Junkyard datacenters

Carbon-efficient computing systems from old phones

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How many smartphones have you had in

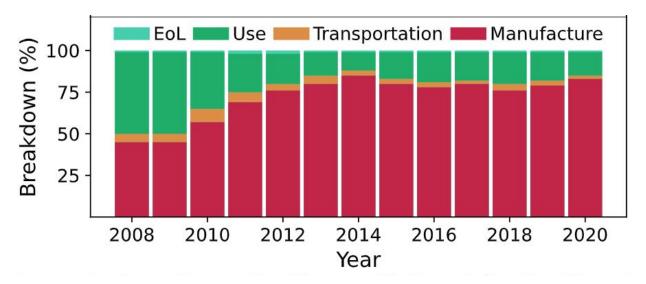
your life?





Most of these phones were still functional!

Short lifetimes + low power = Majority of carbon emissions from manufacturing.



Example from Apple.

The result: Reducing carbon intensity requires extending lifetimes.

Takeaway 6: Given the energy-efficiency improvements from software and hardware innovation over the last decade, amortizing the manufacturing carbon output requires continuously operating mobile devices for three years—beyond their typical lifetime.

Gupta et al. "Chasing Carbon: The Elusive Environmental Footprint of Computing" HPCA '21.

If we want CO₂ manufacture = CO₂ use, we need to double lifespans

Problem: Lifetime extension is hard.

Consumers want new phones.

Refurbishing market is limited.

Recycling is hard, and only recovers raw materials.

Idea: Lifetime extension through repurposing.

What else can a smartphone be?

A baby monitor?

A parking meter?

A wildlife monitor?

A datacenter?



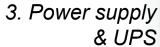




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What's in a phone



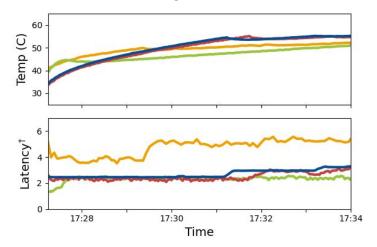




2. Processors (CPU & GPU)

4. Storage

5. Thermal throttling

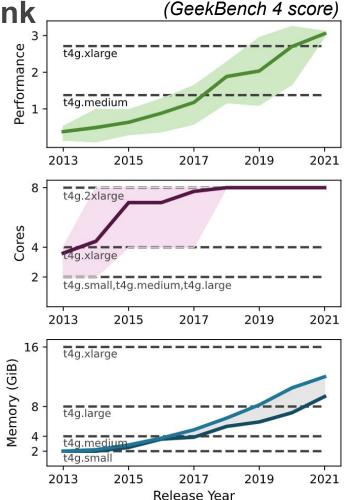


They aren't as weak as you might think

Smaller-scale machines are popular for cloud applications.

Dotted lines show AWS' current-day "burstable cloud" offerings.

Curves represent the average from the most popular 5 smartphones released each year.



What's *not* in a phone (Challenges)

Challenge 1. Smartphones aren't meant for continuous operation.

- They expect human input & may stall without it
- Performance saturates over time
- Battery is not designed for continuous use

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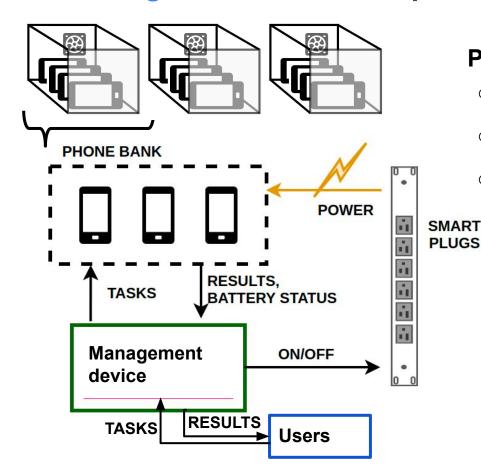
Challenge 2. They still can't compete with a server.

	SGEMM	PDF Rendering	Dijkstra
PowerEdge Server	2,170 Gflops	3,140 Mpixels/sec	80.2 MTE/sec
Nexus 5	13.8 Gflops	85.8 Mpixels/sec	3.31 MTE/sec
Slowdown	157x	37x	24x

Goal: Build a server from old smartphones that is carbon-efficient despite these challenges.

Challenge 1: Continuous Operation

Challenge 1: Continuous Operation



Proposal: Phones in a box.

- Redundancy
- Power management
- FaaS-like interface for programmability

Challenge 1: Continuous Operation



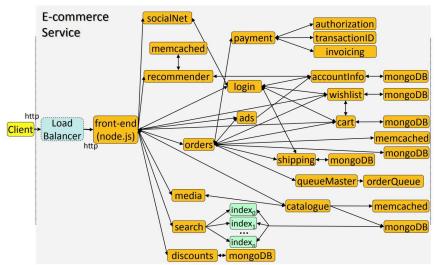
- Four Nexus 4 smartphones
- Raspberry Pi manager
- Smartplugs added
- Android -> Ubuntu Touch OS
- Fans? Overkill, actually.

Challenge 2: Per-device Computational Power

Q: How can we make a cluster of small devices do large-scale work?

A: Microservices.

Microservices break down large applications into smaller, single-purpose components



Gan, Yu, et al. "An open-source benchmark suite for microservices and their hardware-software implications for cloud & edge systems." *ASPLOS* '19.

Ongoing Work

Current cluster: 10 smartphones + 1 repurposed laptop

Target applications: Edge datacenter

Real-time data processing



Content delivery network



Evaluation

How can we define carbon efficiency?

Total carbon footprint isn't enough.

We need a measure of how well we are making use of our carbon expenditure.

$$CCI = \frac{C_{manufacture} + C_{use}}{C_{omputational work done}}$$

$$CCI = \frac{Cmanufacture + Carbon intensity of grid (CO2/J) * mean power *T}{Rate of work (ops/s) *T}$$

We define a new metric: Computational Carbon Intensity (CCI)

Sourced from LCA, includes component replacements and extra peripherals

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Input parameter

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Benchmarked

Device	Description	N devices	Peripherals?
PowerEdge R740	New 2019 Server	1	

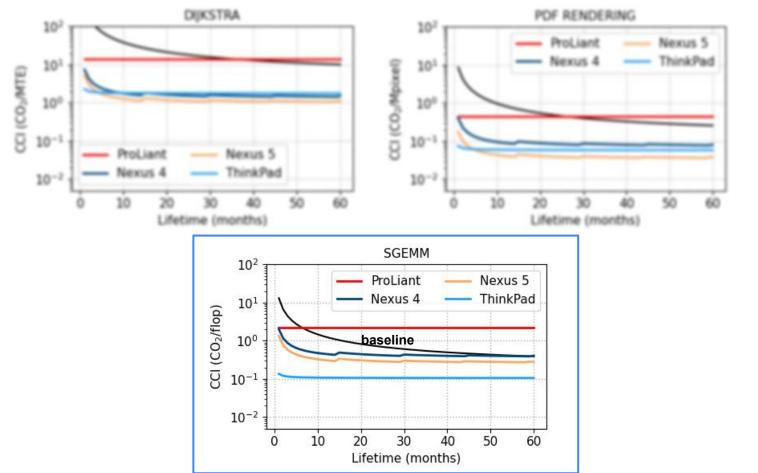
Device	Description	N devices	Peripherals?
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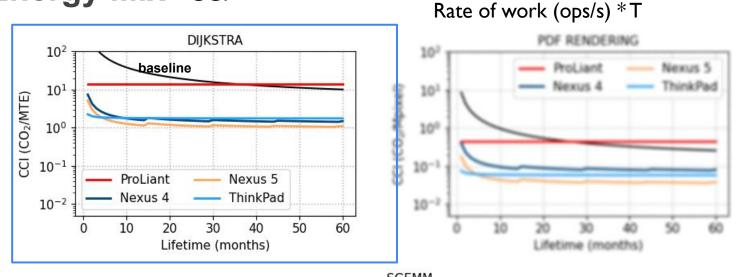
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ThinkPad X1 Carbon G3	Old 2015 Laptop	17	Smartplugs

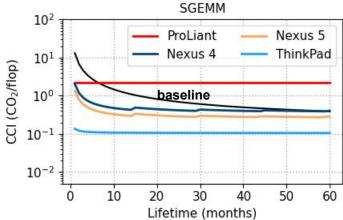
CA Energy Mix cci =



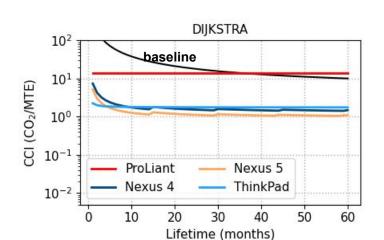


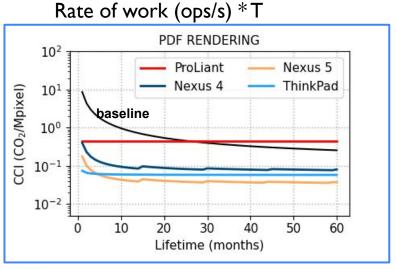
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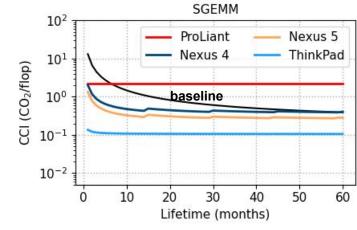




CA Energy Mix cc =







Solar Only

CCI =

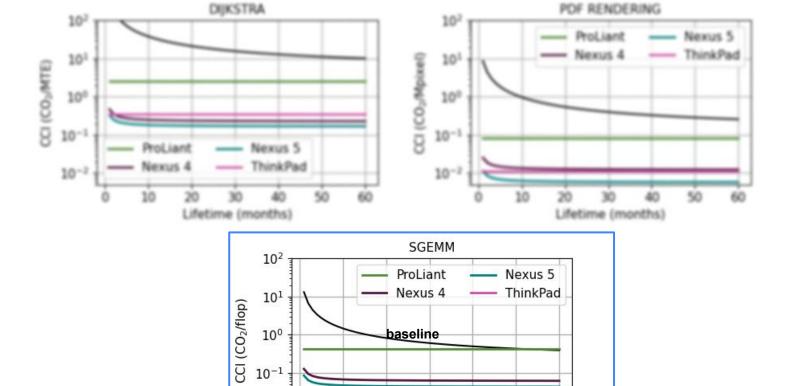
 10^{-2}

10

20

Cmanufacture + Carbon intensity of grid (CO2/J) * mean power * T

Rate of work (ops/s) *T



30

Lifetime (months)

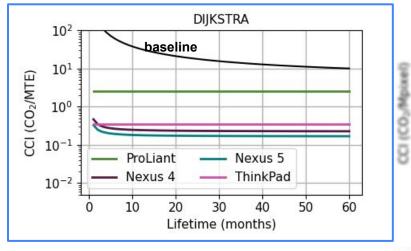
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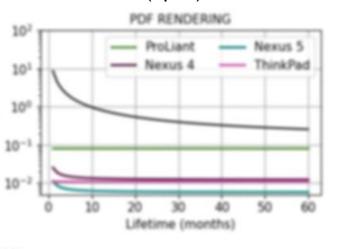
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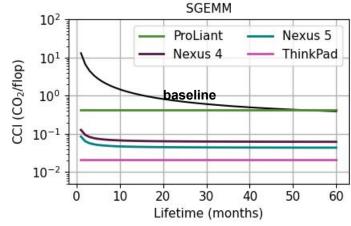
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Solar Only





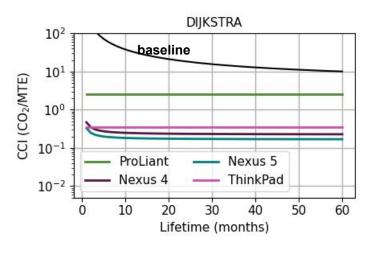


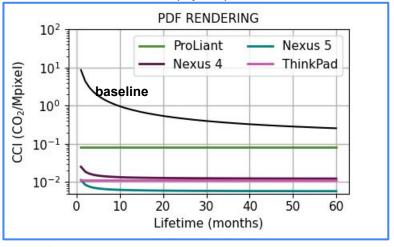


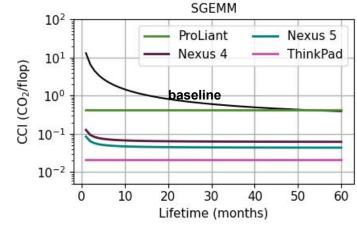
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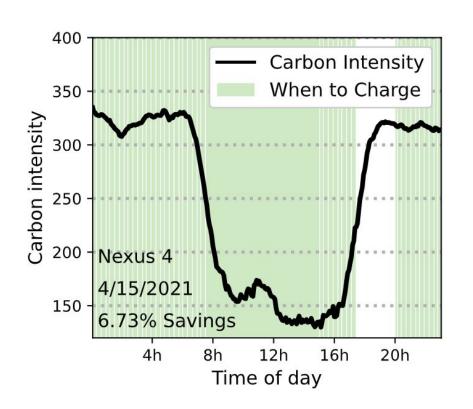


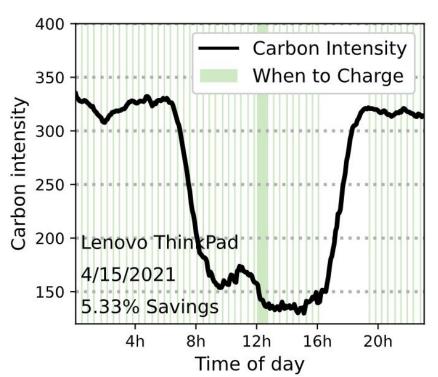






Another advantage: Batteries allow for smart charging



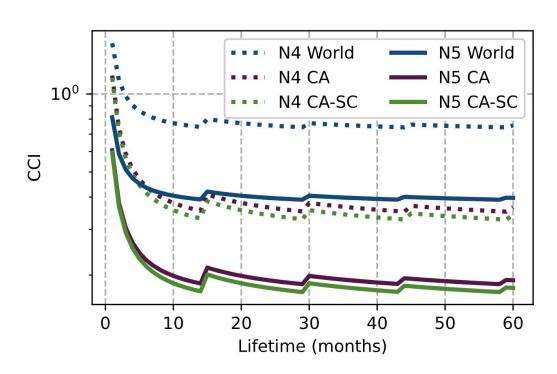


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CCI varies depending on the energy source used.

CCI is lowest when more renewable energy is used, as in the California grid.

Smart charging gives further improvements.



Cmanufacture + Carbon intensity of grid (CO2/J) * mean power * T

 $CCI = \frac{}{\text{Rate of work (ops/s) *T}}$

Summary

Smartphones are carbon intense to manufacture, and discarded guickly.

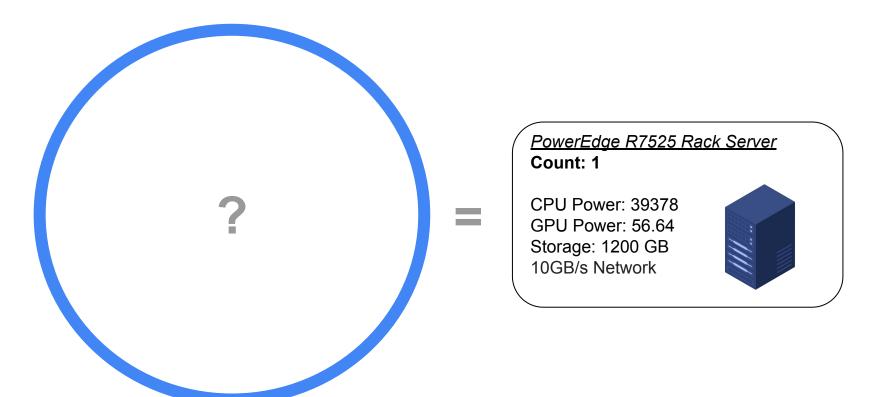
They are capable of so much more than what we ask of them!

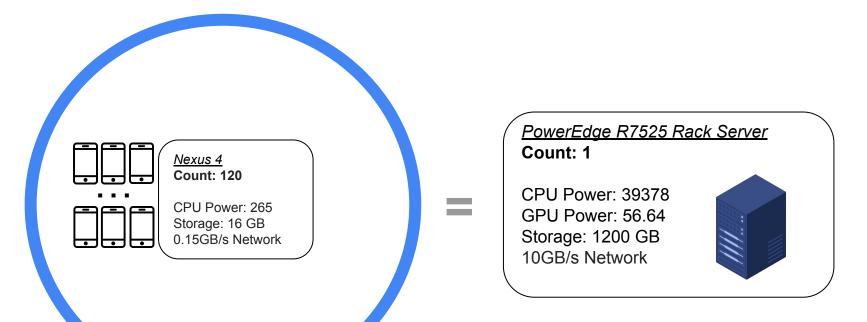
Let's open up new avenues for reuse, and recover some of the

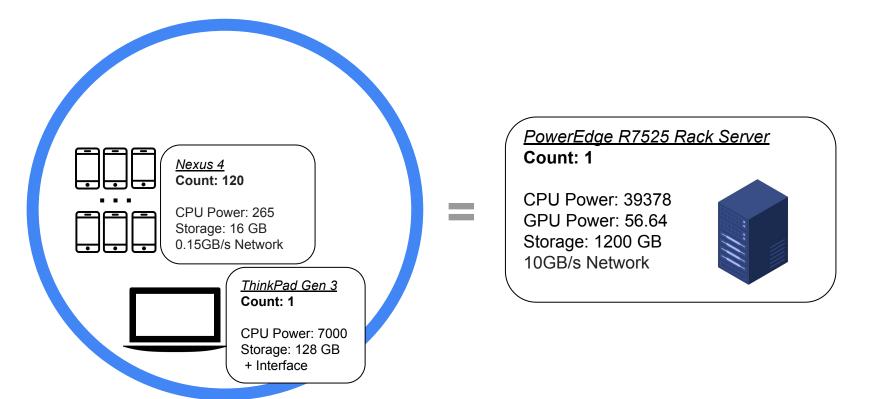
450 million tonnes = 2 million statues of liberty

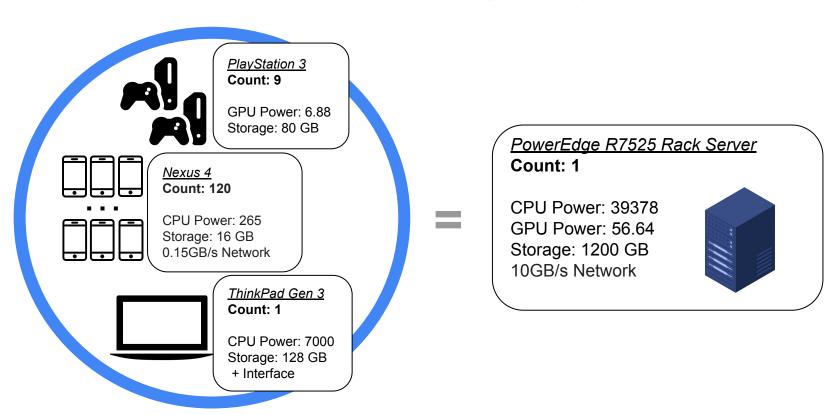


of sunk carbon that we carry around in our pockets.









Revisiting our metrics:

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CCI units	CO2e/flop	CO2e/Mpixel	CO2e/MTE