TEAM DATA DETECTORS

NAVIGATING E-WASTE FROM DATA CENTERS

Our mission is to drive sustainable data center e-waste management through data quantification, accurate data tracking, circular economy principles, robust e-waste policies, stakeholder collaboration, and innovative recycling solutions to minimize environmental impact and promote a greener digital future.

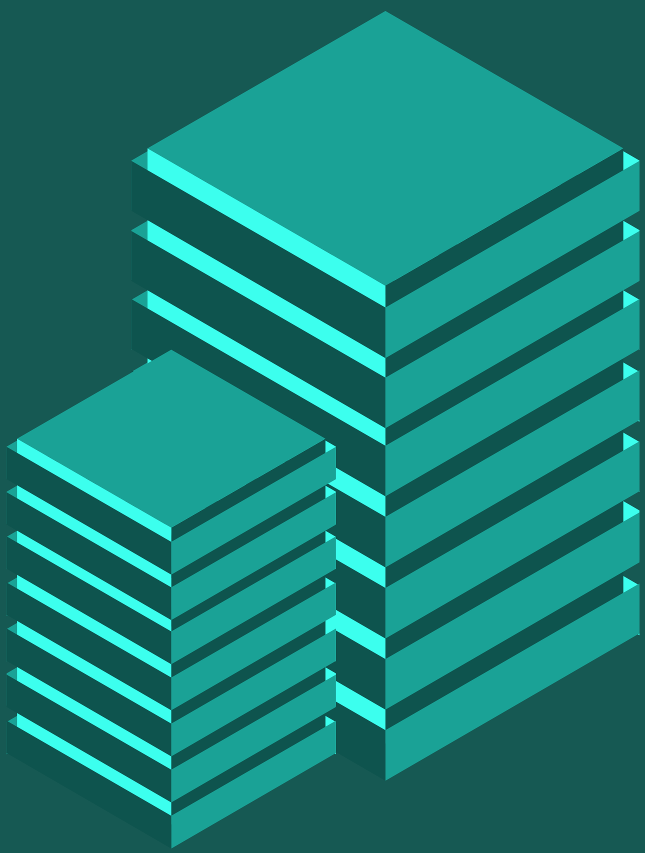

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Table of content

1. Introduction

The exponential growth of digital technology and the increasing demand for data-intensive applications, such as artificial intelligence (AI) and cloud computing, have led to a significant expansion of data centers (DC) worldwide (Statista, n.d.). These facilities are the backbone of modern information and communication technologies, processing, storing, and transmitting vast amounts of data. Data centers play a substantial role in the worldwide e-waste crisis due to the rapid replacement cycles of their computing infrastructure and associated hardware components (Baldé et al., 2017). Servers and other IT equipment are typically being replaced every 3 to 5 years due to technological advancements and the need for increased computing power (Fennewald, 2019). As a result of this frequent replacement cycle, the e-waste problem is growing. With a growing number of data centers installed annually, countries like Germany (the second largest colocation space in the European Union) are at the forefront of this challenge. Effective policies, regulations and innovative solutions are urgently needed to ensure the sustainable management of DC e-waste.

This report aims to examine the e-waste challenge posed by data centers in Germany by quantifying the problem, assessing the existing regulatory framework and practices for e-waste collection and recycling, and proposing actionable recommendations. By addressing this issue, we can pave the way for a more sustainable and environmentally responsible data center industry, aligning technological progress with environmental stewardship and thereby promoting a more sustainable digital future.

2. Challenge

As new hardware and software solutions emerge, IT equipment's lifespan and disposal patterns may change, requiring continuous monitoring and adaptation of e-waste management strategies. To be able to solve this ever-growing problem, one must first quantify the problem. Quantifying the quantity of data centers currently sold, in stock, and waste generated is crucial to estimating the size of the problem and providing sustainable recommendations. As part of a UNITAR project, there exists a general e-waste measurement framework, but this includes no classification of e-waste from DC.

Our challenge is to compile data on sales, estimate an average lifetime based on literature, and estimate the waste generated over the years with a sales-lifetime approach. This research aims to extend the existing "E-waste Statistics" and thereby help countries report data center e-waste specifically. Furthermore, an evaluation of existing legislation and practices for the disposal and recycling of e-waste from DC is required to develop a comprehensive understanding of the challenges and opportunities in managing e-waste from DC and to identify practical, sustainable solutions. Based on these analyses, policy and regulatory measures are recommended to promote sustainable DC e-waste management and recycling. The implementation of these recommendations would contribute to a sustainable digital infrastructure.

3. Analysis

We employed a robust methodological approach to quantify the e-waste generated by DC. This involved data collection on equipment sales in 'Put on Market' (POM) values, operational lifetimes, and disposal patterns within the industry. A statistical model based on the sales lifetime approach is then employed to estimate the volume of e-waste generated over time.

3.1. Calculation of POM

The existing e-waste measurement framework calculates e-waste in tonnes. We need to have the Put-on Market (POM) value in tonnes to be able to estimate the e-waste generated.

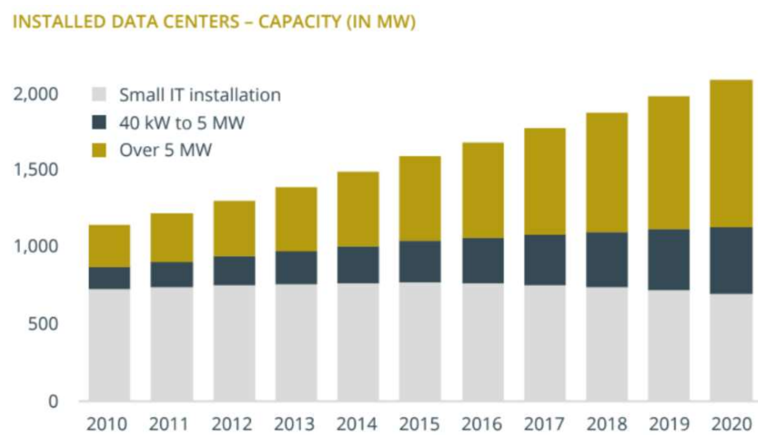

Figure 1 Installed DC capacity in MW (Datacenter Outlook Germany, 2022)

However, all the data available on the annual installed capacity of DC in market data sources is expressed in megawatts (MW). This energy unit represents the DC facility's total power consumption, including the energy used by the IT equipment (servers, storage, network) and the cooling systems required to remove the heat generated. To overcome this unit issue, we converted MW to tonnes using certain factors and estimates. We calculated annual installed capacity data for 2011 to 2020 in MW from the overall installed capacity of data centers data provided in Datacenter Outlook Germany, 2022 (Fig.1). We followed the categorization of data centers based on their size: small IT installation, between 40kW and 5MW, over 5MW.

Power Usage Effectiveness (PUE) is a metric that measures the energy efficiency of a data center by comparing the total energy used by the facility to the energy used by the IT equipment alone (The Green Grid, 2012). PUE values for the same period were taken from the same publication. To estimate the IT Equipment Power (MW) for each year, we divided the total facility energy consumption by the PUE values.

$$Avg.\ IT_{Energy} = \frac{Capacity\ (MW)}{PUE}$$

Data centers comprise numerous server racks, the fundamental units housing the IT equipment. To estimate the number of racks, we use an average power consumption of 10 kilowatts (kW) per rack (Enconnex, n.d.). Subsequently, we divided the total IT equipment energy consumption by the average power per rack (10 kW) to derive the number of racks required for each category and year.

$$NUM = \frac{Avg.\ IT_{Energy}}{Avg.\ Power}$$

A rack weighs, on average,1.13 tonnes (Robertson, 2022). Utilizing this estimate, we calculated the total weight in tonnes of data center equipment introduced to the market by multiplying the number of racks by the weight per rack in tonnes.

$$W\ =\ NUM \times Weight\ per\ rack$$

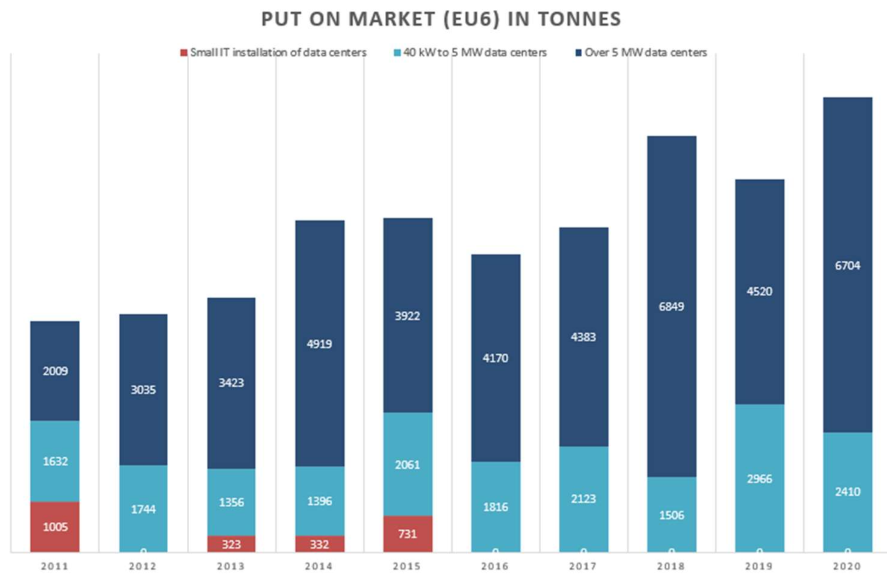

Figure 2 Put on Market (POM) of data centres in tonnes.

This approach allowed us to quantify the magnitude of DC IT equipment deployment, a crucial factor in assessing the potential e-waste generation. We visualized this annual POM of data centers by category (Fig. 2). This provides a clear overview of the data center market dynamics over the period in tonnes.

3.2. Calculation of E-Waste

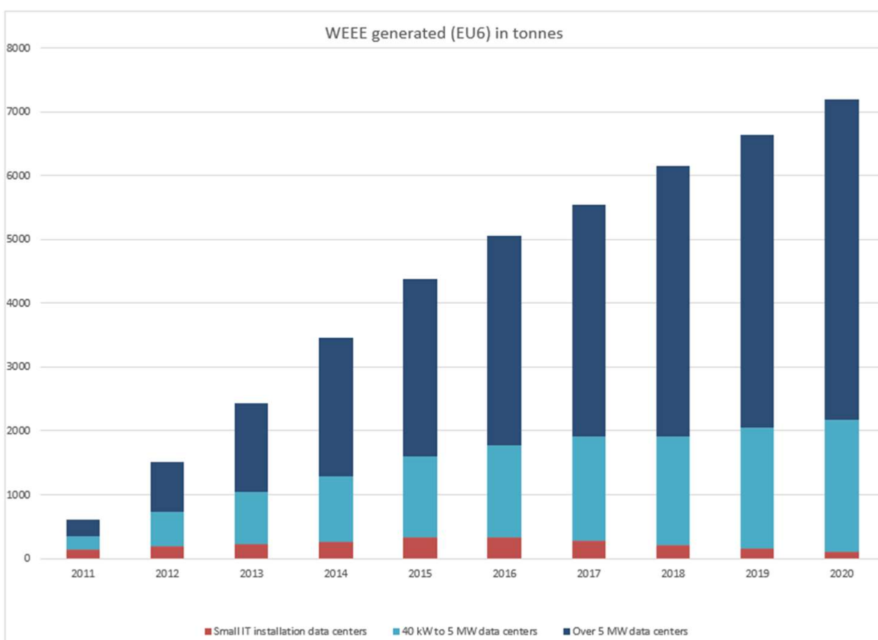

Figure 3 Estimated e-waste generated by data centres in tonnes (2011 to 2020).

Inputting our estimated POM in tonnes into the existing e-waste measurement tool, we were able to visualize the E-waste generated in tonnes for the years 2011 – 2020 (Fig.3). The results demonstrate the growing e-waste contribution from larger DC over time while smaller facilities exhibit a decreasing trend, indicating their gradual replacement by larger, more efficient installations.

This tool employs Weibull distribution with shape parameter (k) and scale parameter (λ) to capture the increasing failure rate of electronic equipment over time, aligning with the aging process of DC (Forti et al., 2018). We used a shape parameter (k) of 1.5 and a scale parameter (λ) of 4.0 to model the average lifetime of 3.5 years for DC (See Appendix A). Using this, we could visualize the cumulative distribution of annual e-waste generated as a percentage of the POM for each of the three categories. For illustration, Fig. 4 shows the cumulative distribution of E-waste generated per year in the percentage of POM (2010) for DC with an installed capacity between 40kW and 5MW. It is shown that approximately after 3.5 years, 50% of POM becomes E-waste.

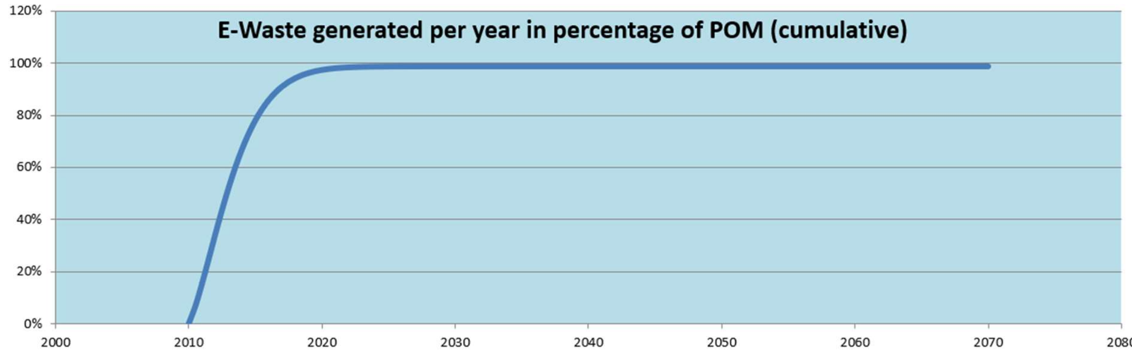

Figure 4 E-waste generated per year in the percentage of POM (cumulative) for category 40kW and 5MW

3.3. Assessing the Formal Collection and Recycling of E-Waste

Assessing the formal collection and recycling of e-waste from German DC poses a significant challenge due to the lack of comprehensive data. Without dedicated reporting mechanisms or centralized databases specific to the DC industry, it becomes arduous to accurately quantify. This data scarcity hinders the ability to estimate the scale of the problem and develop targeted solutions.

According to E-waste Statistics, in 2022, out of 1767 kT of e-waste generated in Germany, approximately 54%, i.e., 957 kT, was formally collected and recycled. While an exact figure cannot be provided, it is reasonable to assume that DC could account for a substantial portion, perhaps 10-20%, of the total e-waste collected. Dedicated data collection and reporting mechanisms specific to the DC industry in Germany would be beneficial to better understand and address this issue and inform targeted policies and solutions for sustainable management and recycling of this waste stream. If e-waste is not properly collected and recycled, improper disposal risks releasing hazardous substances into the environment and wastes the potential for material recovery through recycling processes. Additionally, despite regulations, there is a risk of illegal export of DC e-waste from Germany to other countries where it could be processed unsafely, causing pollution (Schmidl, 2021).

3.4. Leveraging Data for Stakeholder Collaboration

The comprehensive data collected and analyzed in this project provides valuable insights to extend the existing e-waste measurement framework by adding three specific categories for DC e-waste. Now that we can quantify the extent of the problem, it can facilitate collaboration among various stakeholders and support informed decision-making processes. Using this data, various stakeholders can take action. DC operators can implement sustainable practices, extend equipment lifespans, and adopt circular economy models. Policymakers and regulators can develop effective legislation and enforcement mechanisms. Equipment manufacturers can prioritize eco-friendly product design and incorporate ‘Design for Recycling’ principles based on the identified needs. Recyclers and waste management companies can optimize operations and invest in advanced recycling technologies using e-waste volume projections. Environmental organizations can raise awareness and advocate for policy changes using the report's findings. By leveraging this comprehensive data, stakeholders can collaborate and make informed decisions, driving collective efforts toward sustainable e-waste management in the DC industry.

4. Recommendations for data center e-waste management

At the European level, the Waste Electrical and Electronic Equipment (WEEE) Directive provides the overarching framework for managing e-waste and recycling. In Germany, the Electrical and Electronic

Equipment Act (ElektroG) aims to improve the situation by introducing new take-back obligations for retailers and better consumer information. This is enforced by the Federal Environment Agency (Umweltbundesamt). However, there appears to be a gap in specific provisions targeting the data center industry and its unique e-waste challenges.
To cover this gap, we recommend the following:

1. **Strengthen the WEEE Directive for Data Centers:** Amend the EU's WEEE Directive to introduce binding regulations specific to data center e-waste reporting and management. Additionally, mandate the implementation of IT Asset Disposal programs, comprehensive asset tracking systems, and partnerships with certified e-waste recyclers for DC .
2. **Extend Producer Responsibility (EPR)for Data Center Equipment:** Introduce EPR obligations for manufacturers of servers, storage systems, and networking equipment used in DC. Require these producers to establish take-back and recycling programs for their end-of-life products, promoting a circular economy approach.
3. **Implement Incentives and Disincentives:** Provide positive incentives, such as grants, subsidies, and tax credits, to DC that implement best practices in e-waste management, including responsible disposal, recycling, and refurbishment initiatives. Conversely, introduce an "E-Waste Management Fee" or other financial disincentives for DC that fail to meet e-waste management standards, encouraging compliance and sustainable practices.

By implementing these recommendations, the EU can address the growing challenge of e-waste from DC, promote transparency and accountability, incentivize circular economy principles, and drive the adoption of sustainable practices throughout the DC lifecycle.

5. Conclusion

The e-waste challenge posed by data centers demands a comprehensive and collaborative approach. This report provides a way to calculate the put-on Market values of DC in tonnes from MW. Consequently, e-waste generated by DC can be quantified for every year based on a lifetime approach. This extends the existing e-waste measurement framework and can help countries understand the growing e-waste challenge in the DC industry. This enables stakeholder collaboration and informed decision-making to address this issue. By enhancing data transparency, fostering stakeholder engagement, and investing in research and innovation, we can pave the way for sustainable e-waste management practices. Collective efforts from policymakers, industry leaders, researchers, and communities are crucial to mitigating the environmental impact of DC e-waste and transitioning towards a circular economy in the digital age.

6. Outlook

The implementation of the recommendations outlined in this report can catalyze several vital developments. Enhanced data transparency through improved collection and reporting mechanisms will enable policymakers to leverage accurate and granular data for evidence-based decision-making and targeted interventions. Stakeholder engagement will foster a shared responsibility culture, facilitating synergistic efforts among DC operators, manufacturers, and recyclers to implement sustainable practices. Continuous research and development will drive innovation, yielding solutions such as longer-lasting equipment, advanced recycling technologies, and circular economy models, thereby reducing the environmental footprint of DC. International cooperation and knowledge-sharing will facilitate the adoption of global standards and best practices. Regular policy reviews and adaptations will be crucial to maintain relevance and effectiveness in addressing emerging challenges and opportunities in the rapidly evolving digital landscape. This multifaceted approach will be instrumental in mitigating the e-waste impact of the growing data center industry while promoting sustainable practices and a circular economy.

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Appendix A

Weibull distribution of data centers

The average lifetime of IT equipment at a data center is an average of 3.5 years. Since the average lifetime of data centers is governed by a Weibull distribution determined by a shape parameter (k) and a scale parameter (λ), we came up with our own parameters, k and λ, to obtain a mean lifetime of 3.5 years. According to (Frost J., 2023), the Weibull distribution is a continuous probability distribution used to model random variables capturing the time to failure for systems or parts. In this context, the shape parameter k has the following interpretation: a value of k greater than 1 indicates that the failure rate increases with time, capturing, for instance, an "aging" process. This is indeed the case for data centers whose performance and efficiency decrease as time goes by. Hence, a shape parameter k = 1.5 was chosen in our calculations. Based on the latter, knowing that the mean of a random variable X that follows a Weibull distribution with shape k and scale λ is

$$E[X] = \lambda \times \Gamma\left(1 + \frac{1}{k}\right)$$

Where $\Gamma\left(1 + \frac{1}{k}\right)$ is the gamma function evaluated at $1 + \frac{1}{k}$, we were able to retrieve the scale parameter $\lambda = 3.88$.