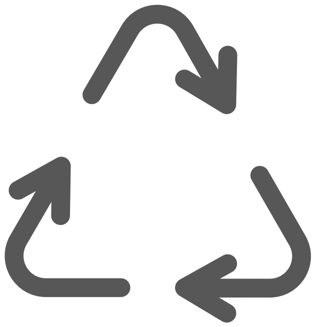
Recycling and Reuse in Hyperscalers: Sustainable Asset Management

INTRODUCTION

"With hyperscaler data centers contributing 70% of toxic landfill waste, the growing e-waste market is expected to reach $145 billion by 2030. Implementing circular economy practices alongside 4IR technologies offers a path toward reducing e-waste and advancing sustainable digital infrastructure."

In 2019, we threw away 600 billion pounds of plastic, which is the weighted sum of all human beings combined. As waste burned our land and waters away, humans desperately turned to the circular economy to save their homes. You may find some familiarity with the circular economy—unlike the typical “take-make-dispose” approach in a typical linear fashion, the circular economy is a model that sustainably uses waste and resources.

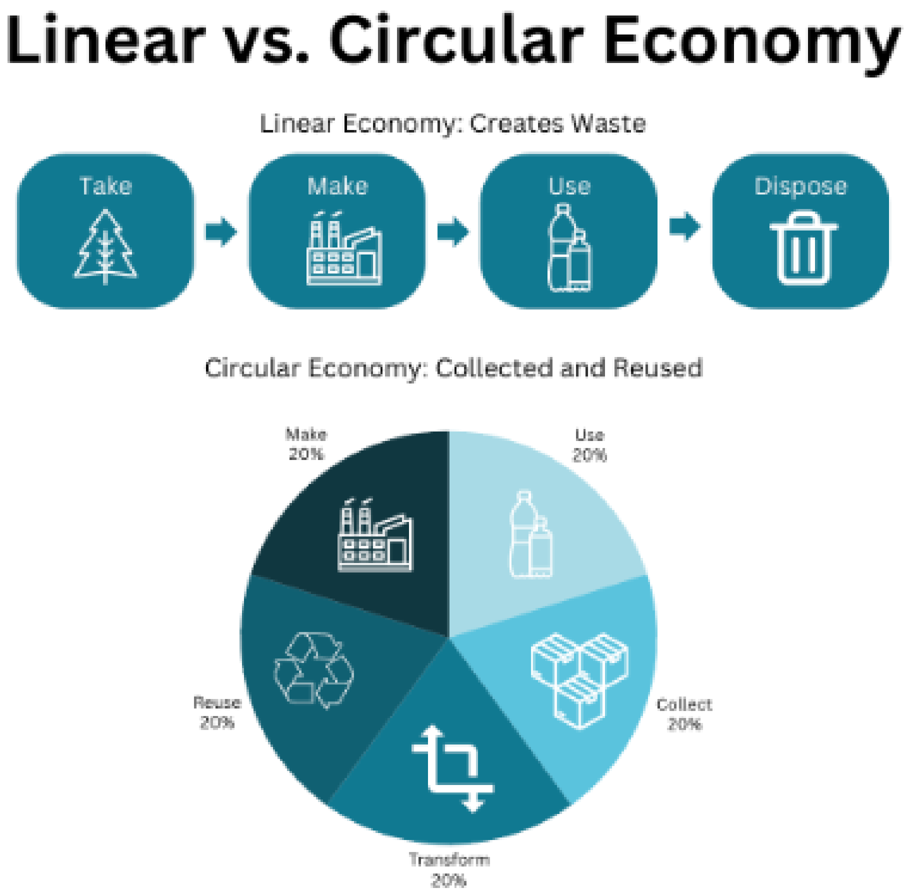
According to the Ellen MacArthur Foundation, the circular economy maximizes resources and materials, eliminating waste. The root of this mass waste in the digital world stems from hyperscaler data centers, which form the backbone of global IT infrastructure. These data centers are significant contributors to electronic waste (e-waste) and energy consumption, accounting for 70% of toxic material in landfills.



The e-waste market is predicted to grow at a CAGR of 13.2%, up to approximately 145 billion dollars by 2030, almost doubling over a decade. As such, the ITAD, ITAM, and data destruction industries must play crucial roles in the circular economy. ITAD focuses on the end-of-life, ITAM covers the entire lifecycle, and data destruction ensures secure deletion of data. Implementing circular economy (CE) practices and leveraging fourth industrial revolution (4IR) technologies within hyperscaler data centers can significantly reduce global e-waste as well. Here, we will explore how CE and 4IR tie in with each other to help accelerate the shift from e-waste to less waste and more haste.

CIRCULAR ECONOMY PRACTICES IN HYPERSCALERS

E-waste is the fastest growing waste, expected to double to 100 million tons by 2050, as mentioned by the World Economic Forum. Moreover, 26% of global companies fully do not recycle their IT assets, which is only 2% less than companies that do reuse. Knowing that refresh cycles are also getting longer due to lagging chip performance still contributes to e-waste. However, as cloud services become more prominent, e-waste mitigation methods fall into the hands of the tech-giants, also known as the hyperscalers. To combat e-waste and to be less dependent on third party data destruction companies, the Circular Electronics Partnership (CEP) was established, consisting of Microsoft, Google, Amazon, Iron Mountain, Vodafone, and Dell. Here, we will analyze various incentives for circular practices with a few hyperscalers.



Source: https://www.techtarget.com/searchdatacenter/tip/Use-the-data-center-circular-economy-for-sustainability

Microsoft

With Microsoft's recent project in 2020, Circular Centers, dedicated to reusing servers and hardware, average lifespan is expected to increase from 5 to at least 10 years by 2025. Microsoft's plan to be carbon negative by 2030 is ambitious yet achievable, setting various goals in the industry. For example, Microsoft Circular Center establishment in Sweden contributes to the 83% resume and 17% recycle of crucial IT parts of the Circular Centers Model, whilst also decreasing carbon emissions by 150,000 metric tons. This new center will support 12,000 servers per month, and Microsoft plans to further expand, if not already, to more locations such as Virginia, Ireland, and Singapore. These projects can save around 100 million dollars per year. In addition to Circular Centers, Microsoft developed Microsoft Dynamics 365 Supply Chain Management and Microsoft Power Platform, which effectively regulates inventory and manufacturing. These incentives will drive a significant impact in the shift to sustainability.

Amazon

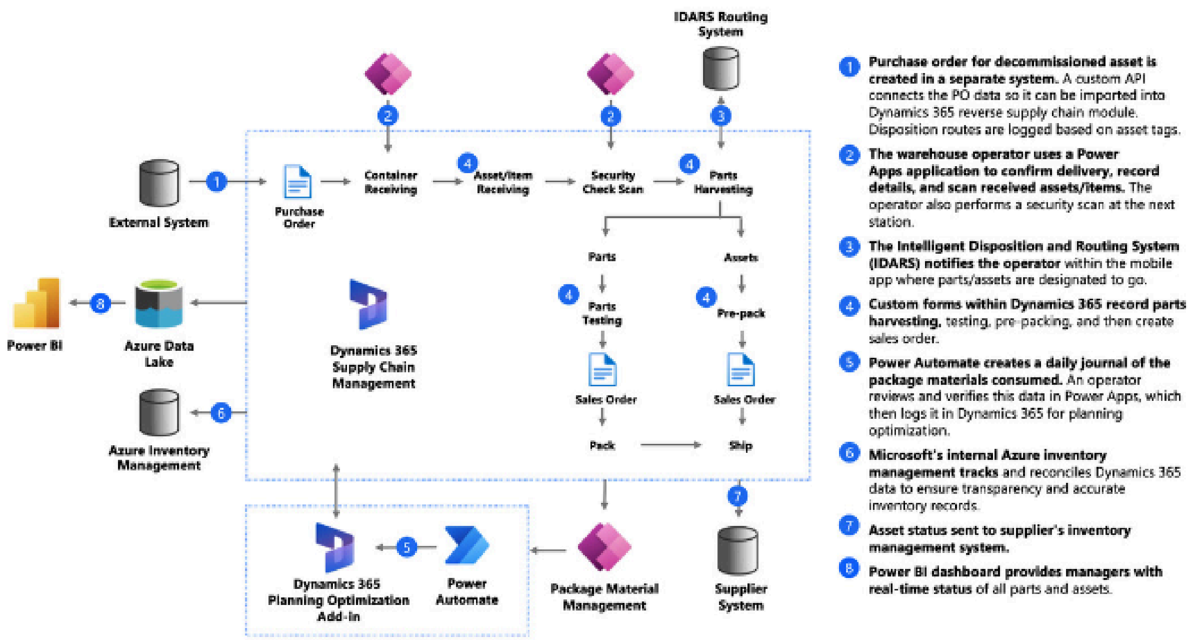
Amazon Web Services (AWS) also CE practices, focusing on its reverse logistics hubs, in which consumer data in server racks are cleaned, de-manufactured into individual parts, then tested and resued to improve future designs. Artificial intelligence and machine learning methods are also added to this process to optimize efficiency and effectiveness. More recently, in 2023, Amazon collaborated with the Ellen MacArthur Foundation to commit to The Climate Pledge, where Amazon hopes to reach net-zero carbon emissions by 2040.

Not only Ellen MacArthur, Amazon also is working with the NSF and the International and Scientific Certification Systems Global (SCS Global). In working with third party companies, Amazon hopes to create various certifications, which help consumers make better decisions when recycling. In May, Amazon developed the Recycled Content Standard for Electrical and Electronic Equipment, where products are required to be made from one or more recycled materials. Rich Loretto, the director of Amazon's circular economy, says that these steps towards a more sustainable future will "scale to have a greater impact across the industry."

Google

Google has made significant contributions with CE practices in their data centers. Google established a data center in Fredericia, Denmark, which reached zero waste since its establishment, thanks to a partnership with a waste collection and separation company. Moreover, in 2022, Google was able to achieve zero-waste goals with 23 data centers, preventing 90% and more of solid waste from reaching landfills. These numbers are astonishing yet impressive, and Google plans to continue their plans for sustainability with the program Google for Startup Accelerator: Circular Economy, where Google brings their products and services to Seed to Series A technology startups and organizations to innovate and reduce waste. In trying to reduce data center waste, Google has even resulted in 44 million hardware parts in conjunction with the Zero Waste to Landfill initiative since 2015, reselling more than 7 million alone in 2023. From sustainable packaging to product longevity, Google has very holistic perspectives to becoming more sustainable.

Microsoft Circular Centers' end-to-end reverse supply chain and warehouse management process



Fourth Industrial Revolution (4IR) Technologies

As hyperscalers lead the way in adopting CE principles, the integration of Fourth Industrial Revolution Technologies is pivotal in optimizing these efforts. With the onset of the 18th century and the beginning of the Industrial Revolution, we have seen a rapid increase in technological advancements. From steam engines to electricity, and finally automation, we are now at the dawn of a new industrial technology called Industry 4.0 or Fourth Industrial Revolution (4IR) Technologies, representing the fourth technological wave in the industry. 4IR refers to the current and upcoming advancements in technologies such as AI, the Internet of Things (IoT), Blockchain, and Big Data.

These technologies have the potential to make a significant impact on the management of e-waste. In 2019, the Global E-waste Monitor reported that 53.6 million tonnes of e-waste were generated worldwide with only 17.4% of it being documented, collected, and appropriately recycled. They also estimate that globally e-waste is expected to increase up to 74.7 million tonnes by 2030. Most of this e-waste is currently being disposed of in landfills with other types of waste, leading to various risks associated with the toxicity of the environment. Manually handling this e-waste further increases these risks and results in workers being exposed to toxic substances, thus necessitating proper e-waste management. To address these issues, 4IR technologies are being utilized to ensure the safe and effective management of global e-waste.

Further, we explore each of the 4IR technologies and how they can be used to reduce e-waste:

IoT (Internet of Things)

The IoT is a technology that connects several devices into a network, where connected devices can act as sensors, communicating and exchanging data via the internet. IoT sensors can gather data on temperature, humidity, power consumption, and other environmental factors of data centers.

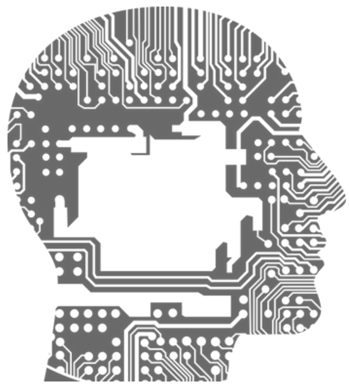
This also helps to prolong the lifespan of IT hardware, thus reducing replacements and costs. IoT can be adopted both by households and corporations. In households, they can be used to connect smart home devices (like thermostats and lights) while corporations can use them for asset tracking, supply chain optimization, and energy management since these practices can contribute to e-waste reduction. IoT-created networks and marketplaces lower the cost of acquiring information which enables an online-based platform economy, facilitating e-waste tracking, collection, and recycling. In terms of e-waste management, IoT primarily plays a role in e-waste monitoring and data collection.

Through the IoT-enabled sensors, we can monitor the status, location, and usage of electronic devices which is a significant step forward in e-waste tracking. Several studies have also implemented smart sensors in IoT to collect data on temperature, power levels, humidity, and location and have found that tracking this information is essential to ensure a safe environment and to pick up on any hazards associated with e-waste. Since the IoT system is able to provide remote and real-time monitoring of this data, it can be used to track e-waste throughout its lifecycle, from production to disposal.

Artificial Intelligence (AI)

AI and machine learning algorithms are vital to data center operations as they can analyze vast amounts of data to predict equipment failure and optimize energy usage. For example, Google's DeepMind was able to consistently achieve a 40% reduction in energy usage for cooling through its machine learning system. The benefits of using AI for predictive maintenance are also significant in cost savings as a study by Deloitte found that it can reduce maintenance costs by 30% and breakdowns by 70%.

The scope of AI in e-waste management primarily revolves around 2 uses: e-waste classification and detection and machine learning prediction. Firstly, it is well-known that AI algorithms can analyze data from images and videos and extract valuable information.



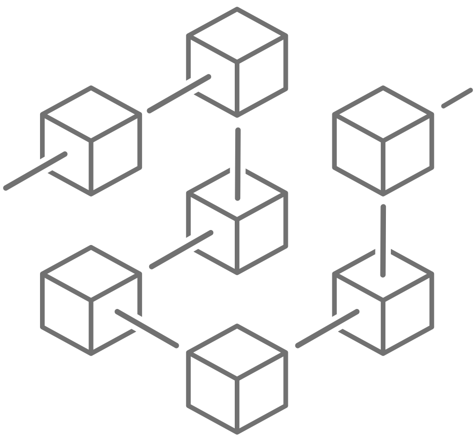
E-waste classification builds off of this capability as it is an automated sorting system that identifies and classifies different types of e-waste. AI-powered robots can not only sort e-waste effectively but also identify recyclable materials like metals and plastics from non-recyclable ones.

Classification therefore offers an intelligent way to categorize e-waste as it requires minimal human involvement. It reduces the volume of e-waste sent to landfills and increases the recovery of more valuable materials.

On the other hand, machine learning prediction assists data centers in predicting equipment failures and optimizing maintenance schedules. By reducing downtime and extending the lifespan of IT hardware it ultimately decreases the amount of e-waste generated.

Blockchain

Blockchain technology provides a decentralized register to track data center transactions, ensuring data security and transparency. Blockchain technology is a novel topic in e-waste management as it can control the cycle of e-waste treatment starting from production up to recovery with each phase being stored on a blockchain network. This suggests that blockchain technology can especially impact the tracking and tracing of electronic devices throughout their lifecycle.



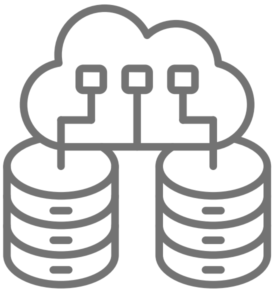
Blockchain is a potential solution for implementing traceability as it can generate an audit history to ensure data integrity and security. As e-waste moves through various stages like sorting, recycling, and disposal, blockchain can track and record its real-time location and the amount of toxicity it contains.

This ensures the proper management of electronic devices from production to disposal and reduces the risk of illegal e-waste dumping, thus promoting responsible recycling. Auditors can also verify the legitimacy of recycling using blockchain records.

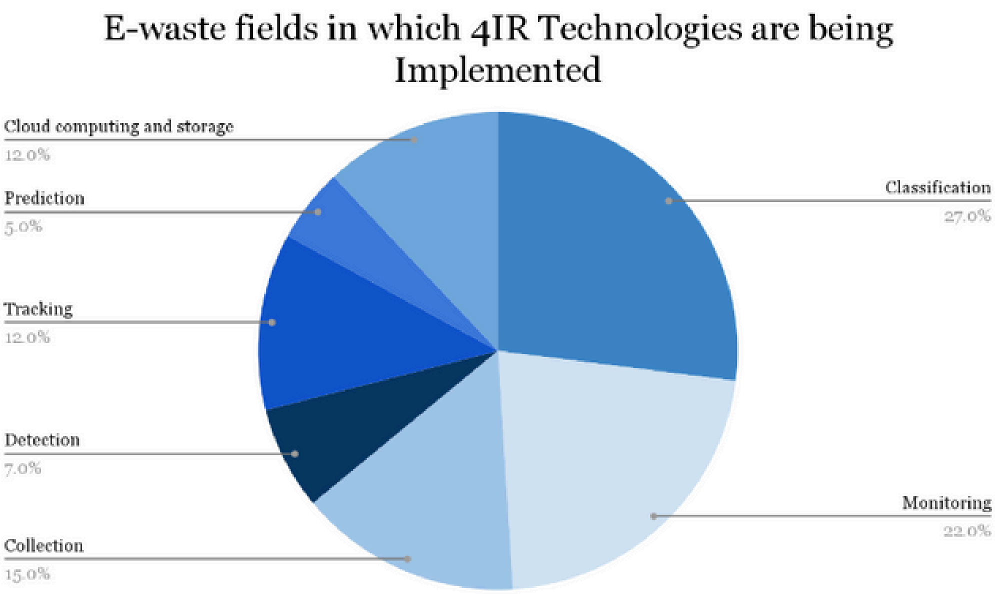
Big Data and Cloud

Big data analytics are able to analyze large datasets to identify patterns and optimize resource allocation. It is mainly used for data collection and storage and predictive analysis. Large storage databases are required to store and manage large amounts of data.

Therefore cloud storage services are essential for e-waste management as they provide storage of collected data related to e-waste. This helps in determining the most efficient routes for e-waste collection trucks, minimizing fuel consumption and emissions. They can also analyze material composition to answer questions about the components that yield the highest value when recycled. Additionally, it can also be used to predict the amount of e-waste produced.

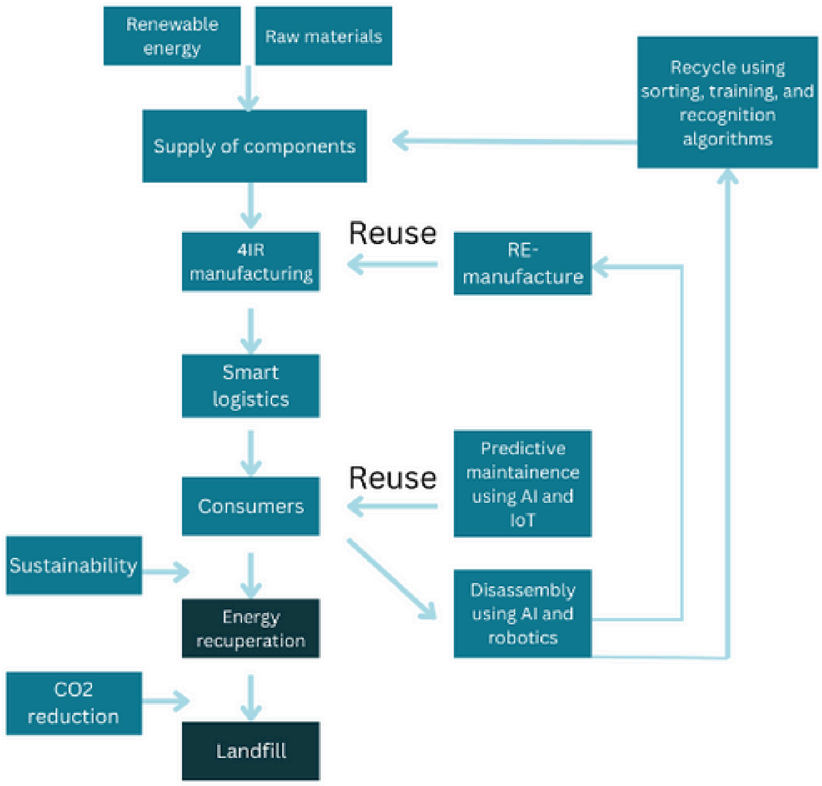


Technology	Key Advantages	Description
AI	Automation	- Provides streamlined and scale decision making. - Automation in this case speeds up the process of classification, reduces risk. - Reduced human interaction
Blockchain	Data security, privacy, transparency	- Sensitive information in blockchain is encrypted and prevents unauthorized activities. - Creates an audit trail that records the location of e-waste at every step on its journey.
IoT	Monitoring and control in real time	- Deliver continuously updated data of the process or system.
Big data and cloud	Scalability, cost-effectiveness	- Handle large amount of data. - Reduce the cost of hardware storage



Source: https://journals.uob.edu.bh/handle/123456789/5638

Integration of Circular Economy and 4IR in Data Centers



Source: https://www.mdpi.com/2071-1050/12/23/10143

This diagram is adapted from the Ellen MacArthur Foundation's butterfly diagram, which encapsulates the integration of CE principles with 4IR technologies in data centers. 4IR plays a key role in the circular economy as it precisely regulates the flow of materials in the circular path. By implementing smart logistics and predictive maintenance using AI and IoT, data centers can enhance resource tracking and reduce maintenance costs. CE principles such as re-use, remanufacturing, and advanced recycling techniques further extend product life cycles and minimize environmental impact. Together, their synergy creates closed loop systems that emphasize the importance of energy recuperation and CO_2 reduction, hence contributing to substantial environmental and economic benefits like cutting maintenance costs by 25-30% through predictive maintenance.

Need for Global R&D of CE and 4IR

Global Cooperation for E-Waste

Not only for hyperscalers, the need for CE and 4IR is widespread around the world. E-waste has been a critical global issue, especially in regions like Africa, where other major countries like the United States and Korea have been dumping their waste. The United Nations University writes that global e-waste was almost at 54 million metric tons in 2019, with only 17% of that properly recycled. This number further underscores the need for collaborative attempts in research and development of the field.

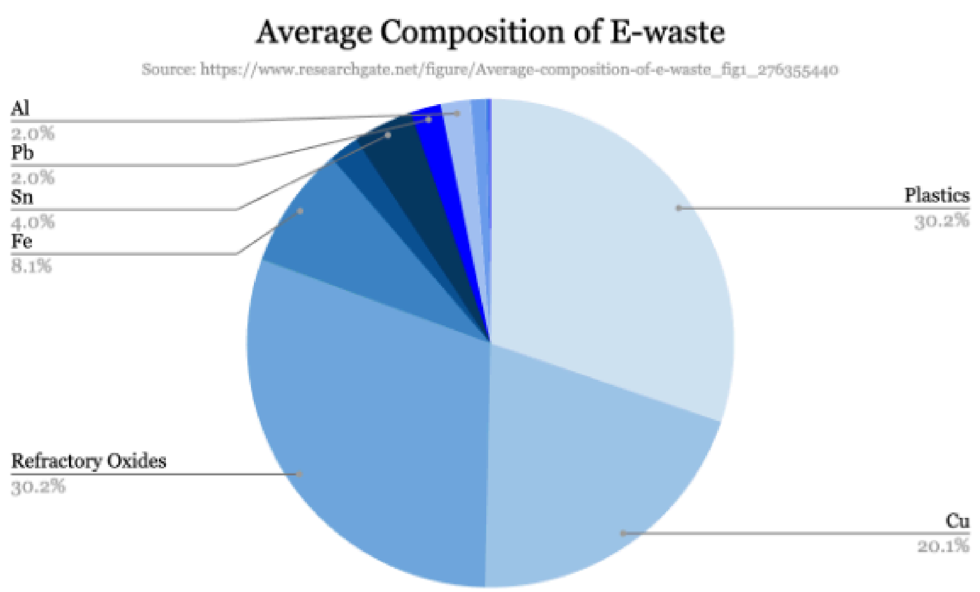
In terms of international cooperation, the Basel Convention, which controls transboundary waste movement, and the Bamako Convention, which bans placing waste into Africa, are powerful regulations that assist Africa in its goals. Future recommendations from sources indicate that governments should adopt Extended Producer Responsibility (EPR) policies, which regulate producers and importers for end-of-life e-waste. Financial incentives and education are also necessary to raise awareness, not only in Africa, but globally. The global concern of e-waste only further highlights why CE and 4IR are so crucial beyond hyperscalers.

Economic Benefits

Reducing e-waste also has several economic benefits. Recycling just 1 million used cell phones can recover as much as 772 lbs of silver, 352,000 lbs of copper, 75 lbs of gold, and 33 lbs of platinum.As a comparison, in the USA alone, there are 126.3 million cell phones found in e-waste every year, while 5.3 billion are found globally. It is estimated that the 53.6 tonnes of e-waste generated in 2019 contained such raw materials (gold, silver, copper, etc) that were worth $57 billion. Since only 17.4% of that e-waste was recycled, this translates into $47 billion worth of raw materials that were never recovered. These substantial opportunities for revenue can even create job opportunities and contribute significantly to developing economies.

CHALLENGES AND BARRIERS

One of the most difficult challenges in mitigating e-waste is the complex composition of e-waste, consisting of dangerous and non-dangerous materials. E-waste can contain up to 69 elements, with heavy metals such as mercy, lead, and even flame retardants. In separating and recycling these materials, there are specialized processes that are oftentimes too advanced and costly. Since one pound of e-waste costs around 20-40 cents, 54 million metric tons of e-waste from 2019 would result in more than billions of dollars. In addition, the continuous updates of AI and GPUs will further increase the amount and variability of e-waste, making the previous process even more challenging. Lastly, as every country has their own e-waste regulations, there is no way yet to standardize a global policy for reducing e-waste.



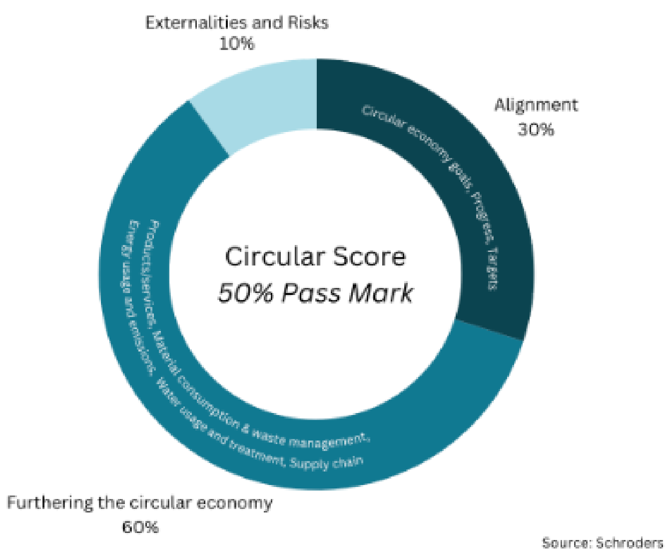
A significant barrier to the adoption of 4IR technologies in data centers is the substantial capital investment required to implement technologies like AI and IoT. For reference, the global market for data center infrastructure management is expected to expand at a CAGR of 11.6%, reaching $3.2 billion by 2026, reflecting the significant financial commitment required. Another issue arises from the fact that IoT systems require interoperability and ensuring interoperability between new and legacy systems requires expertise and considerable customization. The expertise required in this field is the primary issue as IT executives have cited talent shortage as the most significant barrier to the adoption of 64% of emerging technologies. Implementing 4IR technologies requires specialized skills but there is a shortage of talent to meet this demand.

FUTURE DIRECTIONS AND INNOVATIONS

Overall, hyperscalers are actively involved in circular economy and 4IR methods, which emphasizes the relevance and importance of sustainable measures to manage e-waste. Microsoft, compared to other hyperscalers, is cited to have the most "comprehensive" approach, having reached significant milestones; thus, putting them in the forefront in the tech race to sustainability. Microsoft also stressed the importance of working with startups and third party companies, with several investments such as $30 million into Closed Loop Partners' funds into the circular economy approach.

However, other sources write that Microsoft and other hyperscalers fail the circular score because it does not contribute to the circular economy in a "direct manner," but rather plays as a "good citizen." As such, we predict that there will be similar evaluation methods like the circular score in the future to access hyperscalers and their sustainability benchmarks. For future firms, the circular score approach is a promising method to support long-term growth in the industries of ITAM, ITAD, and data destruction as it focuses on smaller and mid-cap parts of the market instead of "mega-caps," as these smaller firms are more dedicated to the circular economy.

Circular Score Criteria



Conclusion

With hyperscalers at the forefront of e-waste management, the global landscape is experiencing significant shifts, driven by the fusion of circular economy (CE) principles and Fourth Industrial Revolution (4IR) technologies. The integration of CE with advanced technologies such as IoT, AI, blockchain, and automation is reshaping industries by improving resource efficiency, extending product lifecycles, and minimizing waste. This combination of sustainability and digital transformation not only helps large firms streamline operations, reduce costs, and maintain infrastructure, but also aligns with evolving environmental regulations and stakeholder expectations around ESG (Environmental, Social, and Governance) compliance.

However, despite the many advantages, challenges remain, especially in making these approaches scalable and financially viable for smaller economies, startups, and developing regions. The implementation of CE strategies and 4IR technologies often requires substantial upfront investments in infrastructure, research, and workforce training—barriers that smaller players find difficult to overcome. Without the same access to resources as hyperscalers or multinational corporations, many startups and SMEs struggle to adopt these sustainable business models at the same pace. Additionally, regulatory frameworks supporting CE adoption vary globally, creating uneven conditions that hinder broader participation.

To bridge this gap, new tools and metrics, such as the circular score, are emerging to provide a more precise understanding of the social, environmental, and economic impacts of business operations without fully integrated CE and 4IR practices. These tools offer a transparent, data-driven way to assess how sustainable a business is across its value chain, helping firms identify areas for improvement and track progress. Evaluation methods like these can empower smaller businesses and less industrialized economies to engage in sustainable practices more effectively by lowering the entry barriers to circular innovation.

As the e-waste industry becomes one of the fastest-growing sectors globally, it presents enormous potential for economic growth. From recycling critical raw materials like rare earth metals to refurbishing electronic devices and reselling components, the industry opens new avenues for both entrepreneurs and investors. The rising demand for sustainable products and services has also encouraged the growth of green tech ventures and circular business models focused on reuse, remanufacturing, and reverse logistics.

Ultimately, the intersection of CE and 4IR technologies is not just a strategic advantage for large enterprises but also an opportunity to democratize sustainability. Policymakers, investors, and industry leaders will need to collaborate to build ecosystems that foster inclusivity—offering incentives, subsidies, and knowledge-sharing platforms to ensure smaller economies and startups can participate in the e-waste revolution. In doing so, they will unlock the full potential of the circular economy, driving innovation, job creation, and sustainable development on a global scale.