AI and energy infrastructure. Available at: https://bipartisanpolicy.org/explainer/strategic-federal-actions-aim-to-strengthen-ai-and-energy-infrastructure/ (Accessed: 23 November 2025).

[48] White House, 2025. Accelerating federal permitting of data center infrastructure. Available at: https://www.whitehouse.gov/presidential-actions/2025/07/accelerating-federal-permitting-of-data-center-infrastructure/ (Accessed: 23 November 2025).

[49] Congressional Research Service, 2025b. Energy tax benefits for data centers: in brief. Available at: https://www.congress.gov/crs-product/R48583 (Accessed: 23 November 2025).

[50] Abitos, 2025. Tax incentives for building and operating data centers. Available at: https://abitos.com/tax-incentives-data-centers-2025/ (Accessed: 23 November 2025).

[51] AWS, 2024. AWS is making data centers more sustainable with a circular strategy. Available at: https://www.aboutamazon.com/news/aws/aws-data-center-ai-circularity (Accessed: 22 November 2025).

[52] US Green Building Council, 2025. The impact of state and local incentives on sustainable data centers. Available at: https://www.usgbc.org/articles/impact-state-and-local-incentives-sustainable-data-centers (Accessed: 23 November 2025).

[53] Sites Selection Group, 2025. States rethink data center incentives amid new pressures. Available at: https://info.siteselectiongroup.com/blog/states-rethink-data-center-incentives-amid-new-pressures (Accessed: 23 November 2025).

[54] DMA Inc., 2025. How states are rewriting the rules for data center incentives in 2025. Available at: https://dmainc.com/news-and-insights/state-rules-data-center-incentives-2025/ (Accessed: 23 November 2025).

[55] ResearchAndMarkets, 2025. Sustainable data centers: Global strategic business report (Report No. 6111039). Available at: https://www.researchandmarkets.com/reports/6111039/sustainable-data-centers-global-strategic (Accessed: 22 November 2025).

[56] Trax Technologies, 2025. Data centers must lead tech's AI-driven circular economy transformation. Available at: https://www.traxtech.com/ai-in-supply-chain/data-centers-must-lead-techs-ai-driven-circular-economy-transformation (Accessed: 22 November 2025)

[57] World Resources Institute, 2025. Powering the US data center boom: why forecasting can be so challenging. Available at: https://www.wri.org/insights/us-data-centers-electricity-demand (Accessed: 23 November 2025).

[58] Congressional Research Service, 2025a. Data centers and their energy consumption. Available at: https://www.congress.gov/crs-product/R48646 (Accessed: 23 November 2025).

[59] Clark, A., 2025. Data centres: planning policy, sustainability, and resilience. House of Commons Library Research Briefing CBP-10315. Available at: https://commonslibrary.parliament.uk/research-briefings/cbp-10315/ (Accessed: 23 November 2025).

[60] Institution of Engineering and Technology, 2025. IET responds to plans for 100 new data centres across UK. Available at: https://www.theiet.org/media/press-releases/press-releases-2025/press-releases-2025-july-september/18-august-2025-iet-responds-to-plans-for-100-new-data-centres-across-uk (Accessed: 23 November 2025).

[61] Department for Energy Security and Net Zero, 2025. UK net zero research and innovation framework delivery plan. Available at: https://www.gov.uk/government/publications/uk-net-zero-research-and-innovation-framework-delivery-plan-progress-report-2022-to-2025/uk-net-zero-research-and-innovation-framework-delivery-plan-progress-report-2022-to-2025-accessible-webpage (Accessed: 23 November 2025).

[62] Mitsubishi Electric, 2025. Data centres: heat reuse for a low carbon future. Available at: https://europe.mitsubishielectric.com/en/data-center/pdf/Heat_Reuse_for_a_Low_Carbon_Future.pdf (Accessed: 23 November 2025).

[63] AECOM, 2025. Enough heat to power up to half a million homes escaping from London's data centres. Available at: https://aecom.com/uk/press-releases/enough-heat-to-power-up-to-half-a-million-homes-escaping-from-londons-data-centres/ (Accessed: 23 November 2025

[64] Energy Institute, 2025. How data centres can become allies in the net zero heat transition. Available at: https://knowledge.energyinst.org/new-energy-world/article?id=139807 (Accessed: 23 November 2025).

[65] University of Manchester, 2025. Too hot to ignore: fixing the infrastructure gap in data centre cooling. Available at: https://blog.policy.manchester.ac.uk/sci-tech/2025/08/too-hot-to-ignore-fixing-the-infrastructure-gap-in-data-centre-cooling/ (Accessed: 23 November 2025).

[66] techUK, 2025a. Our 2025 work programme for the Climate, Environment and Sustainability Programme. Available at: https://www.techuk.org/resource/our-2025-work-programme-for-the-climate-environment-and-sustainability-programme-get-involved.html (Accessed: 23 November 2025).

[67] UKGBC, 2022. Insights on how circular economy principles can impact carbon and value in the built environment. Available at: https://ukgbc.org/wp-content/uploads/2022/08/Whole-Life-Carbon-Circular-Economy-Report.pdf (Accessed: 23 November 2025).

[68] Data Centre Review, 2025. Remanufactured compressors can boost circular economy in data centre cooling. Available at: https://datacentrereview.com/2025/05/remanufactured-compressors-can-boost-circular-economy-in-data-centre-cooling/ (Accessed: 23 November 2025).

[69] Weatherite Group, 2025. Heat recovery in data centres: turning waste into efficiency. Available at: https://www.weatheritegroup.com/heat-recovery-in-data-centres-turning-waste-into-efficiency/ (Accessed: 23 November 2025).

[70] Data Center Dynamics, 2025a. UK district heating networks look to data centers for waste heat. Available at: https://www.datacenterdynamics.com/en/news/uk-district-heating-networks-look-to-data-centers-for-waste-heat/ (Accessed: 23 November 2025).

[71] techUK, 2025b. Data centres climate change agreement target periods 7–9 announced. Available at: https://www.techuk.org/resource/data-centres-climate-change-agreement-target-periods-7-9-announced.html (Accessed: 23 November 2025).

[72] techUK, 2025c. How data centres can supercharge UK economic growth. Available at: https://www.techuk.org/resource/techuk-report-foundations-for-the-future-how-data-centres-can-supercharge-uk-economic-growth.html (Accessed: 23 November 2025).

[73] UKGBC, 2025. UKGBC impact report 2024–2025. Available at: https://ukgbc.org/wp-content/uploads/2025/09/ImpactReport25_SepAGM.pdf (Accessed: 23 November 2025).

[74] University College London, 2025. Building the circular economy. Available at: https://www.ucl.ac.uk/engineering/sites/engineering/files/7_final_report_building_the_circular_economy.pdf (Accessed: 23 November 2025).

[75] Orbital Materials, 2025. Wasted power: data center regulation in the UK. Available at: https://orbitalmaterials.com/posts/wasted-power-data-center-regulation-in-the-uk (Accessed: 23 November 2025).

[76] techUK, 2025d. Industrial strategy 2025: what it means for the energy infrastructure and digital tech sector. Available at: https://www.techuk.org/resource/industrial-strategy-2025-what-it-means-for-the-energy-infrastructure-and-digital-tech-sector.html (Accessed: 23 November 2025).

[77] Tom's Hardware, 2025. UK couple's garden shed datacenter heats home and cuts energy bills. Available at: https://www.tomshardware.com/tech-industry/uk-couples-garden-shed-data-center-heats-home-and-cuts-bills (Accessed: 23 November 2025).

[78] Nairametrics, 2025. Nigeria data centre capacity to hit 218 MW by 2030 — report. Available at: https://nairametrics.com/2025/11/11/nigeria-data-centre-capacity-to-hit-218mw-by-2030-report/ (Accessed: 23 November 2025).

[79] Yahoo Finance, 2025. Nigeria data center market investment report 2025–2030. Available at: https://finance.yahoo.com/news/nigeria-data-center-market-investment-080400869.html (Accessed: 23 November 2025).

[80] Mordor Intelligence, 2025. Nigeria data center market size & share outlook to 2030. Available at: https://www.mordorintelligence.com/industry-reports/nigeria-data-center-market (Accessed: 23 November 2025).

[81] Credence Research, 2025. Nigeria data center market size & share outlook to 2032. Available at: https://www.credenceresearch.com/report/nigeria-data-center-market (Accessed: 23 November 2025).

[82] Ken Research, 2025. Nigeria cloud data center market | 2019 – 2030. Available at: https://www.kenresearch.com/nigeria-cloud-and-data-center-services-market (Accessed: 23 November 2025).

[83] Guardian Nigeria, 2025. Surge in data centre construction, demand excites investors. Available at: https://guardian.ng/property/surge-in-data-centre-construction-demand-excites-investors/ (Accessed: 23 November 2025).

[84] Bloomberg, 2025. Nigeria AI data center projects draw in $1 billion investment. Available at: https://www.bloomberg.com/news/articles/2025-10-17/nigeria-ai-data-center-projects-draw-in-1-billion-investment (Accessed: 23 November 2025).

[85] Datacenters.com, 2025. Is Africa the next big data center hub? Available at: https://www.datacenters.com/news/is-africa-the-next-big-data-center-hub (Accessed: 23 November 2025).

[86] Arizton, 2025. Nigeria data center colocation market analysis report. Available at: https://www.arizton.com/market-reports/nigeria-data-center-colocation-market (Accessed: 23 November 2025).

[87] Professional UK, 2025. Nigeria data center colocation market size, share, opportunities analysis 2025–2035. Available at: https://www.professionalsuk.co.uk/article/marketing-and-pr/114132/nigeria-data-center-colocation-market-size-share-opportunities-analysis-2025-2035 (Accessed: 23 November 2025).

[88] Data Insights Market, 2025. Nigeria data center market 2025 trends and forecasts 2033. Available at: https://www.datainsightsmarket.com/reports/nigeria-data-center-market-10842 (Accessed: 23 November 2025).

[89] Awodele, I.A. et al., 2025. Advancing circular economy transition in the Nigeria construction industry through digital twin technology adoption. Green Technologies and Sustainability, 3(3), p.100201.

[90] Eco-Standards Group, 2025. How data centre expansion risks derailing climate goals. Available at: https://ecostandard.org/wp-content/uploads/2025/09/Data-centres-report.pdf (Accessed: 23 November 2025).

[91] Omokaro, G.O. et al., 2025. Waste management in Nigeria: systemic failures, circular economy pathways and sustainable solutions. Environmental Development, p.101363.

[92] Dosumu, I. et al., 2025. The challenges and barriers faced in implementing circular economy practices in waste management in Karu LGA of Nasarawa State, Nigeria. International Journal of Research and Innovation in Social Science, IX(IX), pp.1991–1998.

[93] Mishra, S., Sahoo, D. & Mohapatra, S., 2025. Barriers to circular economy adoption in MSMEs: a WINGS analysis of challenges in developing economies. Circular Economy and Sustainability, pp.1–26.

[94] Olanrewaju, G. et al., 2025. The state of sustainability in Nigeria: environmental footprints, risk assessment and mitigation. Available at: https://www.preprints.org/manuscript/202509.1029/v1 (Accessed: 23 November 2025).

[95] Open Compute Project, 2024. Data center facility sustainability metrics. Available at: https://www.opencompute.org/documents/dcf-sustainability-metrics-final-r3-docx-pdf (Accessed: 22 November 2025).

[96] Pomponi, F. & Moncaster, A., 2017. Circular economy for the built environment: a research agenda. Journal of Cleaner Production, 178, pp.710–719.

[97] Huang, P. et al., 2020. A review of data centres as prosumers in district energy systems: renewable energy integration and waste heat reuse for district heating. Applied Energy.

[98] World Green Building Council, 2023. The circular built environment playbook. Available at: https://worldgbc.org/wp-content/uploads/2023/05/Circularity-Accelerator-Playbook_2023.pdf (Accessed: 22 November 2025).

[99] NDEPS, 2020. National Digital Economy Policy and Strategy (2020–2030). Federal Ministry of Communications and Digital Economy, Nigeria.

[100] UK Government, 2024. Overcoming barriers to drive the circular economy in digital. Available at: https://assets.publishing.service.gov.uk/media/684aa1f81c8d5c94e201ab63/Barriers_to_Circularity_Recommendations_Paper.pdf (Accessed: 24 November 2025).

[101] NICER Programme, 2025. UKRI National Interdisciplinary Circular Economy Research final report. Available at: https://ce-hub.org/wp-content/uploads/2025/03/NICER-Programme-Final-Report-2025-compressed.pdf (Accessed: 24 November 2025).

[102] Hoosain, M.S. et al., 2023. Tools towards the sustainability and circularity of data centers. Circular Economy and Sustainability, 3(1), pp.173–197.

[103] Andrews, D. et al., 2021. A circular economy for the data centre industry: using design methods to address the challenge of whole system sustainability in a unique industrial sector. Journal of Cleaner Production.

[104] Romo, M.F.R. et al., 2025. Circular economy and digital technologies: a research agenda for intelligent circular systems. Resources, Conservation & Recycling Advances, p.200292.