ACT: **A**rchitectural **C**arbon Modeling **T**ools

@ MICRO 2022
Tutorial

Udit Gupta

ACT Tutorial: Today

Time	Topic
1:00 – 1:15pm	Introductory remarks
1:15 – 1:30pm	Motivation: Understanding the source of computing’s emissions
1:30 – 2:15pm	Overview of ACT: An Architectural Carbon Modeling Tool
2:15 –2:30pm	*Coffee Break*
2:30 – 3:00pm	**Hands-on ACT demo’s**
3:00 – 3:15pm	Extending ACT
3:15 – 3:45pm	*Office Hours*
3:45 – 4:00pm	Closing remarks

Sing up on our Google form!

https://forms.gle/hEAju2suaeEnisRQA

ACT MICRO 2022 tutorial registration form

Developing modular, extensible, and commensurate architectural carbon modeling tools will require community-wide efforts. We hope ACT will help jumpstart such efforts.

If you are attending the inaugural ACT tutorial at MICRO 2022 or interested in being part of the community please register below.

Estimating the embodied footprint of 2 devices using ACT

<table>
<tr><th>IC component</th><th>ACT vs. Dell R740 server LCA</th><th>ACT vs. Fairphone 3 mobile device LCA</th></tr>
<tr><td>Compute (processors, SoC’s)</td><td>Within 2.2x</td><td>Within 1.18x</td></tr>
<tr><td>Memory</td><td>Within 1.62x</td><td rowspan="2">Within 2.1x</td></tr>
<tr><td>Storage</td><td>Within 1.05-2.2x</td></tr>
</table>

Takeaways

(1) ACT provides first-order approximate of LCA’s that use old technology nodes (45nm NAND, 32nm CPU)

(2) ACT enables architects to study new technology nodes

How to set up ACT

```
>$ git clone https://github.com/alugupta/ACT.git

>$ cd ACT/

>$ source setup.sh

>$ python model.py
```

```
[Fab logic] Carbon/area from energy consumed 1209.5
[Fab logic] Carbon/area from gasses 240
[Fab logic] Carbon/area from materials 500
[Fab logic] Carbon/area aggregate 2228.0
```

https://github.com/alugupta/ACT

Estimating embodied footprint of Fairphone 3

https://www.fairphone.com/wp-content/uploads/2020/07/Fairphone_3_LCA.pdf

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IZM

FRAUNHOFER-INSTITUT FÜR ZUVERLÄSSIGKEIT UND MIKROINTEGRATION IZM

LIFE CYCLE ASSESSMENT OF THE FAIRPHONE 3

Marina Proske
David Sánchez
Christian Clemm
Sarah-Jane Baur

Berlin, July 2020

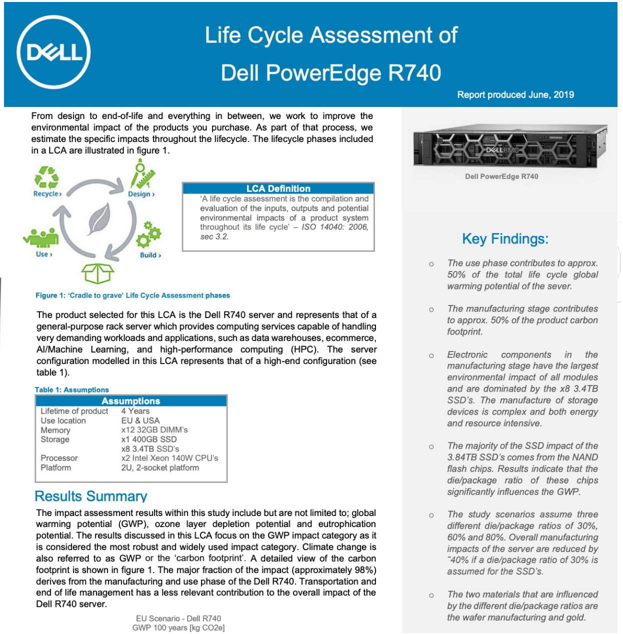
```
# Make sure you are in root directory
>$ cd ACT

>$ python tutorial/fairphone3_tutorial.py
```

```
-------------------------------
ACT RAM + Flash 0.0 kg CO2 vs. LCA 11 kg CO2
ACT CPU 0.0 kg CO2 vs. LCA 1.07 kg CO2
ACT ICs 0.0 kg CO2 vs. LCA 5.3 kg CO2
```

Full end to end example can be found here:
https://github.com/alugupta/ACT/blob/main/exps/fairphone3/fairphone3.py

Estimating embodied footprint of Dell R740

https://corporate.delltechnologies.com/content/dam/digitalassets/active/en/unauth/data-sheets/products/servers/lca_poweredge_r740.pdf



Life Cycle Assessment of Dell PowerEdge R740

Report produced June, 2019

From design to end-of-life and everything in between, we work to improve the environmental impact of the products you purchase. As part of that process, we estimate the specific impacts throughout the lifecycle. The lifecycle phases included in a LCA are illustrated in figure 1.

Recycle › Design › Use › Build ›

LCA Definition

'A life cycle assessment is the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle' – *ISO 14040: 2006, sec 3.2.*

Figure 1: 'Cradle to grave' Life Cycle Assessment phases

The product selected for this LCA is the Dell R740 server and represents that of a general-purpose rack server which provides computing services capable of handling very demanding workloads and applications, such as data warehouses, ecommerce, AI/Machine Learning, and high-performance computing (HPC). The server configuration modelled in this LCA represents that of a high-end configuration (see table 1).

Table 1: Assumptions

Assumptions	
Lifetime of product	4 Years
Use location	EU & USA
Memory	x12 32GB DIMM's
Storage	x1 400GB SSD x8 3.4TB SSD's
Processor	x2 Intel Xeon 140W CPU's
Platform	2U, 2-socket platform

Results Summary

The impact assessment results within this study include but are not limited to; global warming potential (GWP), ozone layer depletion potential and eutrophication potential. The results discussed in this LCA focus on the GWP impact category as it is considered the most robust and widely used impact category. Climate change is also referred to as GWP or the 'carbon footprint'. A detailed view of the carbon footprint is shown in figure 1. The major fraction of the impact (approximately 98%) derives from the manufacturing and use phase of the Dell R740. Transportation and end of life management has a less relevant contribution to the overall impact of the Dell R740 server.

EU Scenario - Dell R740
GWP 100 years [kg CO2e]

Dell PowerEdge R740

Key Findings:

- *The use phase contributes to approx. 50% of the total life cycle global warming potential of the sever.*
- *The manufacturing stage contributes to approx. 50% of the product carbon footprint.*
- *Electronic components in the manufacturing stage have the largest environmental impact of all modules and are dominated by the x8 3.4TB SSD's. The manufacture of storage devices is complex and both energy and resource intensive.*
- *The majority of the SSD impact of the 3.84TB SSD's comes from the NAND flash chips. Results indicate that the die/package ratio of these chips significantly influences the GWP.*
- *The study scenarios assume three different die/package ratios of 30%, 60% and 80%. Overall manufacturing impacts of the server are reduced by ~40% if a die/package ratio of 30% is assumed for the SSD's.*
- *The two materials that are influenced by the different die/package ratios are the wafer manufacturing and gold.*

```
# Make sure you are in root directory
>$ cd ACT

>$ python tutorial/dellr740_tutorial.py
```

```
--------------------------------
ACT SSD main 0 kg CO2 vs. LCA 3373 kg CO2
ACT SSD secondary 0 kg CO2 vs. LCA 64.1 kg CO2
ACT DRAM 0 kg CO2 vs. LCA 533 kg CO2
ACT CPU 0 kg CO2 vs. LCA 47 kg CO2
```

Full end to end example can be found here:
https://github.com/alugupta/ACT/blob/main/exps/dellr740/dellr740.py

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Extending ACT with new SSD model

https://hotcarbon.org/pdf/hotcarbon22-tannu.pdf *(HotCarbon workshop 2022)*

The Dirty Secret of SSDs: Embodied Carbon

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Abstract

Scalable Solid-State Drives (SSDs) have revolutionized the way we store and access our data across datacenters and hand-held devices. Unfortunately, scaling technology can have a significant environmental impact. Across the globe, most semiconductor manufacturing use electricity that is generated from coal and natural gas. For instance, manufacturing a Gigabyte of Flash emits 0.16 Kg CO_2 and is a significant fraction of the total carbon emission in the system.

To better understand this concern, this paper compares the sustainability trade-offs between Hard Disk Drives (HDDs) and SSDs and recommends methodologies to estimate the embodied carbon costs of the storage system. In this paper, we outline four possible strategies to make storage systems sustainable. First, this paper recommends directions that help select the right medium of storage (SSD vs HDD). Second, this paper proposes lifetime extension techniques for SSDs. Third, this paper advocates for effective and efficient recycling and reuse of high-density multi-level cell-based SSDs. Fourth, specifically for hand-held devices, this paper recommends leveraging elasticity in cloud storage.

1 Introduction

Manufacturing, operating, transporting, and recycling computing systems, directly and indirectly, emit carbon dioxide (CO_2) and other greenhouse gases. As computing systems scale, their greenhouse contributions significantly impact global warming. This is highlighted by the pervasiveness of computing via hand-held devices, such as smartphones and tablets, and web services built around them. Moreover, digital data creation and consumption across the globe is snow bowling. As a result, carbon emissions due to personal devices, data centers, and networking infrastructure (known as the information and Communication Technologies (ICT) sector) are increasing rapidly. Today, about 2% of the total carbon emissions are estimated due to computing and networking devices combined [22, 23], and it is estimated to double in the next decade.

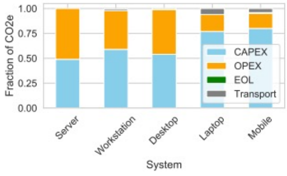

Figure 1: Breakdown of CO2e in Manufacturing (CAPEX) Operations (OPEX), Transport, and End of Life (EOL) phases.

For example, the average household in the US has five to ten devices connected to the internet [30, 31]. We estimate that manufacturing and operating these devices for a year emits 2000 Kg CO_2 – equivalent to CO_2 emissions from driving a car for 5000 miles [20].

Most of the carbon emissions are because of the "conventional" electricity [6] that is used in the manufacturing and operation of computing systems [25]. For example, running and cooling the computing and networking hardware consumes significant electricity. If this electricity is generated from conventional carbon-intensive sources such as coal, natural gas, and crude oil, it will contribute to global warming. In contrast, electricity generated from renewable sources such as wind, solar, nuclear, and hydroelectric have a significantly small Global Warming Potential (GWP). Unfortunately, irrespective of whether they are hand-held devices or server nodes, manufacturing hardware and/or operating them require a significant amount of electricity – often from carbon-intensive conventional sources.

How to quantify Global Warming Potential? Typically, Global Warming Potential is the amount of CO_2 (or the equiv-

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