Scavenging for sustainability: Are decades-old servers worth saving?

ABSTRACT

Most computing devices—from personal smartphones to server-class machines—are retired before they need to be. Motivated by the performance and features offered by new devices, consumers and corporations alike dispose of their computers while they are still fully or partially functional. This is unsustainable.

Recent work has shown that scavenging discarded electronics has the potential to save carbon by displacing the manufacture of new devices. Whether or not a device is worth scavenging is largely determined by its energy efficiency. Low-power consumer electronics—smartphones and laptops—are worth repurposing, while old servers are generally not. In this work, we explore what it might take to get around this limitation and build carbon-efficient systems from elder hardware.

1 INTRODUCTION

Quantifying the environmental impact of compute requires going beyond energy efficiency. The manufacture of electronic devices is responsible for a significant and growing piece of their overall carbon footprint—about 50% for server-class machines [3].

Computational Carbon Intensity (CCI) is a lifecycle-conscious carbon-efficiency metric that measures the carbon efficiency of computing systems [11]. CCI is the ratio of a device or system's lifetime carbon emissions to the operations computed during that life.[1] The formula can be expressed as follows:

$$\text{CCI} = \frac{\mathbb{C}_{\text{CAP}} + \mathbb{C}_{\text{OP}}}{\sum_{lifetime} \text{ops}} = \frac{\mathbb{C}_{\text{CAP}} + \sum_{lifetime} \text{CI}_{\text{grid}} * E}{\sum_{lifetime} \text{ops}} \tag{1}$$

$\mathbb{C}_{\text{CAP}}$ is the carbon associated with the manufacture of the device. It is a single upfront cost at the beginning of its lifetime. $\mathbb{C}_{\text{OP}}$ is the carbon associated with operating the device. It is equivalent to the carbon intensity of the energy used (CI_{grid}) multiplied by E, the device's energy consumption.

The carbon intensity is therefore a function of three things:

(1) The carbon footprint of manufacturing the device, $\mathbb{C}_{\text{CAP}}$.
(2) The efficiency of the device, in terms of the energy expended per operation, E/ops.
(3) The carbon intensity of the energy used, CI_{grid}.

Previous work recommends the reuse or repurposing of already-retired devices as one strategy for building carbon-efficient systems [11]. Building a system from discarded devices saves carbon since no new devices need to be manufactured, i.e. $\mathbb{C}_{\text{CAP}} = 0^2$. However, such a system might still be carbon inefficient if operational carbon costs ($\mathbb{C}_{\text{OP}}$) are high. This work explores this trade-off, and proposes two possible strategies for getting around a high $\mathbb{C}_{\text{OP}}$.

[1]The definition of operations will vary depending on the target application.
[2]This is not quite true in cases where the repurposed device requires added peripherals to function as attended; we address this later.

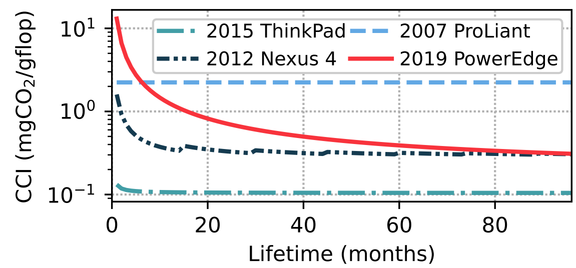

Figure 1: Carbon intensity for various retired devices, compared to the cost of building a new server (2019 PowerEdge). A California energy mix is assumed. Numbers from [11].

2 CASE STUDY: HP PROLIANT

Figure 1 plots the CCI of three repurposed devices against that of a new server. The smartphone (Nexus 4) and laptop (ThinkPad Gen3) studied achieve a lower carbon per operation than the new server. This is for two reasons. First, they are relatively efficient (E/ops is low). Second, their upfront capital expenditure is very low ($\mathbb{C}_{\text{CAP}}$ is small). The device is already manufactured and so the only upfront carbon expenditure is from the peripherals needed to transform the laptop or phone into an always-on machine—fans, networking dongles, and periodic replacement batteries. We think of the capital cost of these peripherals as the repurposing overhead. It is much smaller than the capital cost of a new server.

The old server studied (ProLiant Gen6) is more carbon intense than the new server. The old ProLiant is already manufactured and does not require any added peripherals, meaning that $\mathbb{C}_{\text{CAP}} = 0$. However, it is much less energy efficient than the new PowerEdge, i.e. $(E/\text{ops})_{\text{old}} >> (E/\text{ops})_{\text{new}}$. It is this inefficiency that makes it not quite worthwhile to repurpose.

A natural question that arises is: How old is too old? It is perhaps not surprising that a machine from 2007 is not very efficient. Figure 2 gives the carbon intensity of several generations of ProLiants. Based on this analysis, only the penultimate model—the Gen9—is worth keeping in service. For generations older than the Gen9, the carbon savings achieved by preventing the manufacture of the new machine are more than offset by the lower energy efficiency.

The rest of this paper proposes two alternate strategies for making effective use of old, inefficient machines.

3 STRATEGY 1: SOURCE CLEANER ENERGY

The operational carbon footprint of a device is directly proportional to the carbon intensity of the energy source, CI_{grid}. If a completely carbon-free energy source were possible, then it would always (in terms of carbon) be worthwhile to keep machines in service. However, such a zero-carbon energy source does not exist: Even renewable energy sources such as solar incur some carbon emissions.

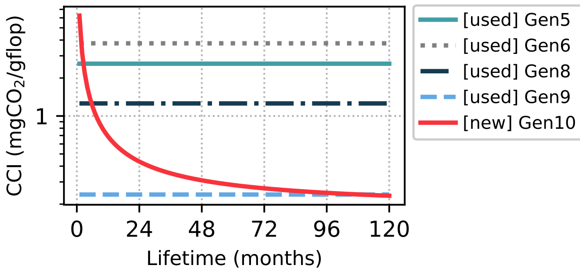

Figure 2: Carbon intensity of a new HP ProLiant DL380 Gen10 (red line), compared to reusing an already-manufactured ProLiant DL380 from a previous generation. Assumes a California energy mix. Calculated based on reported max and idle power [2, 4, 9, 10] and GeekBench 4 scores [8]

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Table 1: How green the energy has to be to make each previous generation of ProLiant worth keeping.

ProLiant	CI_{MAX}	Comparable to
DL380 Gen5	11 gCO_2e/kWh	Wind or greener
DL380 Gen6	7 gCO_2e/kWh	Geothermal/hydro or greener
DL380 Gen8	24 gCO_2e/kWh	Solar or greener
DL380 Gen9	465 gCO_2e/kWh	Natural gas or greener

For each used ProLiant featured in Figure 2, we can calculate how "green" our energy needs to be to make their continued service worthwhile. For this analysis, we define worthwhile as being less carbon-intense over a 5-year lifetime than the alternative of deploying a new ProLiant 10.

The results are given in Table 1. The Gen9 is almost always worth it. Any energy source equivalent to or "greener" than natural gas is acceptable. The Gen8 requires full-solar or greener. This might be realistic in the near future, given the pledge of datacenter operators like Google to transition to fully renewable energy in the next decade [5]. The Gen5 and Gen6 machines require very green energy to be worthwhile. One way to go about this might be to co-locate clusters of these machines with large sources of hydro, geothermal, or wind. This sort of opportunistic co-location has been explored [12, 13], but not through the lens of the maximum carbon intensity needed to make old devices worth keeping.

4 STRATEGY 2: COMPONENT-WISE SALVAGE

Different components are responsible for different fractions of the manufacturing and operational carbon footprints. That is, some components take a lot of energy (and carbon) to manufacture, while others are power-hungry in life and contribute heavily to the operational carbon footprint. This can be leveraged for selective repurposing of individual sub-components. Components that cost a lot of carbon to manufacture will provide the most displacement savings, and low-power components will be less sensitive to changes in efficiency over device generations.

This is illustrated in Figure 3, which gives the fractional manufacturing footprint [3] and fractional operational power [1] for various server components: Storage (SSD), memory (RAM), mainboard, peripherals (includes network hardware), and CPUs.

There are several interesting things to note. First, the manufacturing carbon footprint is dominated by storage, which is responsible for 80% of the manufacturing footprint. This is due to the comparably large die area of the SSD's NAND flash chips. Contrary to their high manufacturing cost, storage is responsible for a relatively small fraction of a server's total energy consumption (about 5%). This makes them an excellent target for reuse.

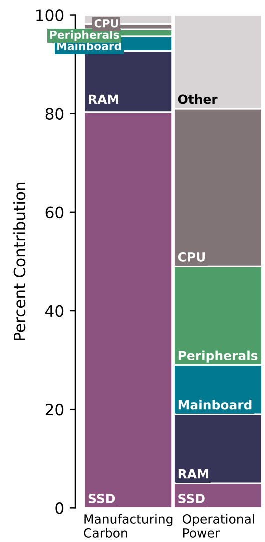

Figure 3: Per component contributions.

For CPUs, the opposite is true. Despite being responsible for approximately 30% of the server's power consumption, the CPU makes up a very small fraction of the manufacturing footprint–about 1%. This number is so small because the die area of the CPU is significantly less than that of the SSD and RAM. RAM is relatively significant across both metrics, making it a better target for reuse than the CPU but less attractive than SSDs.

There is a strong case for focusing reuse efforts on SSDs. Under this model, unused SSDs would be scavenged from retired servers and redeployed alongside modern CPUs. These franken-servers would have the advantage of more efficient processors while still saving significant carbon on the SSD. We enumerate a few anticipated challenges below.

Reduced data speeds: The NVMe SSDs that are available for DL380 Gen10 and Gen9s are capable of 3000 MB/s—far outpacing the 500 MB/s of earlier SATA SSDs. Reusing older storage hardware requires accepting reduced data speeds, which poses new challenges for application developers.

Privacy & data management: Reused SSDs must be wiped in a reliable and trustworthy manner. For corporations that handle sensitive data, SSD reuse might never be an option; for instance, Google physically destroys end-of-life drives [6]. Furthermore, a storage device that is no longer being accessed might still hold data that should be preserved. Deciding when to wipe and reuse a drive poses a data management problem.

Error rates. Recent studies have observed a modest increase in SSD failure rates over time—from 0% to 0.9% over five years [7]. Depending on how this trend holds for longer lifetimes (repurposed SSDs would be in service for 10-20 years), this will need to be addressed, perhaps through added redundancy.

5 CONCLUSION

Scavenging discarded electronic devices shows great potential for carbon savings, but these savings must be balanced against the reduced operational efficiency of older devices. This work has presented new research directions for getting around this inefficiency, with a focus on both operational (Section 3) and embodied (Section 4) emissions.

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