CO_2 REDUCE

Reducing the Climate Impact of Data Center Hardware

White Paper

White Paper
by Lars Olesen
for Nordic Computer

Intended Audience

This white paper is intended for everybody having an interest in the climate impact of data centers. Central decision makers like CEOs, CIOs and managers of CSR departments are obviously intended receivers of the **Executive Summary**, while CSR and data center specialists are expected to appreciate a deeper dive into the context and details of the methodology behind CO_2 REDUCE.

To get a feeling for climate impacts numbers, consult the table with examples of relatable sources and activities in reference [1].

Contact

Contact Nordic Computer to learn how the carbon footprint of your data center can be reduced. Call **+45 7020 1979** or send a message **here**.

Units

Tonnes are metric - one tonne (t) being equal to 1000 kg. Greenhouse gas emissions are measured in CO_2 equivalents ($kgCO_{2,eq}$ or $tCO_{2,eq}$).

Disclaimer

The intention of this white paper is to shed light on the full life-cycle climate impacts of data center hardware. The approach and the tool described have been developed to make the best use of existing data. Limitations are the availability of data, their accuracy and the assumptions made, and no guaranteed accuracy can be promised.

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1 Preface

For decades, the energy efficiency of servers, storage and network equipment has increased with each new generation. As a consequence, it has not only been the need for an increased computational capacity that has dictated the hardware exchange rate, but also an incentive to decrease the energy consumption of data centers. The driving argument has been to reduce the operational cost and the greenhouse gas emissions. Especially in recent years, the latter has gained attention as the consequences of climate change become increasingly apparent.

Unsurprisingly, manufacturers of data center hardware use the potential reduction of operational greenhouse gas emissions in their marketing strategies. Their message is clear: A data center can reduce the operational cost while benefiting the climate by making a hardware refresh - i.e. replacing the existing hardware with the newest versions on the market.

Apart from strengthening the manufacturers' own businesses, their marketing focus on energy efficiency has also influenced the narrative in the entire data center industry: The climate impact of data center hardware is predominantly discussed in relation to electricity consumption in the use phase. What is very seldom considered is the climate impact of manufacturing the hardware. Intended or not, this makes the entire climate-impact discussion flawed.

Unless manufacturing emissions are taken properly into account, any decision referring to the climate impact of data center hardware will be misguided and will likely result in increased greenhouse gas emissions rather than the opposite.

In the majority of cases, the best way to minimize the climate impact of data center hardware is to keep it in operation for as long as possible.

This is not in the interest of hardware manufacturers and retailers, which might explain why data are scarce. As a result, it is very difficult for data centers to make a proper judgment of the most climate-friendly approach. To remedy this situation, Nordic Computer has invested in the development of CO_2 REDUCE.

CO_2 REDUCE is an algorithm that can estimate the climate impact of a data center hardware refresh versus a lifetime extension of the existing equipment.

This white paper documents how CO_2 REDUCE utilizes the newest available data in an empirical approach to quantify the greenhouse gas emissions of IT hardware used in data centers.

2 Executive Summary

When operating a data center, there are two dominant climate impacts to consider that are relevant for a company's or an organization's ambitions to meet defined emission reduction targets. The most obvious contribution is the climate impact from direct energy use in the data center. That's within scope 2 emissions.

A comparable contribution is the climate impact caused by the manufacture of the data center hardware. This scope 3 contribution is often forgotten or ignored, but it is significant. Any evaluation of the climate impact of a data center will be flawed, if the impacts of hardware manufacturing are not included.

It can be difficult to reduce scope 3 emissions along the value chain, but data center hardware is an exception. By keeping existing hardware in operation for longer, not only can money and time be saved, the climate impacts can also be reduced considerably.

The obstacle is a lack of data, which makes it difficult to quantify the emission reductions. CO_2 REDUCE is a tool that has been developed to fill this gap. It can quantify the reductions achieved by extending the operational lifetime of existing hardware.

Look up **Box 1** and **Box 2** to get a quick insight into the emission-reduction potential.

3 The Life-Cycle Perspective

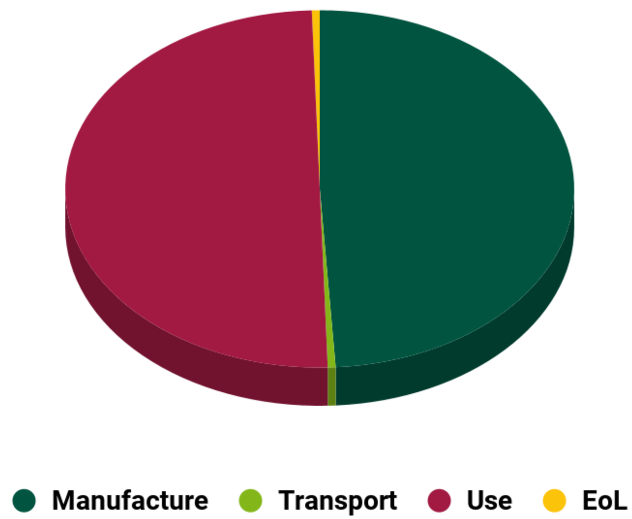
The total climate impact of a product is the sum of the impacts from all phases of the product's life cycle. Figure 1 shows a common way to divide the life cycle into phases. The manufacture phase covers every step from mining of minerals and metals to final assembly of the product, while distribution from the assembly site to the location of use is covered by the transport phase. Usually, the use phase is the longest of all life-cycle phases, and it covers the entire operational life of the product. Finally, the end-of-life phase covers all disassembly, material recycling, incineration and landfill activities involved when the product is disposed of.

Focusing on data center equipment, greenhouse gas emissions from the manufacture phase are typically comparable to use-phase emissions, while transport and end-of-life (EoL) emissions are one or two orders of magnitude smaller as illustrated in Figure 2. This general picture holds true for a range of different types of hardware units including complete servers [2], traditional rotating hard disks [3], and solid state disks [4]. It basically reflects how energy intensive the manufacturing process of IT hardware is. This observation can be summarized as follows:

Solid conclusions about the climate impact of any given set of data center hardware can not be made by focusing only on the climate impact of the use phase.

Figure 1: Product Life-Cycle Phases

Figure 2: Typical Distribution of Greenhouse Gas Emissions for Data Center Equipment



Box 1: An Illustrative Example

Assume that a data center has two racks with 50 three-year-old hardware units, and that the service contract is running out. There are no problems, the systems are running fine, and there is still spare capacity. A hardware refresh is thus not about fixing a problem, but rather a mitigation strategy to avoid future problems by getting a new service contract along with new hardware [5].

Hardware-refresh scenario

Apart from a considerable investment cost, time is needed to get the systems up and running on new hardware. It may also lead to some downtime and interruptions in the service. If the new hardware uses 20% less electricity, there is an initial climate impact saving potential of 3.5 tonnes of $CO_{2,eq}$ per year, which will decrease year by year due to the ongoing electricity decarbonisation [6] - see Figure 3. However, manufacturing of the new equipment gives rise to emissions of 60 tonnes of $CO_{2,eq}$ up front, as shown in Figure 4.

Lifetime-extension scenario

There are no interruptions in operations. A new service contract can be set up with a company that has specialized in lifetime extension of data center hardware. The manufacturing of new hardware is postponed for the entire lifetime-extension period.

All in all, the lifetime-extension scenario may well save emissions of over 50 $tCO_{2,eq}$ compared to the hardware-refresh scenario [7].

Figure 3: Electricity Use and Decreasing Carbon Intensity

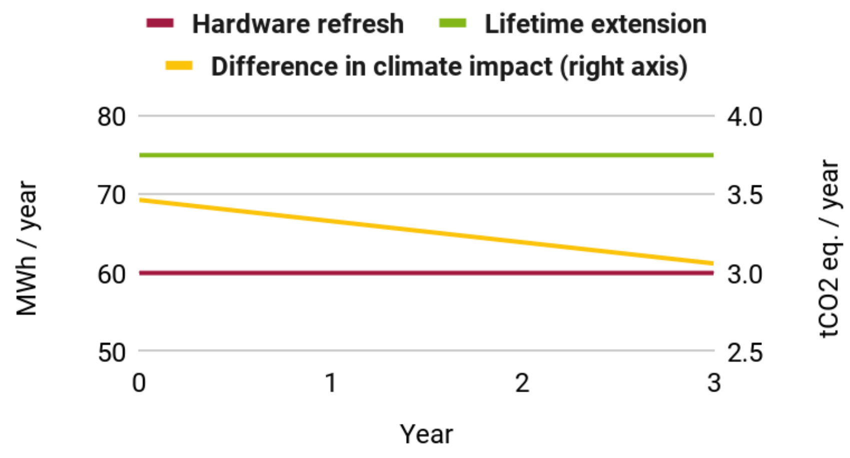
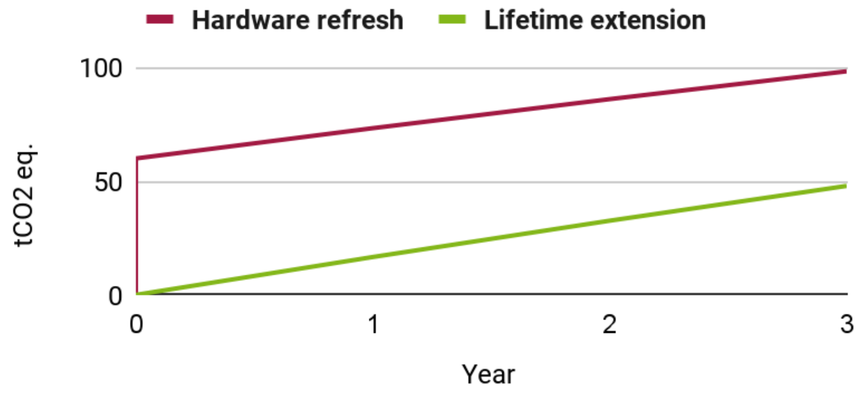


Figure 4: Accumulated Climate Impacts of Scenarios



Box 2: A Real-World Example

For a specific data center Nordic Computer has provided two refurbished and tested all-flash storage systems. The data center needed extra capacity and chose to buy refurbished hardware instead of new. As the refurbished systems had been in use before, no new hardware units were produced as a consequence of the customer's need.

Both storage systems were tested and refurbished in Nordic Computers' own test center and delivered with a standard 2 year warranty. Options to prolong the warranty and to add a service contract were available.

Assuming that the storage systems are operational for 3 years (use phase) and that new equivalent hardware would consume 20% less electricity, CO_2 REDUCE provides the following insight:

New equipment would emit 50 $tCO_{2,eq}$ in the manufacture phase and 10 $tCO_{2,eq}$ in the use phase, while the refurbished hardware solution will emit 12 $tCO_{2,eq}$ in the use phase.

By choosing refurbished instead of new hardware this data center reduces emissions by 48 $tCO_{2,eq}$ over 3 years [1].

4 Complexity and Uncertainty

While the climate impacts from the manufacture and use phases are comparable in magnitude, they are very different in complexity.

The use phase is dominated by the electricity consumption of the hardware itself and the cooling it requires. This is easily measured by an electricity meter and converted to greenhouse gas emissions via the carbon intensity [8]. In addition, the use phase will include impacts from installation, service and maintenance activities, but these contributions are in most cases orders of magnitudes smaller than the dominant electricity contribution. All in all, it is fairly easy to determine the climate impact of the use phase with high accuracy, as it mostly boils down to the electricity consumption caused by a well-defined set of equipment installed at one specific location.

When looking at the manufacture phase the picture is the complete opposite. The value chain for IT hardware is among the most complex. Modern electronics can contain up to two thirds of all naturally occurring elements [9], which requires a supply chain that spans many different parts of the world. Furthermore, the production process is highly advanced involving a huge number of manufacturing steps that can only be carried out in specialized and expensive facilities.

This complexity makes it extremely difficult to assess the climate impact of the manufacture phase. To overcome this obstacle various tools and methods are being developed and applied. For instance, several manufacturers use the tool *Product Attribute to Impact Algorithm* developed at MIT [10], while it has become an established practice to evaluate the climate impact of integrated circuits by using the processed die area as an indicator of the climate impact [11].

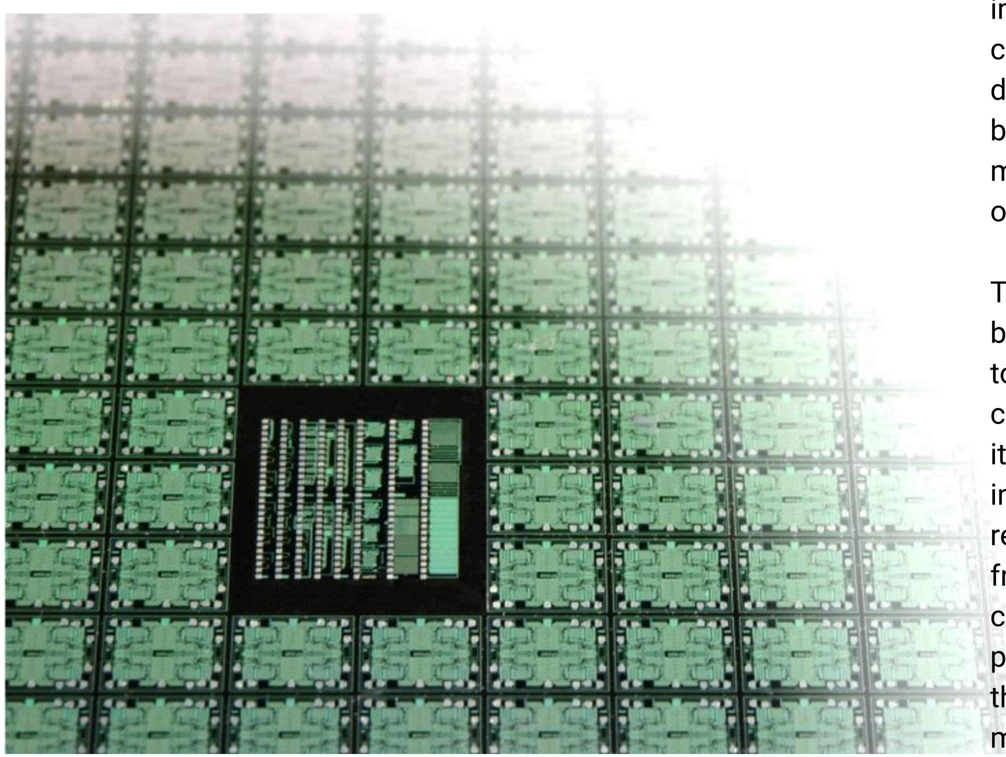
This complexity of the manufacture phase is the main reason for the very large uncertainties in reported life-cycle emissions of data center hardware. Standard deviations of 50% to 100% are the norm, and for some units the uncertainty is reported to be even higher. But that should not be an excuse for ignoring the contribution from the manufacture phase. Whether the accurate number is a factor of 2 smaller or larger, the point is the same:

To properly assess ways to decrease the climate impact of a data center, the manufacture phase has to be included on par with the use phase.

5 CO_2 REDUCE

5.1 Purpose

When evaluating the climate impact of a data center, a full life-cycle assessment of each and every piece of equipment is needed. Unfortunately, doing a life-cycle assessment of just one piece of equipment is no trivial task, and until all manufacturers provide climate-impact data for all their products, alternative approaches must be applied.



As the main challenge is the contribution from the manufacture phase, an economic top-down approach is often resorted to. Basically, it smears out the total climate impact of the entire IT manufacturing industry evenly by assigning a climate impact to each dollar spent on IT equipment. This approach has some advantages. First, it is simple and doable. Second, it catches all impacts as there is no risk of contributions falling between the chairs. On the down side it is an extremely crude approach. It doesn't give any details about which types of equipment are the best/worst from a climate perspective. In this way, it doesn't really make the choice between a hardware refresh and life-time extension of the old equipment any more transparent.

The purpose of CO_2 REDUCE is to fill this gap between a detailed bottom-up approach that, at present, is impossible to carry out due to a huge lack of data, and a top-down approach that is way too crude to be used for informed decision making. The aim is to make it easy for decision makers to get proper insight into the real climate impact of their data centers, and support them in making true reductions going forward. CO_2 REDUCE addresses the contributions from the manufacture phase, i.e. the phase that is very seldom considered when evaluating the climate impact of a data center. In principle, the transport and EoL phases are also covered, but since these are smaller by two orders of magnitude their contributions are masked by uncertainties.

5.2 Overview

CO_2 REDUCE is constructed as a bottom-up approach. But instead of requiring a life-cycle assessment of each unit, it employs an empirical model that is populated with the detailed climate-impact data that are available at present. The data are either made publicly available by manufacturers or through academic studies of specific units.

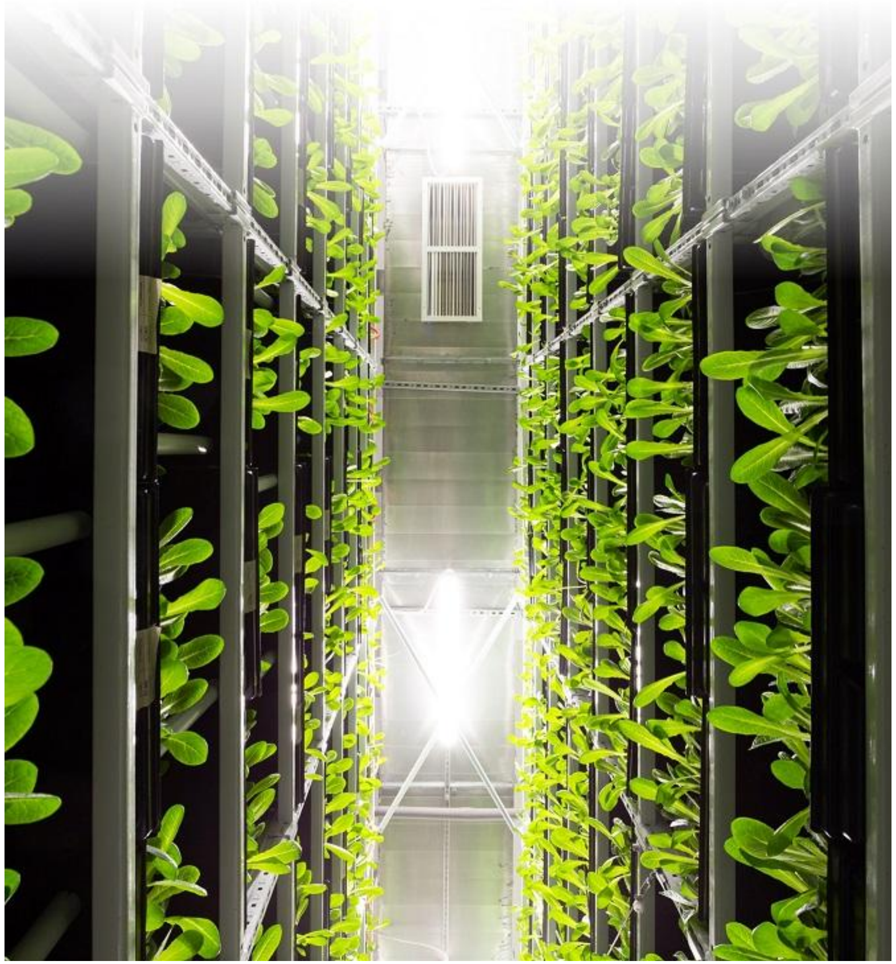
By categorizing the data center equipment according to hardware type and applying some reasonable assumptions, CO_2 REDUCE extrapolates from the available dataset in order to cover all units. The extrapolation for a specific unit is based on the most relevant physical parameter for the category the unit is assigned to.

Specifically, CO_2 REDUCE provides the foundation for answering the pertinent questions:

- **What is the climate impact of our data center?**
- **How does the manufacture phase contribute?**
- **What types of equipment are the best/worst?**
- **Can we decrease the impact by lifetime extension?**
- **If yes, by how much?**

5.3 Basic Assumptions and Justifications

The validity of the extrapolation carried out by CO_2 REDUCE is based on a couple of reasonable assumptions about the characteristics of data center equipment and the corresponding emissions.



5.3.1 Similarity Assumption

The total climate impact of manufacturing a given hardware unit is mainly determined by its specifications and the hardware type.

Basically, this assumption states that when it comes to climate impact, a server is a server and a solid state disk is a solid state disk independent of brand. Two servers with the same specifications will thus give rise to largely the same climate impacts during manufacturing - and likewise for the solid state disks.

The similarity assumption is justified by the data center hardware characteristics. Independent of brand, a unit needs to live up to certain standards. The physical form factor is not random - a rack unit needs to fit into a rack, and a disk needs to comply with the standard 2.5” or 3.5” physical form factors. And hardware and software interfaces need to live up to the accepted standards and protocols in order to communicate with the surroundings.

These external requirements put a lot of restrictions on the physical layout and the internal architecture of hardware. In addition, the critical internal components are often sourced from just a few global suppliers making the units rather similar. For instance, manufacturing an Intel CPU or a Samsung DRAM chip has the same climate impact irrespective of the brand of the unit it is installed in.

Finally, to the extent that data is available from different manufacturers, the data supports the validity of the similarity assumption.

5.3.2 Category and Scaling Assumption

It is possible to distribute all data center hardware units into a limited number of categories. For each category, it is possible to identify a relevant physical parameter with an empirical scaling relationship to the climate impact of the manufacture phase.

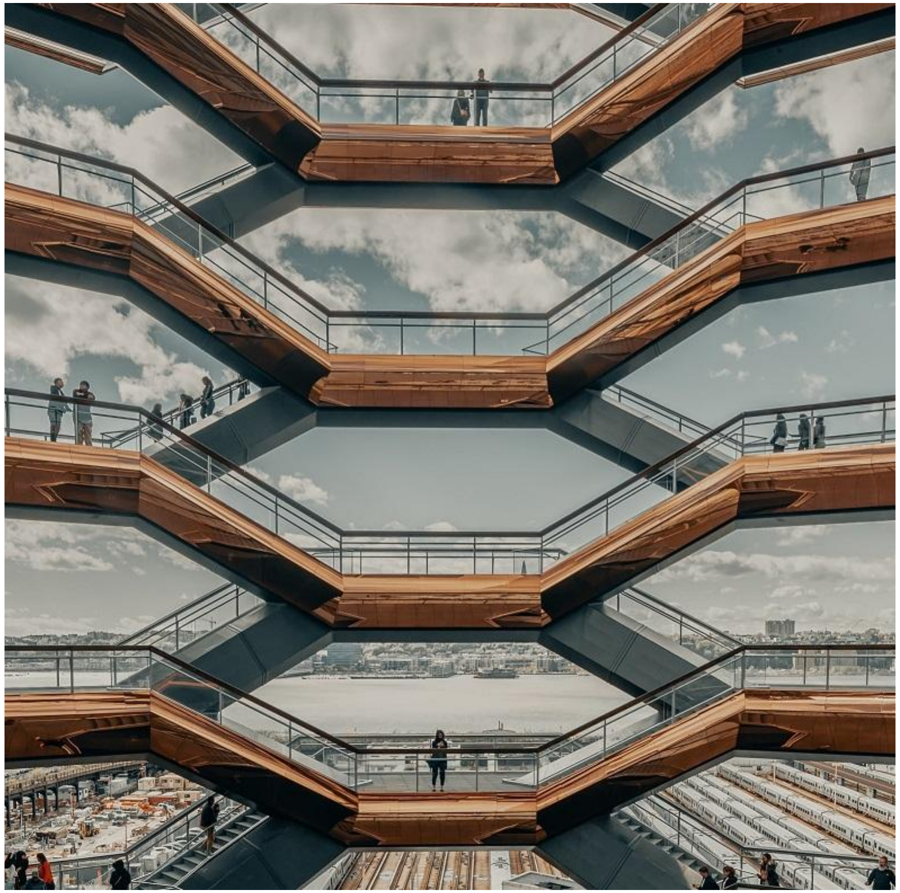
The categories are defined to form the best compromise. First, they have to limit the number of empirical relationships to be established to avoid spreading the existing data too thin. Second, they need to capture the essential scaling characteristics of the climate impact for all units in each category.

The scaling part of the assumption is a generalization of an ordinary working principle when doing life-cycle assessments. The scaling parameter is then the mass or volume of a material, a number of products, or instances of a process.

Likewise, for data center hardware the mass turns out to be a relevant scaling parameter for most categories. However, the data reveals that the scaling with mass is not linear. Doubling the mass of a unit does not give rise to double the climate impact in the manufacture phase [12]. However, the empirical scaling relationship can be determined by fitting to data.

Mass is not the relevant scaling parameter for all categories. For a few categories, the climate impact of manufacturing is, for all practical purposes, independent of mass. Instead, the relevant scaling parameter turns out to be the capacity of the units.

The category and scaling assumption can be justified by comparing to existing data. Furthermore, new data are released continuously as manufacturers start to step up to the challenge. This allows for further testing and refinement of the scaling relationships, and possibly to the definition of more categories. CO_2 REDUCE can thus evolve as more data become available.



5.4 Hardware Refresh Versus Lifetime Extension

The alternative to a hardware refresh, is to keep the old hardware in operation for longer. This is often a very realistic, cheaper and, not the least, a much more climate-friendly alternative. The examples in **Box 1** and **Box 2** illustrate the point.

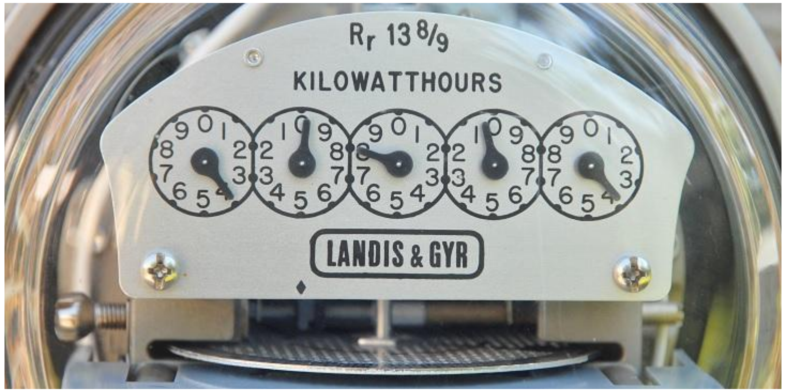
To quantify the difference in climate impact between a hardware-refresh scenario and a lifetime-extension scenario the following quantities are required:

Lifetime extension:

A. Electricity consumption of existing hardware
B. Lifetime extension period

Hardware refresh:

C. Electricity consumption of new hardware
D. Expected operational lifetime of new hardware
E. Climate impact of the manufacture phase



Points A & C: Electricity consumption
In Figure 2 it was illustrated how the climate-impact contributions from the manufacture and life-cycle phases are comparable. However, what matters for the life-cycle phase is not the absolute emissions but rather the difference in emissions between the two scenarios.

Historically, the energy efficiency of computing has doubled every 1.57 years, as described by Koomey's law. But as physical limits have started to play a role, energy efficiency has not improved as fast during the last 10 to 20 years [13]. According to a study, replacing a 2015 server with a new server in 2019 only gave rise to a 20% boost in processing power for the same number of watts [14]. This factor may be different for network and storage equipment. For the latter, a technology shift from traditional rotating harddisks to solid state disks could change the picture significantly. However, a comparative study has suggested that while solid state disks win over traditional rotating harddisks when in idle state, harddisks are the less electricity-consuming devices in the active state [15].

In any case, there is no substantial evidence to suggest that making a hardware refresh of equipment that is 3 to 5 years old will reduce electricity consumption by more than 50%. In addition, as the decarbonisation of the grid proceeds in the coming years, the carbon intensity will decrease too. The difference in climate impact caused by the difference in electricity consumption between the two scenarios will thus become smaller year by year, as illustrated in Figure 3 in **Box 1**.

Point B: Lifetime-extension period

To quantify the climate impact difference between the two scenarios, the lifetime-extension period has to be defined. Can three-year-old hardware units operate for another year, or maybe even three additional years? This is important, not only because it determines the period over which the scenarios are to be compared, but also because it defines for how long the manufacture of new equipment is postponed in the lifetime extension scenario.

Point D: Expected operational lifetime

This defines how much operational lifetime the new hardware has left at the end of the comparison period.

Point E: Climate impact of manufacture phase

To calculate the climate impact of the manufacture phase, a complete specification of the new set of hardware is required. This allows CO_2 REDUCE to categorize all units and perform the extrapolation by applying the empirical relationship for each category.

Result

Having established all quantities from A to E above, CO_2 REDUCE can estimate the climate-impact difference between the hardware-refresh scenario and the lifetime-extension scenario.

CO_2 REDUCE provides decision makers with proper insight into the real climate impact of their data centers and how to reduce it.

5.5 The Effects of Postponing

By extending the lifetime of existing equipment a hardware refresh is postponed. The effects of postponing a hardware refresh are several:

- **Less hardware is needed, reducing the overall climate impact of manufacturing and disposing of hardware.**
- **Manufacturers have additional time to improve their climate performance.**
- **Decarbonisation of grid electricity will reduce the climate impact of manufacturing.**

About the Author

This white paper, along with the approach, database and algorithm behind CO2 REDUCE, has been developed for Nordic Computer by Lars Olesen.

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Lars Olesen has spent many years in research and development within international companies. For ten years, his primary focus was on the green transition of the energy system. First as Systems Engineer within wind turbine design and later as R&D Department Manager working with wind, wave, hydro, and solar power in a utility company.

Since then he has broadened the scope to encompass sustainability in general, and circular economy and emission reductions in particular. In 2017 he founded Circ.eco - a consultancy firm with the purpose and commitment to inform, educate and support companies, organizations and communities in the transition to a circular economy.

His educational background is a Ph.D. in physics with a minor in computer science.

About Nordic Computer

Nordic Computer is a Danish company with more than 40 years of experience with lifetime extension of data center hardware. Their multi-vendor services are focused on helping data centers reduce cost and climate impact, while securing impeccable operation. Specifically, Nordic Computer provides:

- **Third-party data center maintenance**
- **Spare-part service**
- **Refurbished data center hardware**

References and Comments

[1]

Source/Activity	Emissions in $tCO_{2,eq}$
Driving 1000 km in a mid-sized gasoline car, including emissions from production and maintenance of the car as well as extraction, refining and transportation of the fuel [A]	0.33
Worldwide food-waste average per person per year [B]	0.73
Flying from London to Hong Kong return on economy class [A]	3.5
Average consumption-based emissions per person in Denmark per year [C]	17
A new-build brick and mortar four-bedroom detached house in the UK [A]	53
SpaceX Falcon 9 flight to the International Space Station [A]	600

Sources:

[A] Mike Berners-Lee: *How Bad are Bananas? The carbon footprint of everything*, Revised 2020 Edition, ISBN 978-1788163811, eISBN 978-1782837114

[B] Our World in Data: *Food production is responsible for one-quarter of the world's greenhouse gas emissions*, PopulationPyramid.net: *World 2016*, WWF: *Driven to Waste*, [https://ourworldindata.org/food-ghg-emissions, https://www.populationpyramid.net/world/2016/, https://wwf.panda.org/discover/our_focus/food_practice/food_loss_and_waste/driven_to_waste_global_food_loss_on_farms/#:~:text=Driven%20to%20Waste%3A%20Global%20Food,billion%20tonnes%20wasted%20each%20year]

[C] Concito - Denmark's Green Think Tank: *Hvad kan man selv gøre*, [https://concito.dk/bliv-klimaklog/hvad-kan-man-selv-goere]

[2] Full *Life Cycle Assessment of Dell R740* server conducted by *thinkstep* - now *sphera*, [https://www.delltechnologies.com/asset/en-us/products/servers/technical-support/Full_LCA_Dell_R740.pdf]

[3] Seagate *Savvio 10K.5 Enterprise HDD Product Life Cycle Analysis Summary*, [https://www.seagate.com/files/www-content/global-citizenship/en-us/docs/final-savvio-lca-summary-report-10-3-2013-ams-031214.pdf]

[4] Seagate *Koho Enterprise Solid-State Drive Product Life Cycle Assessment Summary*, [https://www.seagate.com/files/www-content/global-citizenship/en-us/docs/seagate-koho-enterprise-ssd-lca-summary-2016-07-29.pdf]

[5] In this example the following representative values are used: An average electricity consumption for the existing hardware of 1500 kWh per unit per year, an average carbon intensity of 0.231 $kgCO_{2,eq}$/kWh (EU generation 2020 [8]), and an average manufacturing impact per unit of 1200 $kgCO_{2,eq}$.

[6] The carbon intensity in the EU has decreased by 9 $kgCO_{2,eq}$/MWh per year on average since 1990, as more renewables are introduced to the grid [8].

[7] This will depend on the lifetime-extension period. In this example, a total reduction of 50 $tCO_{2,eq}$ is realistic, if the existing hardware is kept in operation for double the usual lifetime period or more, e.g. from 3 to 6 years or more. That corresponds to skipping an entire generation of hardware.

[8] Carbon intensities for electricity-generation in the EU are provided by the European Environment Agency: Greenhouse gas emission intensity of electricity generation by country - European level. However, the numbers for the individual countries do not reflect the

real carbon intensities of the electricity in the grid, as it doesn't account for electricity exports and imports between countries. A much better source is ElectricityMap.org, which provides near real time carbon intensities for different electricity grids in the world. It includes the effects of electricity imports and exports and thus gives a correct picture of the climate impact of consuming electricity. [https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-9#tab-googlechartid_googlechartid_googlechartid_googlechartid_chart_11111, https://electricitymap.org/]

[9] According to the report *Recycling – From E-Waste to Resources* published by the UN Environment Programme (www.unep.org) in 2009, modern electronics can contain up to 60 different elements out of the 90 elements that occur in nature in appreciable amounts. [https://www.unep.org/, https://www.thoughtco.com/how-many-elements-found-in-nature-606635]

[10] Product Attribute to Impact Algorithm - PAIA developed by the Materials Systems Laboratory at Massachusetts Institute of Technology (MIT), [http://msl.mit.edu/projects/paia/main.html]

[11] Sarah B. Boyd: *Life-Cycle Assessment of Semiconductors*, Springer, DOI 10.1007/978-1-4419-9988-7, see also the application in [2].

[12] This was no surprise, as some minor contributions, especially for larger modularised units, do not scale with the mass of a unit but rather with the number of units. These contributions will have a larger effect for lighter units.

[13] Jonathan G. Koomey, Stephen Berard, Marla Sanchez, and Henry Wong: *Implications of Historical Trends in The Electrical Efficiency of Computing*, IEEE Annals of the History of Computing, vol. 33, no. 3, July-September 2011, pp. 46-54. [http://doi.ieeecomputersociety.org/10.1109/MAHC.2010.28]

[14] Rabih Bashroush: *Optimizing server refresh cycles with an aging Moore's law*, Journal of Uptime Institute, January 27th. 2020, [https://journal.uptimeinstitute.com/optimizing-server-refresh-cycles-with-an-aging-moores-law/]

[15] Erica Tomes, Nihat Altiparmak: *A Comparative Study of HDD and SSD RAIDs' Impact on Server Energy Consumption*, 2017 IEEE International Conference on Cluster Computing, pp. 625-626, DOI 10.1109/CLUSTER.2017.103, [https://www.researchgate.net/publication/320025946_A_Comparative_Study_of_HDD_and_SSD_RAIDs%27_Impact_on_Server_Energy_Consumption#39;_Impact_on_Server_Energy_Consumption]

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