## Contents



# Mission Statement of 2nitar

1. **What problem do we solve?**

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We address the challenge of gathering not yet existing data on the amount of e-waste generated by data centers. Our research aims to provide a better insight into and a better understanding of this topic.

2. **Who is our audience?**
   As our work aims to preserve the environment for future generations, we believe that everyone benefits from reduced e-waste and an overall healthier planet.
3. **What makes us as a team unique?**
   Our team is unique due to our strong intrinsic motivation to tackle climate change and promote sustainability. We believe that the way we first encountered our planet should also be the standard for how future generations should encounter the earth.
4. **What is our intended contribution or impact?**
   Our goal is to gather and analyze data on e-waste. We want to make sure that the organization we are working with can take countermeasures and or regulate e-waste from data centers based on our research.
5. **In order to make a successful contribution, our next steps are:**
   Our steps consist of the following plan. First, we conduct thorough research, analyzing the gathered data and if possible, utilizing Excel (given by the org.) to provide meaningful conclusions on this matter.
6. **Our vision for the future is:**
   Our vision is to contribute to a sustainable future where e.g. the rapid growth of AI technologies does not result in increased environmental damage. Technological progress is important for making the world a better place, but we believe that e-waste can be minimized.

# Introduction

Nowadays, everybody in the western world walks around with electronic devices. From cellphones to wearables like smartwatches, these products are omnipresent. This trend is also visible in the rapid increase of electrical waste which is produced. In Germany alone there was an increase of 21% in the last 5 Years[1]. The sheer quantity of these devices and the relatively short lifespan creates a problem for the environment and recycling communities.[1]
A second development, which worsens this trend, is the increasing use of artificial intelligence and cloud services.[2] These technologies are computationally very taxing and require the set-up of large data centers, which can deal with the huge amount of server requests.
Therefore, the demand for Data centers all round the world has increased. Within 5 years, from

[1] "E-Waste Challenge," *UNEP - UN Environment Programme*, Nov. 02, 2017. https://www.unep.org/resources/e-learning/e-waste-challenge (accessed Jun. 06, 2024).

[2] T. Dessai, "Data Centers: A Critical Facilitator in Cloud and AI Adoption," *Global X ETFs*, Nov. 17, 2023. https://www.globalxetfs.com/data-centers-a-critical-facilitator-in-cloud-and-ai-adoption/

2019 to 2024 roughly 200 billion dollars were invested globally[3]. This led to a creation of 8000[4] Data centers which are powered by roughly 1% of global energy production[5]. Besides the apparent energy consumption, the high frequencies with which hardware is replaced in data centers lead to a huge negative contribution to sustainability goals. Therefore, many governments such as Germany have introduced laws, which combat the impact of the data centers.
In this report we want to present a method by which the impact of the waste problem can be estimated, quantified and give a recommendation on the policies which can reduce their impact, with a focus on Germany.

## Data Centers in Germany: An Overview

As in the rest of the world Data Centers in Germany are demanded more and more. They play a vital role as critical infrastructure and employ many thousands of people. Furthermore, many industries rely on the services they provide and save vital data on the servers. Key aspects of data centers are, that they are reliable and provide uninterrupted access to the customers data. This is especially of importance for hospitals, powerplants, airports and more, where an interruption in the availability of real time data would lead to a disaster.
In total there are over 450[6] data Centers in Germany. In the year 2023 alone, there was an increase in installed capacity of data centers of 12% reaching a total of 1.6 GW. Over 65.000 people are employed by the data center industry, and they generate a part of the gross domestic product, over 10.4 billion euro.
Forecasts believe that this rise will continue. The German Datacenter Association believes that by 2030 the capacity installed in Germany will rise to 3.3[7] GW and a sum of 2 billion Euros per year will be invested.
From these forecasts one can see that the issue with the waste of data centers will be a concern in future and sensible regulations and recycling and reuse standards are needed, in order to not get overwhelmed by the masses.

## Data Gathering and Analysis

To obtain an estimate of the e-waste produced, Forti et al.[8] have compiled guidelines to classify E-Waste statistics and how to report on the indicators of e-waste. These guidelines

[3] "Global Data Center Market Report 2021: Increased Investment by Cloud and Colocation Providers Drives the Industry - ResearchAndMarkets.com," *www.businesswire.com*, Feb. 16, 2021. https://www.businesswire.com/news/home/20210216005906/en/Global-Data-Center-Market-Report-2021-Increased-Investment-by-Cloud-and-Colocation-Providers-Drives-the-Industry---ResearchAndMarkets.com

[4] B. Daigle, "Data Centers Around the World: A Quick Look," May 2021. Available: https://www.usitc.gov/publications/332/executive_briefings/ebot_data_centers_around_the_world.pdf

[5] "Data center power consumption," *www.danfoss.com*. https://www.danfoss.com/en/about-danfoss/insights-for-tomorrow/integrated-energy-systems/data-center-power-consumption/

[6] Anzahl der Rechenzentren in Europa nach Ländern im Jahr 2023 [Graph], Cloudscene, 26. Oktober, 2022. [Online]. Verfügbar: https://de.statista.com/statistik/daten/studie/1405175/umfrage/rechenzentren-in-europa-nach-laendern/

[7] "Data Center Impact Report Deutschland 2024 | German Datacenter Assiociation," *www.germandatacenters.com*. https://www.germandatacenters.com/dcird-24 (accessed Jun. 06, 2024).

[8] Forti, V.; Baldé, C. P.; Kuehr, R.. "E-Waste Statistics. Guidelines on classification, reporting and indicators". *United Nation University*.

and the data compiled by Forti et al.[7], however lack proper data to quantify and predict waste generated by data centers. This data was therefore compiled by us in accordance with Forti et al.'s[7] suggested methods.

The first step is to define a probability function that shows how likely a data center will be replaced for a given number of years. Forti et al.[7] uses the Weibull function to obtain this probability. The Weibull function has two parameters: shape (α) and size (β). A survey was conducted by Supermicro in 2018, 2019 and 2020, asking 400 different data centers worldwide with which frequency they replace hardware. The findings of this survey can be seen in Figure 1. To obtain the parameters, the average of each year was taken, and a Weibull distribution was fitted to the results.

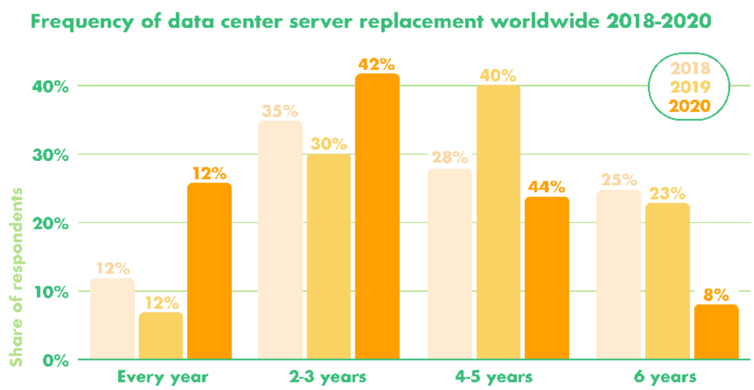


*Figure 1 Frequency of data center server replacement frequencies worldwide 2018-2020*[9]

The fit of the Weibull function yielded the two parameters for the Weibull distribution: The function of the Weibull distribution and the cumulative Weibull distribution function are shown in Figures 2 and 3.

| Parameters | Value |
|---|---|
| α | 2.27773 |
| β | 3.98553 |
| Mean lifetime | 3.53 |
| Max lifetime (99.5% replaced) | 10 |

Having calculated the Weibull distribution one can compute an estimation for the waste generated by hardware which is set on the market at a given year. From the cumulative distribution function one can easily read the value of expected waste each year after the sale of hardware. From this, you can also see that almost all the hardware is being replaced after 10 years.

To make use of the Weibull function, it is necessary to know the weight which is Put-on the Market each year. This data is initially obtained from the German Datacenter Association, which gives us the Mega Watts (MW) installed each year in Germany. To transform this data into kilograms the information obtained of Paper by Zhang[10] is used which gives mean values

[9] Frequency of data center server replacement worldwide 2018-2020 [Graph], Supermicro, March 23, 2021. [Online]. Available: https://www.statista.com/statistics/1109492/frequency-of-data-center-system-refresh-replacement-worldwide/

[10] M. Zhang, "Data Center Power: A comprehensive overview of Energy," *Dgtl Infra*, [Online] Available: https://dgtlinfra.com/data-center-power/ (accessed Jun. 4, 2024).

for capacity per rack and weight per rack. A graph showing the totally installed Data Centers in MW is provided in Figure 4 and the newly put on market Data center weight is provided in Figure 5.

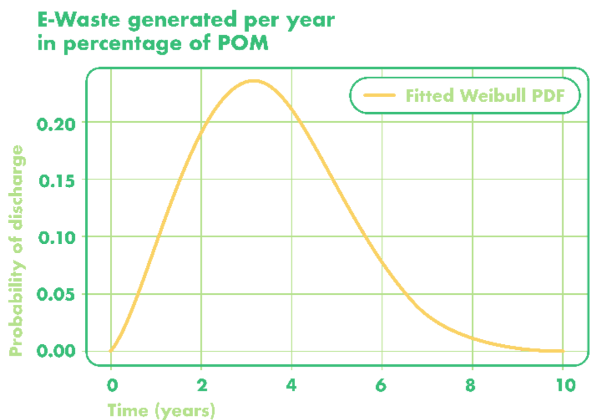


*Figure 2 Weibull function of data center lifetime*

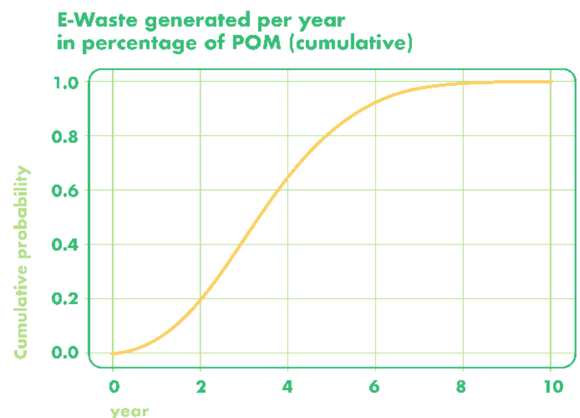


*Figure 3 Weibull cumulative function of data center*

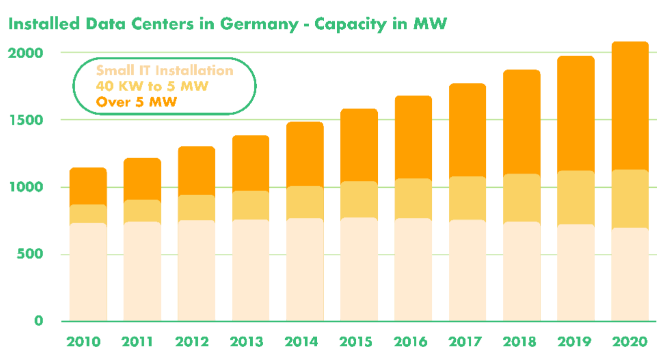


*Figure 4 Installed data centers in capacity [MW]*[11]

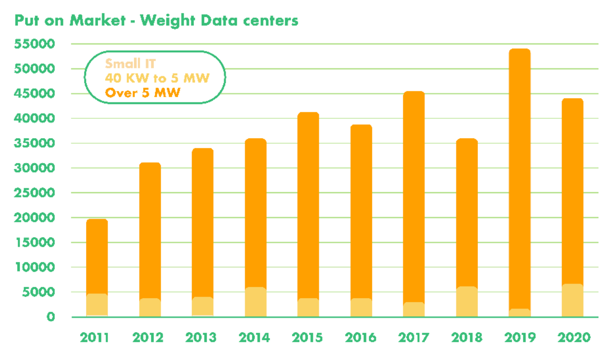


*Figure 5 Weight of Data Centers Put-on Market [kg]*

# Waste Estimation

Finally, using the data obtained from the Weibull function and the weight sold each year in kilograms, an estimate of the e-waste generated per data centers in 2021 is obtained using the Equation described in Forti et al., p.25[7]. The total estimation of e-waste generated by data centers in 2021 is 15519.85 tons, where 298.45 tons correspond to small data centers, 4476.88 tons correspond to medium data centers, and 14922.94 tons correspond to big data centers. Note, that we could provide the full length prediction for all the years from 2020 until 2030 (when 99.5% of the hardware on market will be disposed). However, the estimated weight will be faulty,

[11] "Data Center Impact Report Deutschland", German *DataCenter Association*. [Online]. Available: https://www.germandatacenters.com/dcird-24/

since the hardware sold in the years after 2020 musst be included. From the data available to us this is not feasible and future data musst be awaited.

## GreenCycle

We designed and programmed a platform to address the growing concern of e-waste generated by data centers, which is becoming an increasingly significant environmental issue. By leveraging the Weibull probability function we computed for data centers, our system provides estimations of e-waste production, helping data center managers understand and anticipate their waste output. Additionally, the platform includes a questionnaire-based tool that offers tailored recommendations for recycling, refurbishing, and reselling equipment, promoting sustainable practices within the industry. This comprehensive approach not only aids in effective waste management but also supports the circular economy by extending the lifecycle of electronic devices.
Snapshots of the built platform can be seen in the appendix.

## GreenCycle: E-waste forecast

The primary functionality of the platform is to estimate the e-waste produced by data centers. By inputting relevant data (weight of sales, year of sale), users can receive accurate predictions of e-waste generation over specific periods. This predictive capability allows data center operators to plan for waste disposal more efficiently, allocate resources effectively, and implement proactive measures to mitigate environmental impact. Moreover, the data-driven insights facilitate strategic decision-making, enabling organizations to comply with regulatory requirements and improve their sustainability metrics.

## GreenCycle: Recycling, Refurbishing and Reselling Recommendations

The second key feature of the platform is its ability to provide actionable recommendations for recycling, refurbishing, and reselling data center equipment. After completing a short questionnaire about their equipment and operational needs, users receive customized guidance on the most appropriate actions for each item. This includes detailed instructions on proper recycling methods, potential refurbishment options to extend the lifespan of devices, and viable reselling opportunities to recapture value from used equipment. By offering these tailored recommendations, the platform empowers data center managers to adopt more sustainable practices, reduce e-waste, and contribute to the circular economy. This holistic approach not only benefits the environment but also enhances the operational efficiency and financial performance of data centers.

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# Discussion

All our results hinge on the availability of data. Without the survey of the replacement frequency the fitting of the Weibull distribution function and the following calculation is impossible. Therefore, much emphasis must be placed on such surveys to continually update the parameters of the Weibull distribution. Additionally, the rapid advances in the development of the hardware and improvements will influence the expected lifetime. Hence, the Weibull distribution is not time invariant. This will have to be added over a longer period of time in order to improve the predictions made with this tool.
Furthermore, also the data with which we calculated the weight of sold data center equipment is old. Newer data would improve the calculation of E-waste from data centers. In addition, this data was given in installed capacity of data centers in Germany instead of in kilogram. Since the question posed to us by UNITAR was the calculation of the weight of e-waste we had to estimate an equivalence between the capacity and weight. This calculation is based on averages and premises which have to be critically questioned. Hence, having the data in directly in weight not in capacity would further improve the prediction.
In our model for calculating e-waste in data centers, all hardware is treated as a single, aggregated entity. This simplification, while convenient, introduces significant limitations. Different types of hardware—such as servers, storage devices, and networking equipment—have varying lifespans and replacement cycles. By lumping them together, the model fails to account for these differences, potentially leading to inaccurate e-waste estimates. This approach overlooks the specific degradation and replacement patterns of individual components, which can significantly impact e-waste projections. Future models should adopt a more granular approach, differentiating between hardware categories to improve accuracy and reliability.

# Outlook

To ensure the ongoing accuracy and relevance of our platform, it is imperative that the probability function, based on the Weibull distribution, is continuously updated. As data centers evolve and new technologies emerge, the parameters of the Weibull distribution must be recalibrated to reflect these changes. This involves regularly integrating new data on equipment lifespans, failure rates, and usage patterns. By doing so, we can maintain the precision of e-waste estimations and ensure that our predictions remain reliable over time.
Furthermore, regulatory measures should be established to mandate the disclosure of data center equipment sales and operational data. Public availability of this information will significantly enhance the quality of inputs for our platform, leading to more accurate and comprehensive e-waste assessments. Such regulations will also promote transparency and accountability within the industry, facilitating better compliance with environmental standards and fostering a culture of sustainability.
Lastly, expanding the platform to include links to different resellers and refurbishing companies is essential for maximizing its utility. By tailoring these connections to the specific regions of data center providers, we can offer regional solutions that are more accessible and effective. This

expansion will not only streamline the process of recycling, refurbishing, and reselling equipment but also support the growth of local businesses and contribute to regional economic development. Through these enhancements, our platform can become an valuable tool for data center managers committed to reducing e-waste and advancing sustainable practices.

# Appendix

Here you can see the examples for the two used cases of the GreenCycle tool.
In figures 6 and 7 the waste estimation is shown. In figure 6 you see the data input, where you can add the sales of multiple years and adjust the Weibull parameters (1.). With the possibility of adjusting Weibull parameters this tool can calculate prognosis for multiple cases and is not fixed on the Weibull parameters we found for the e-waste production in datacenters. In figure 7 you can see the calculated estimation for the e-waste from the starting point (2022) up to ten years after the last data entry.

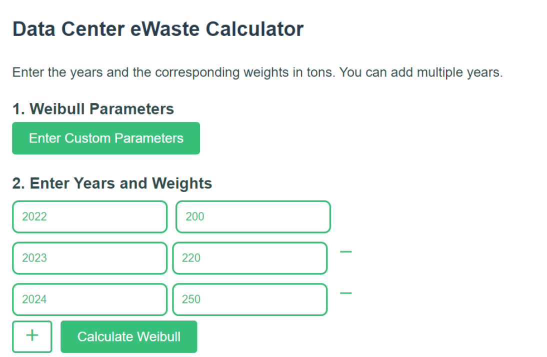


*Figure 6 Arbitrary sales data for the years 2022-2024*

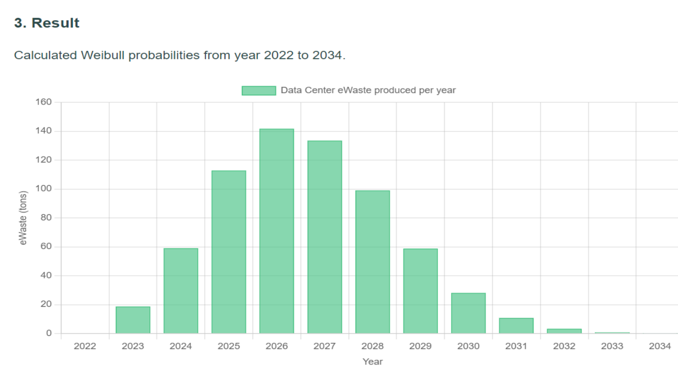


*Figure 7 Distribution of e-waste estimation based on the three entries in Figure 6*

For the second use case we provide figure 8. Here you can see the questionnaire based on which the recommendations for the eco-friendly handling of e-waste will be provided.

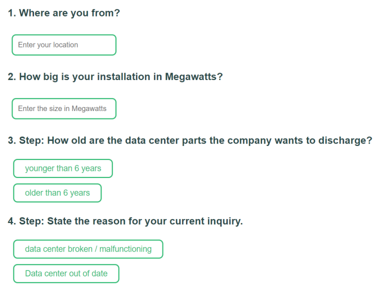


*Figure 8 Questionnaire based upon which the recycling recommendations will be given*

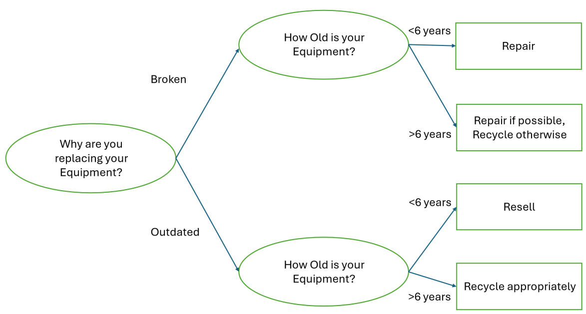


*Figure 9 Decision Tree for the Questionnaire*

This is the decision tree, which will give you the appropriate way of disposing of your equipment. Additionally, there will be a link provided to a service that will help you with the disposal. In the future it will be expanded by regional differences and further by different capacities for the different equipment that is being discarded.