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

@ MICRO 2022
Tutorial

Meta

CORNELL TECH

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

Today

Where does computing’s carbon footprint come from?

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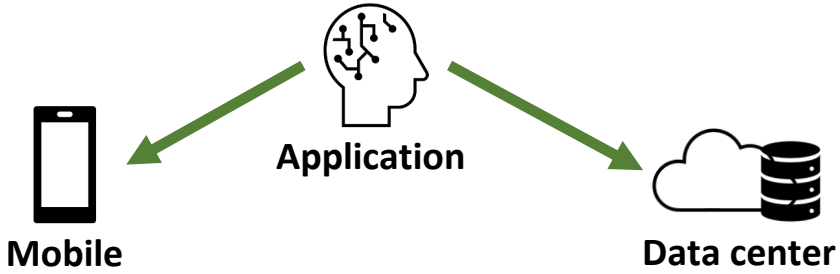

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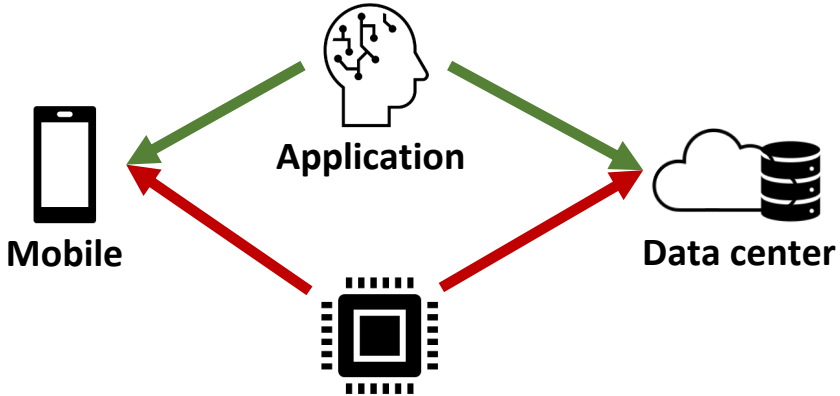
A combination of both energy consumed and hardware manufacturing (embodied carbon).



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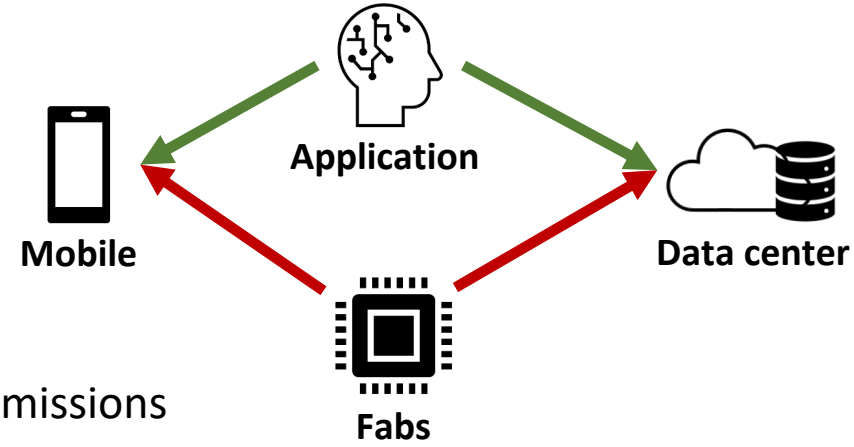

Understanding the breakdown of mobile emissions

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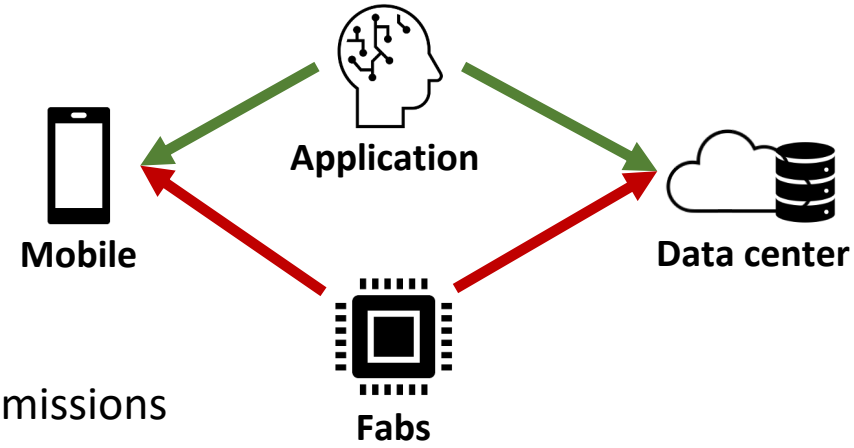

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Understanding the breakdown of data center emissions

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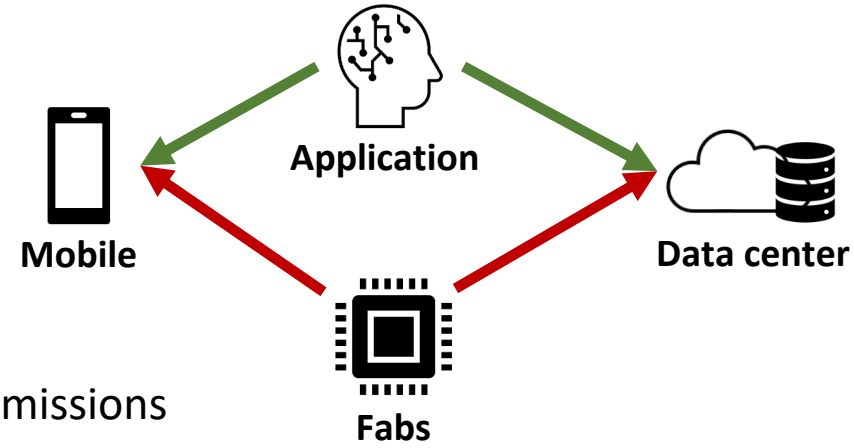

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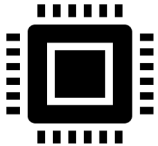

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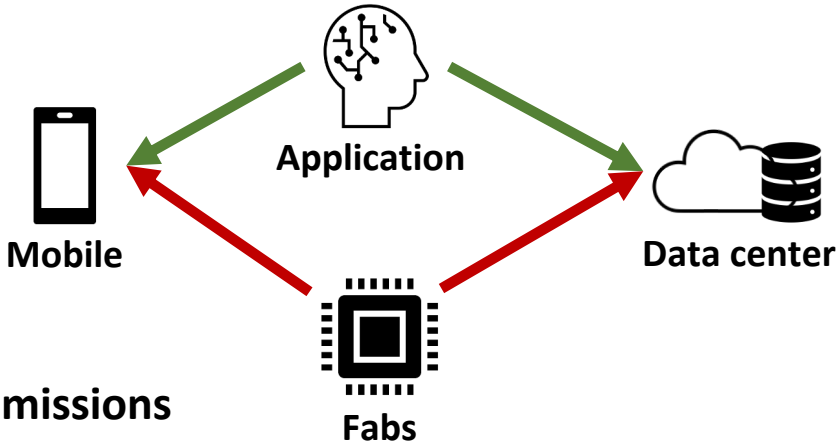

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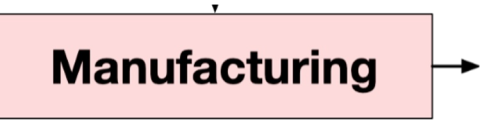
Understanding the breakdown of data center emissions

Understanding the breakdown of semiconductor manufacturing

Life **C**ycle **A**nalysis: key to understanding carbon emissions



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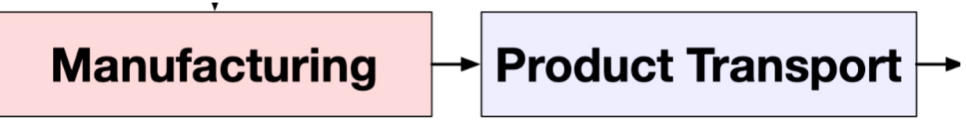

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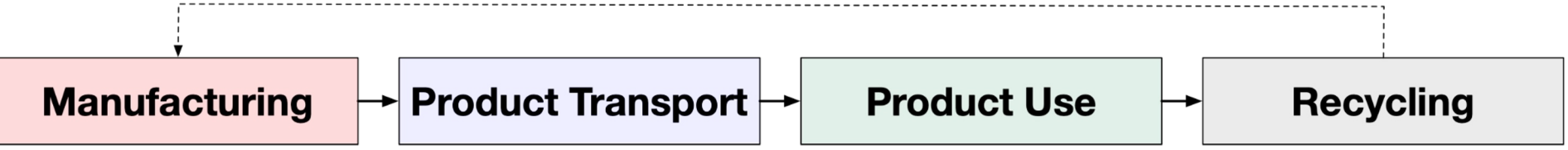

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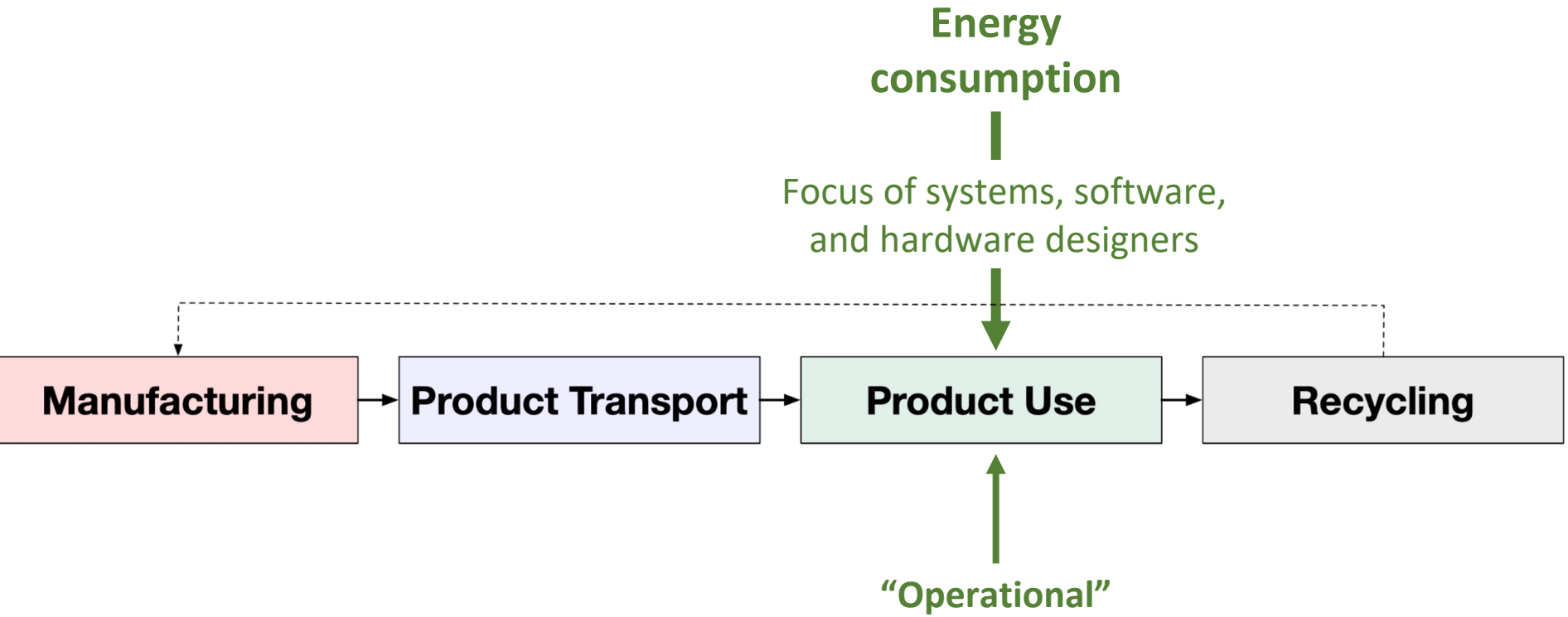

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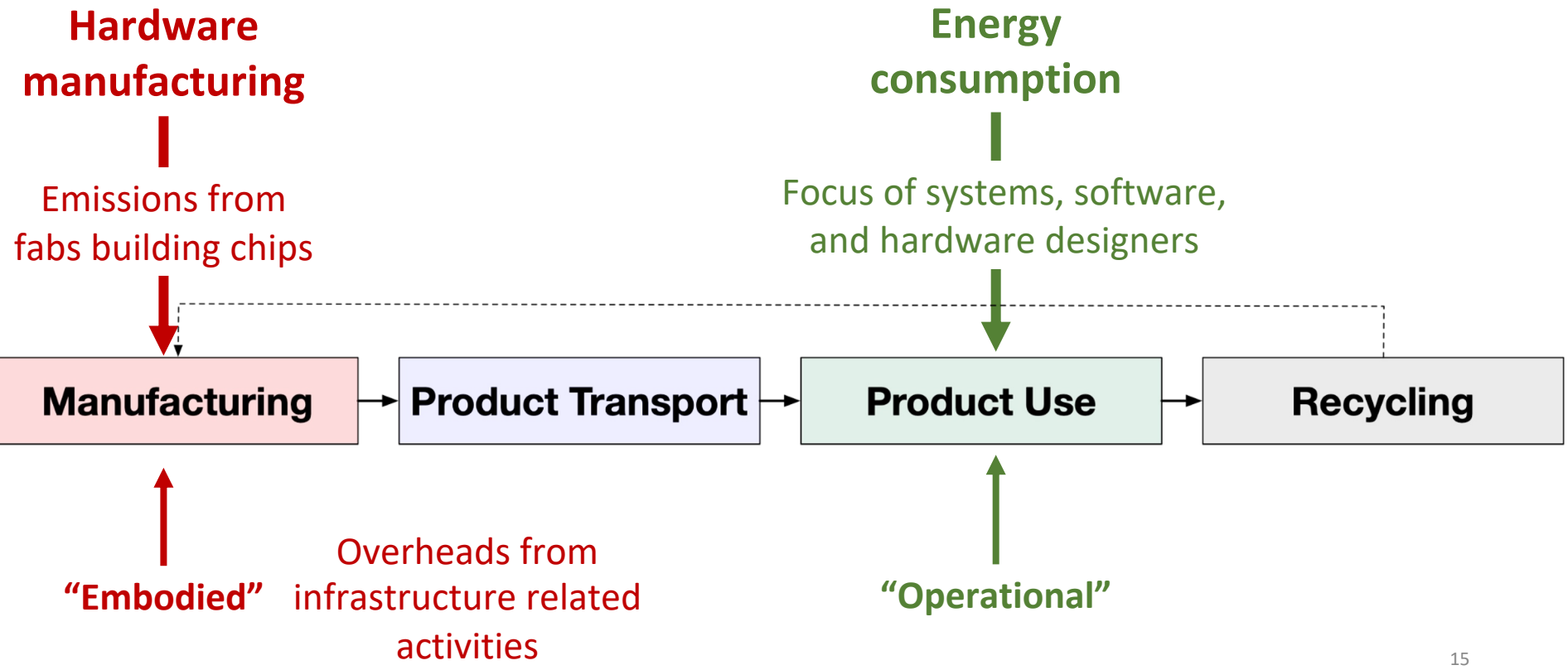
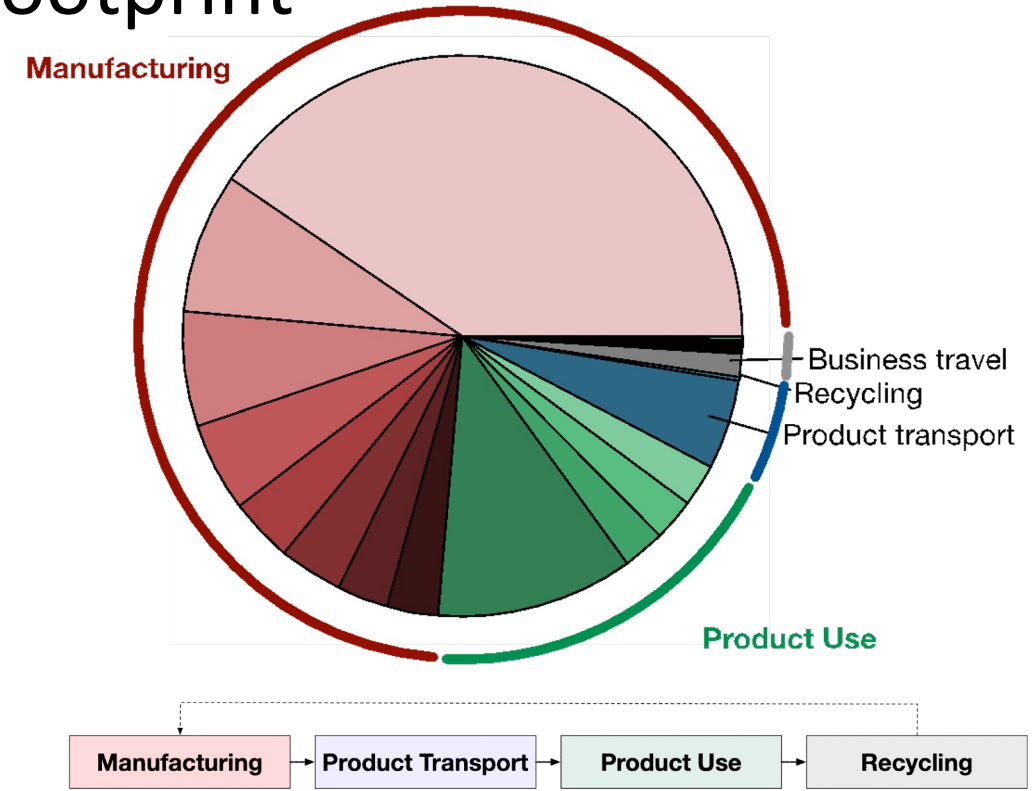


Manufacturing dominates Apple's overall carbon footprint



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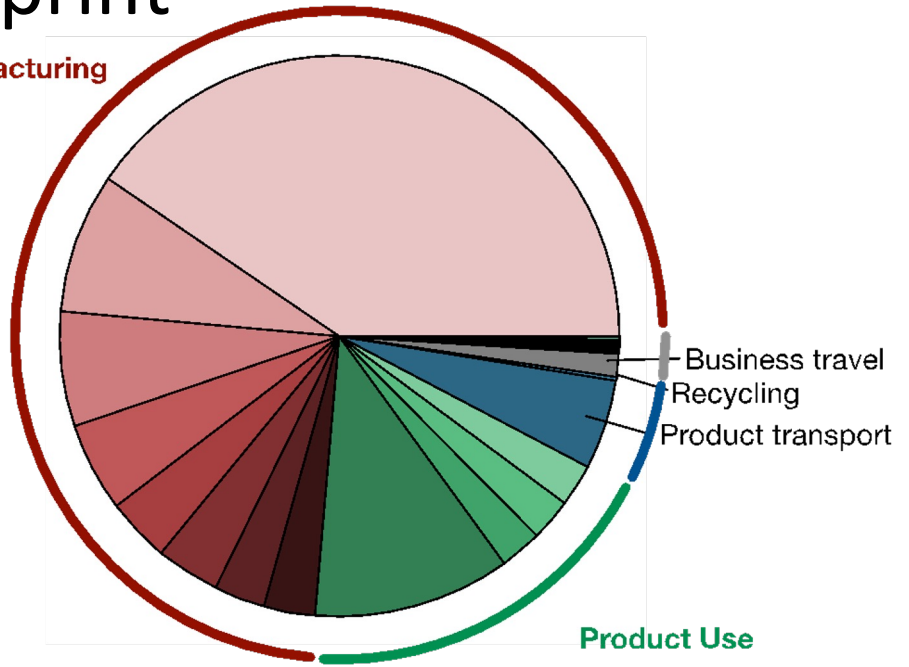
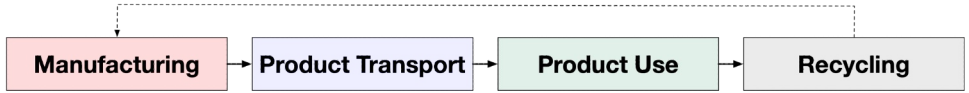
Manufacturing accounts for 74% of Apple's end to end breakdown in 2019





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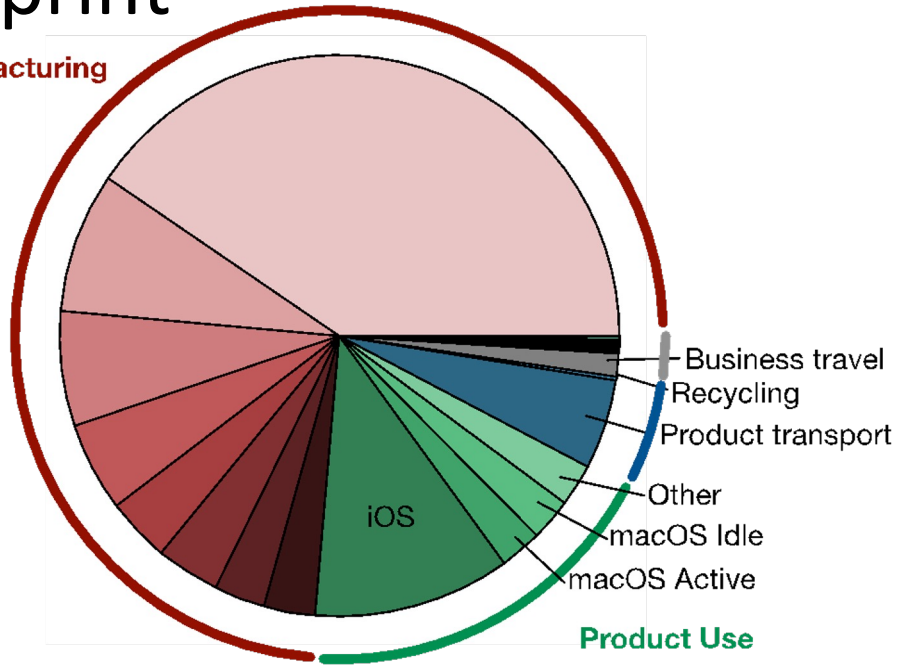

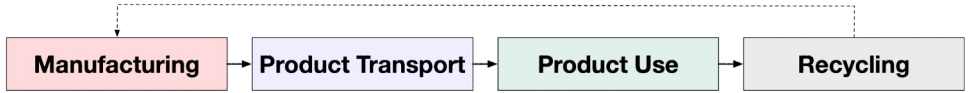

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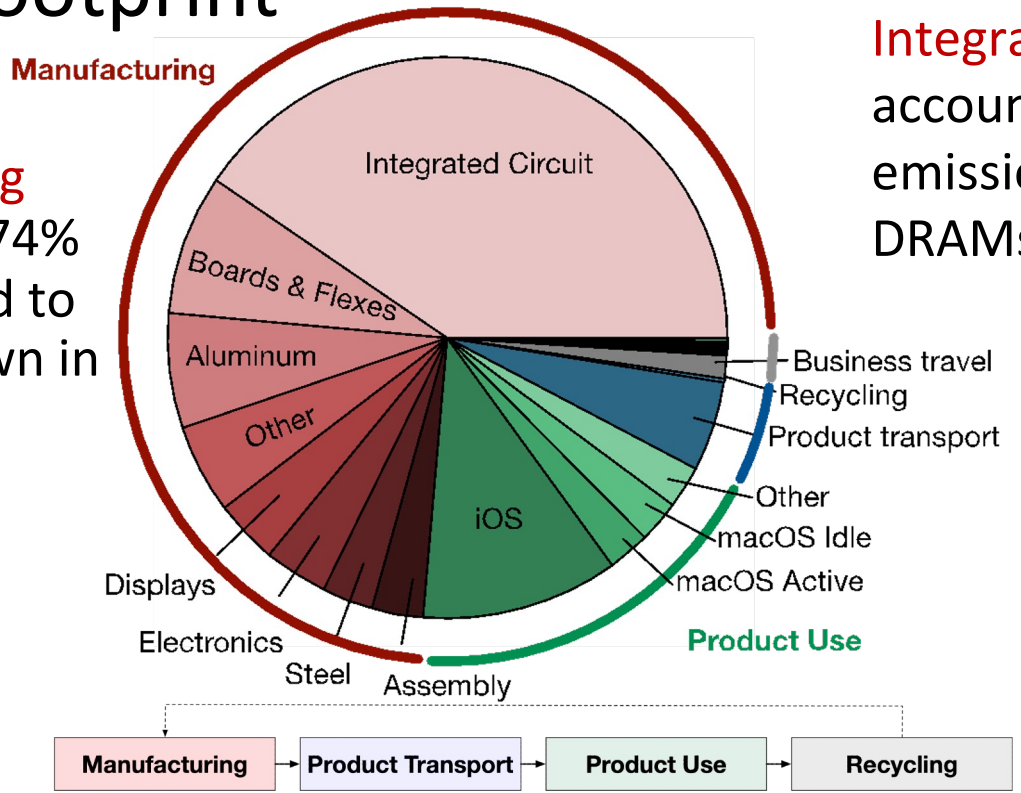

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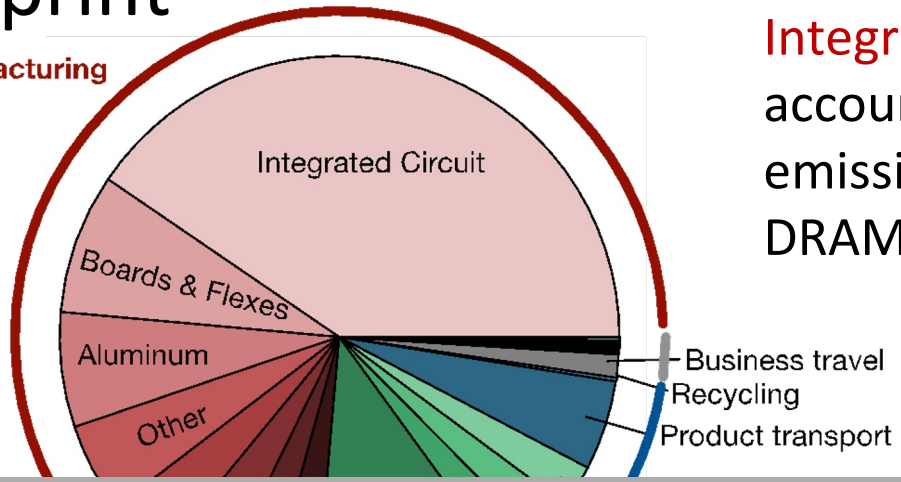
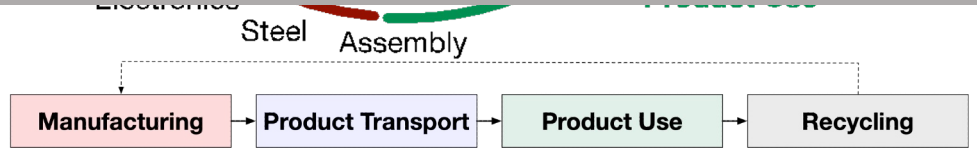


Integrated circuits account for 33% of emissions (SoCs, DRAMs, NAND Flash)

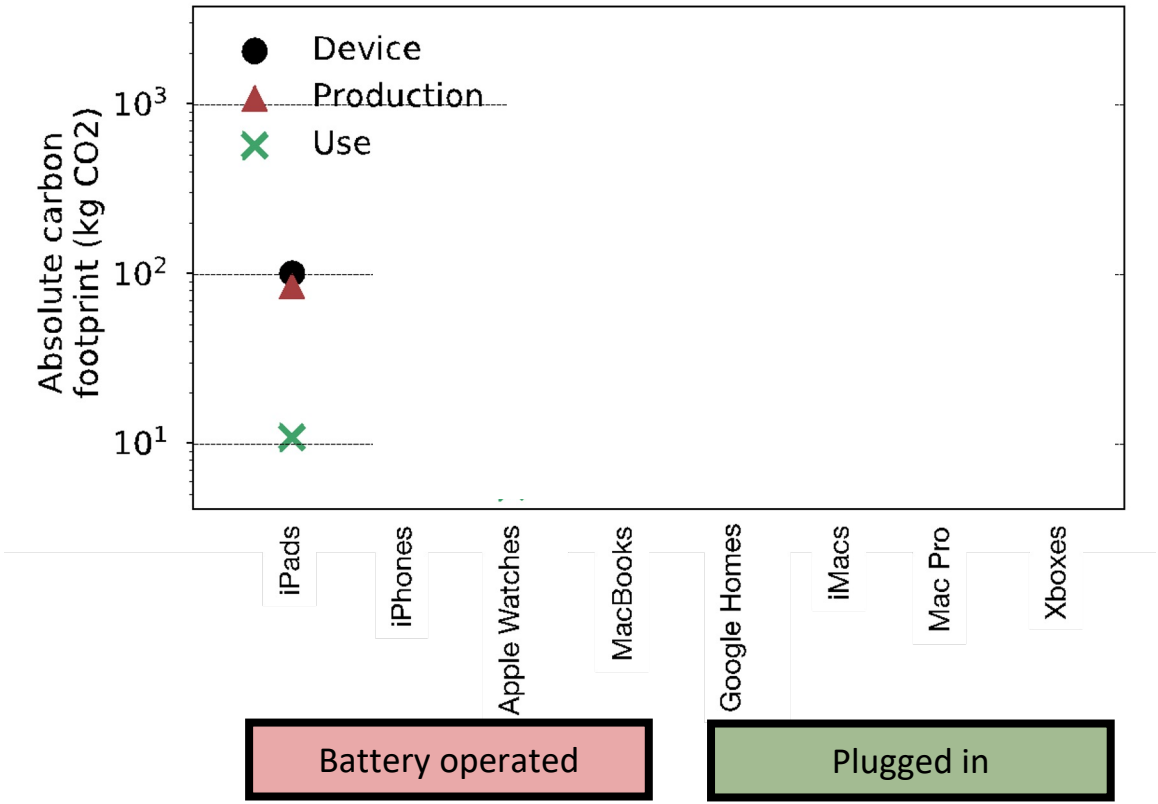
Aggregating across hundreds of millions of phones, iPads, and other consumer devices sold every year!



"Chasing Carbon: The Elusive Environmental Footprint of Computing" Gupta et. al. (HPCA 2021) https://arxiv.org/abs/2011.02839

Carbon footprint characteristics vary across devices

Data from public industry validated sustainability reports and life cycle analyses



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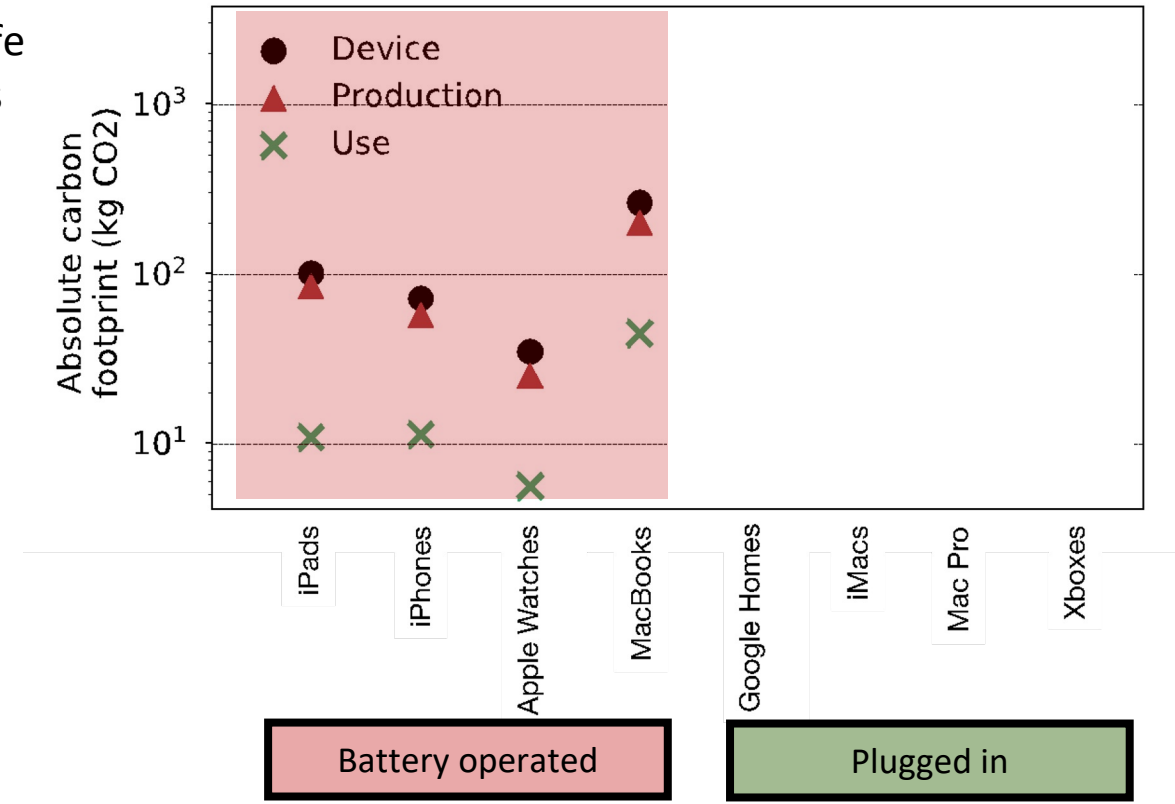
Roughly **75%** life cycle emissions for **battery operated devices** comes from hardware manufacturing.



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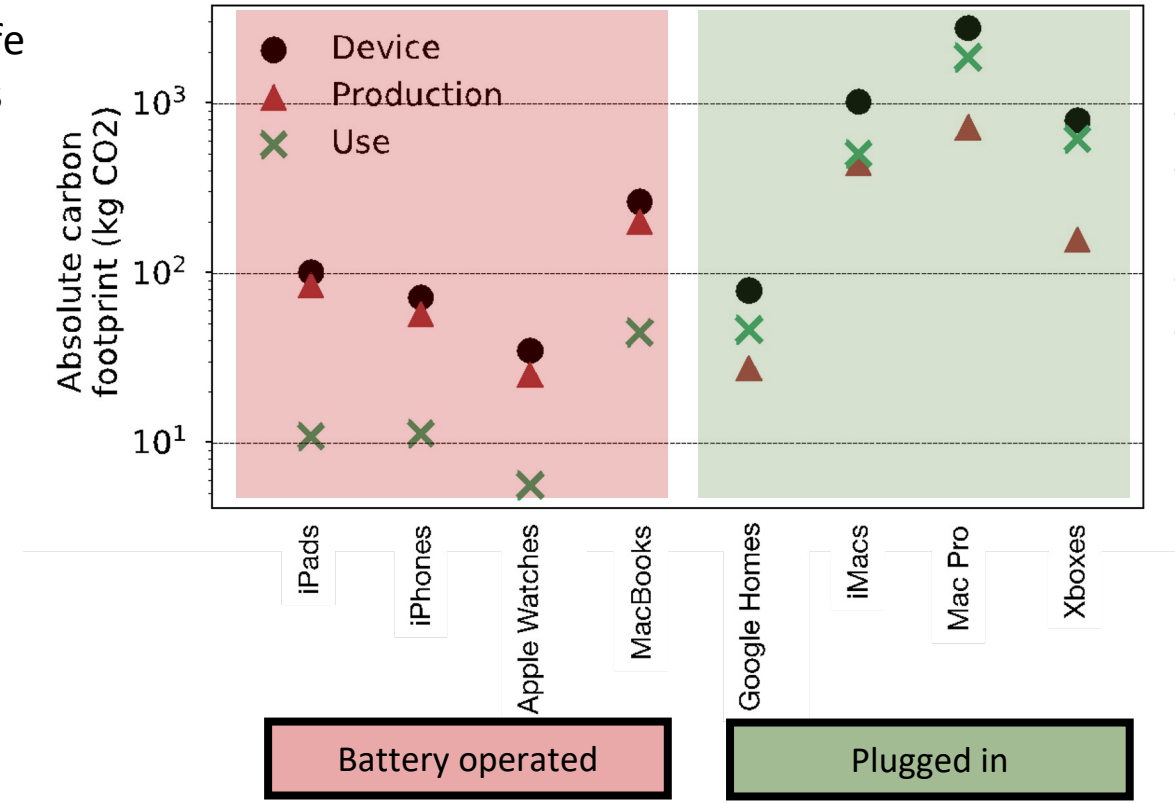

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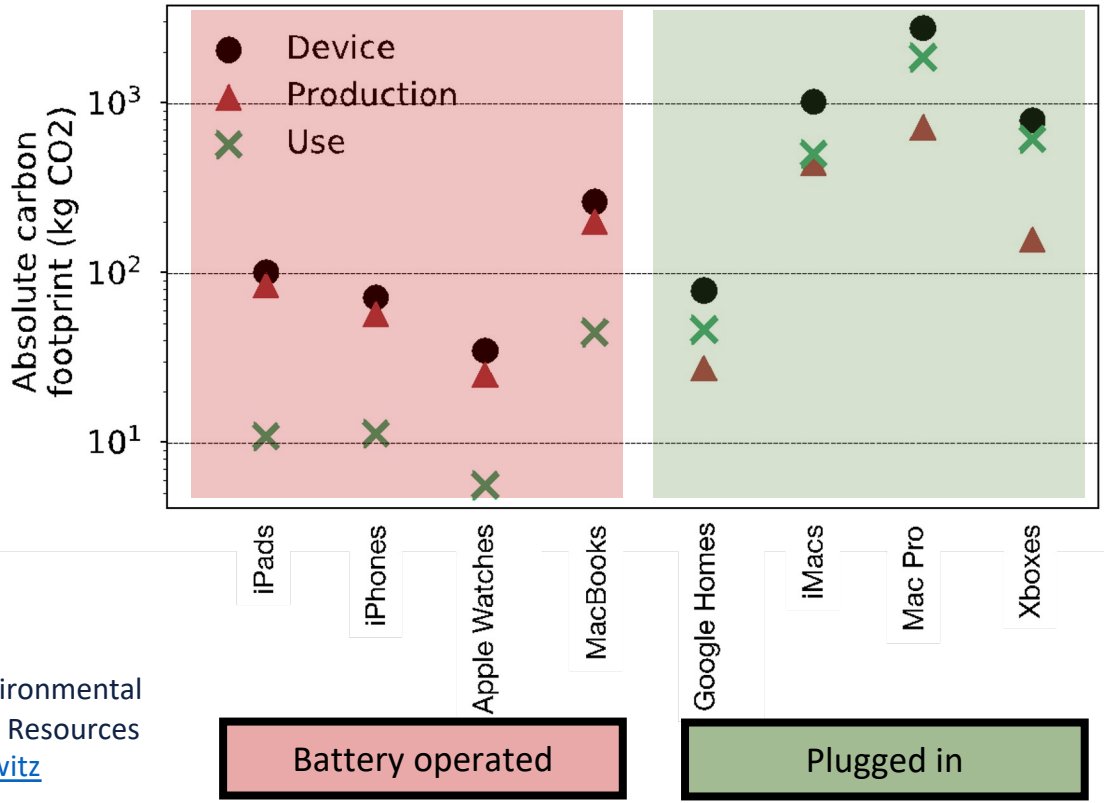

Emissions for **always-connected devices** come mainly from **energy consumption**

[1] Xbox Standby mode consumes 4 billion kWh

[1] "Latest Game Consoles: Environmental Winners or Losers?" National Resources Defense Council. Noah Horowitz

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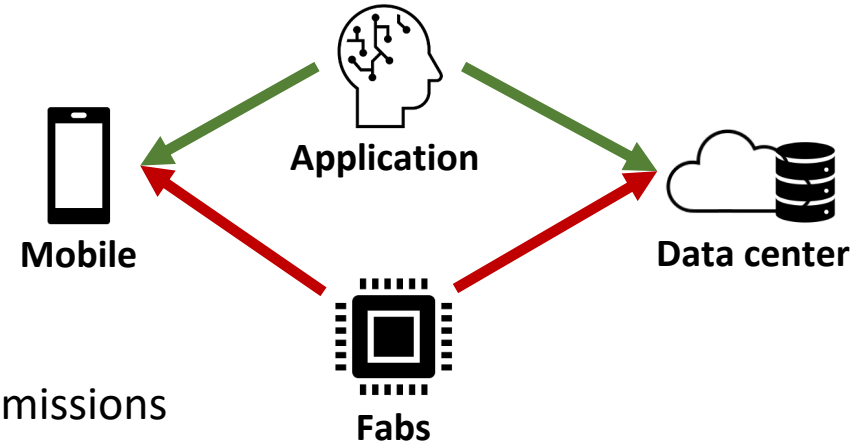

Understanding the breakdown of mobile emissions

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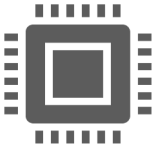
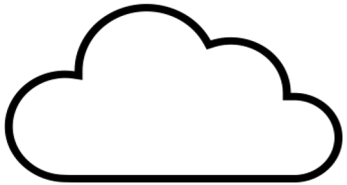
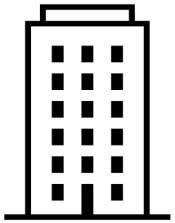


Understanding the breakdown of semiconductor manufacturing

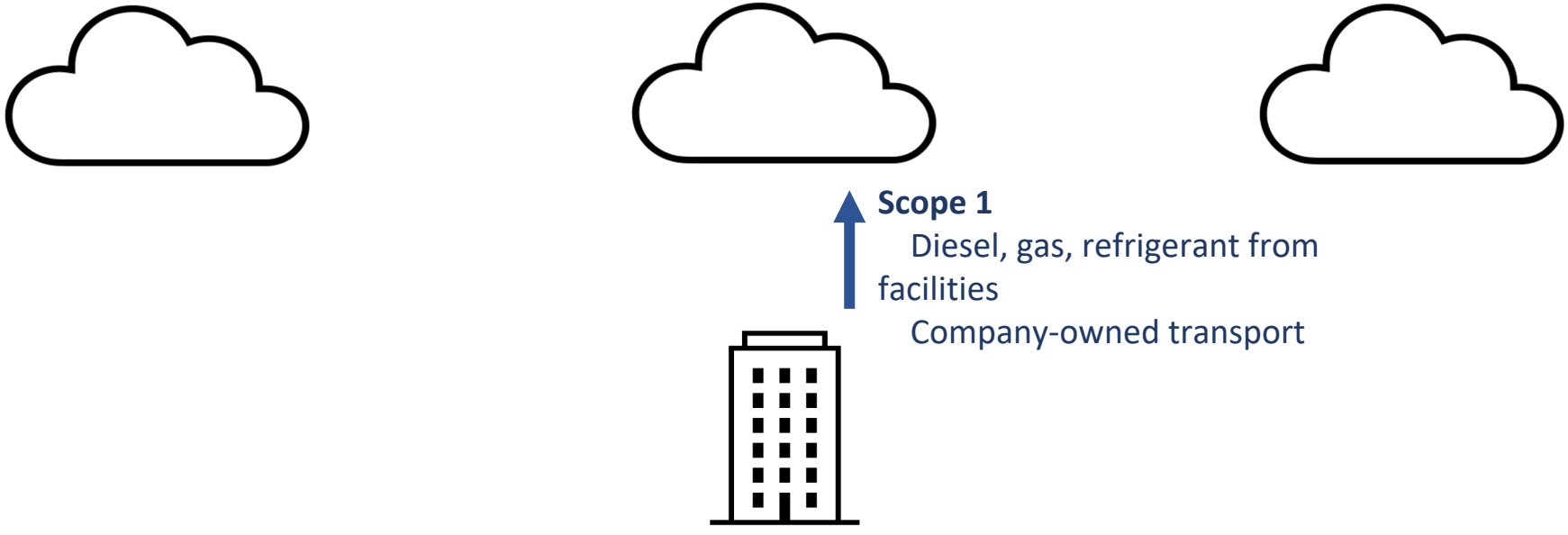
Greenhouse gas (GHG) Protocol





Technology company

Greenhouse gas (GHG) Protocol



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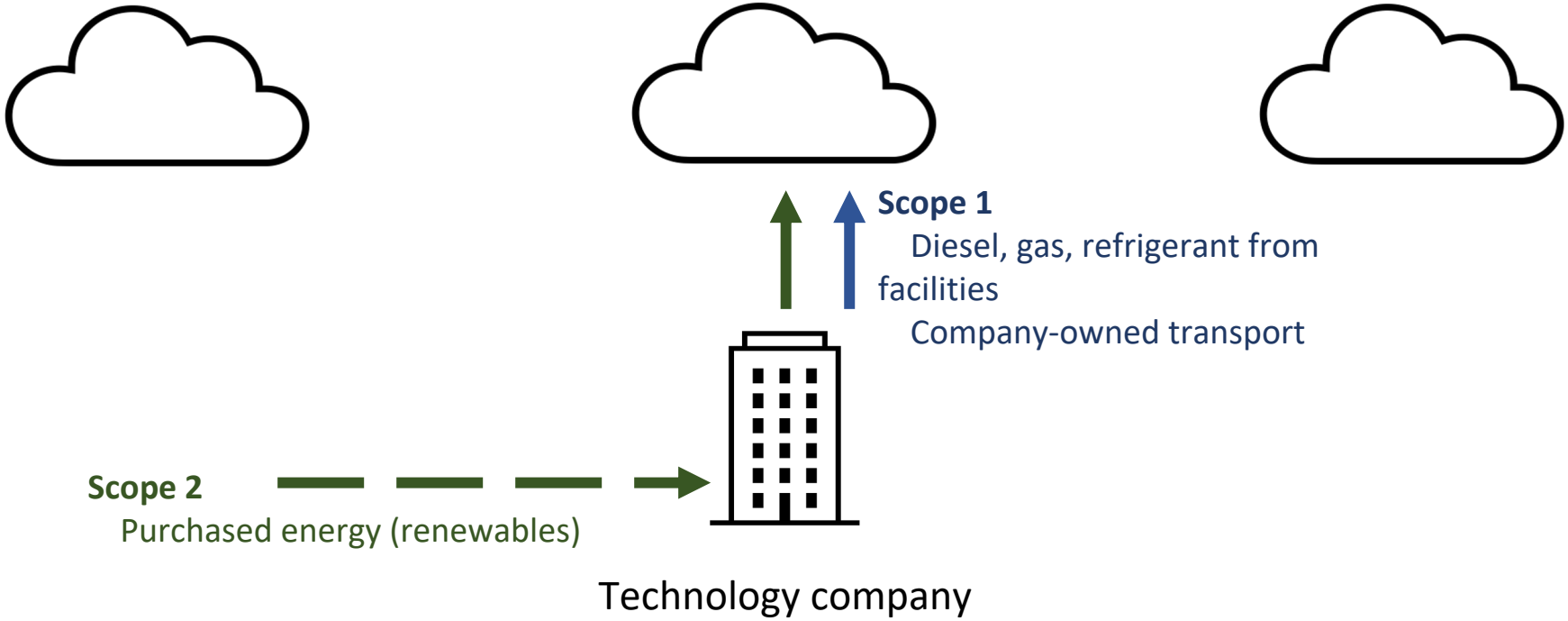

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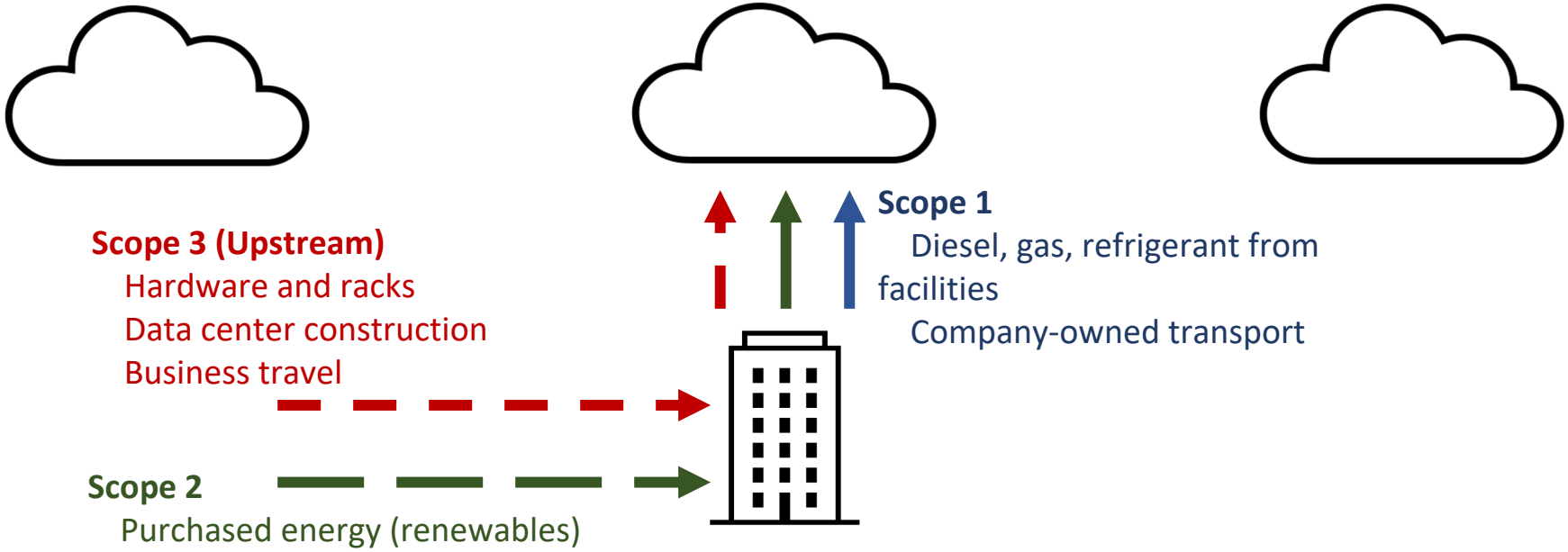

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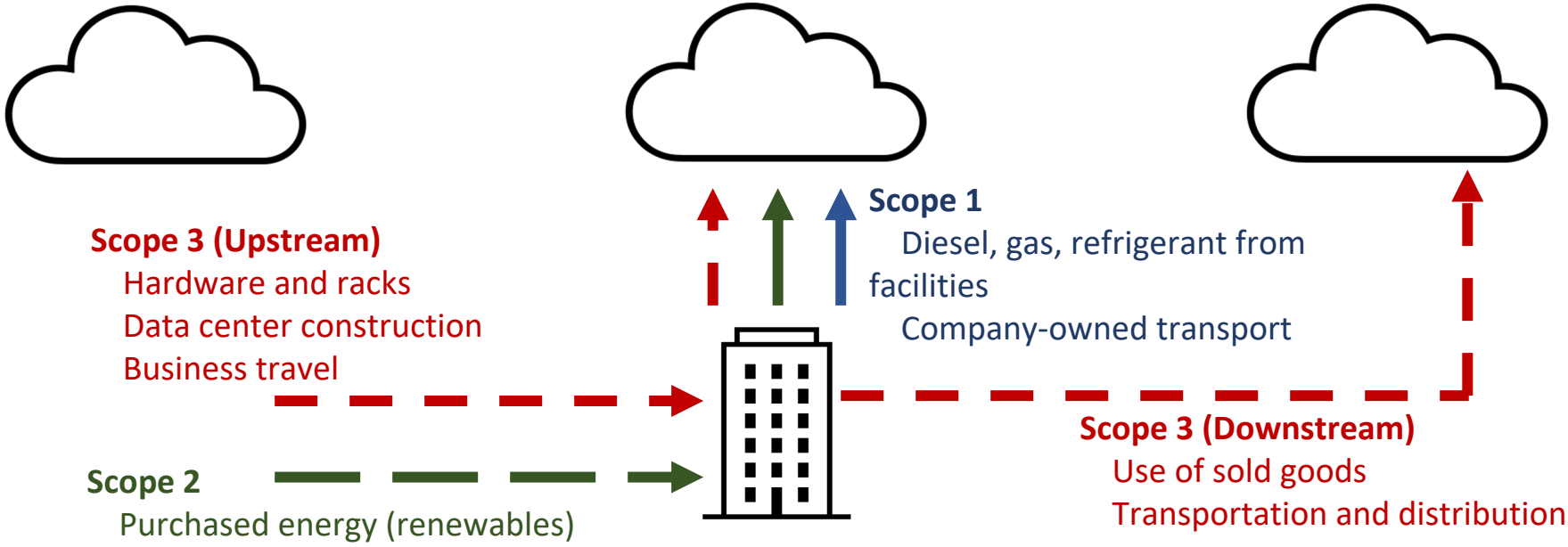

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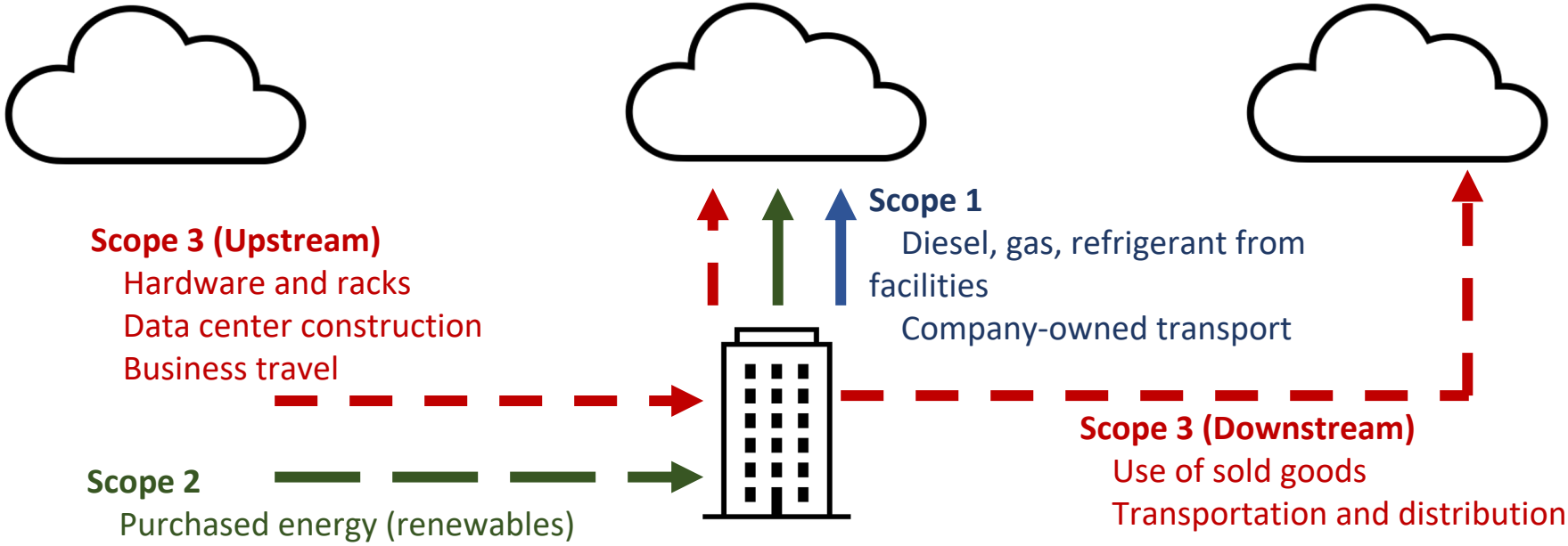
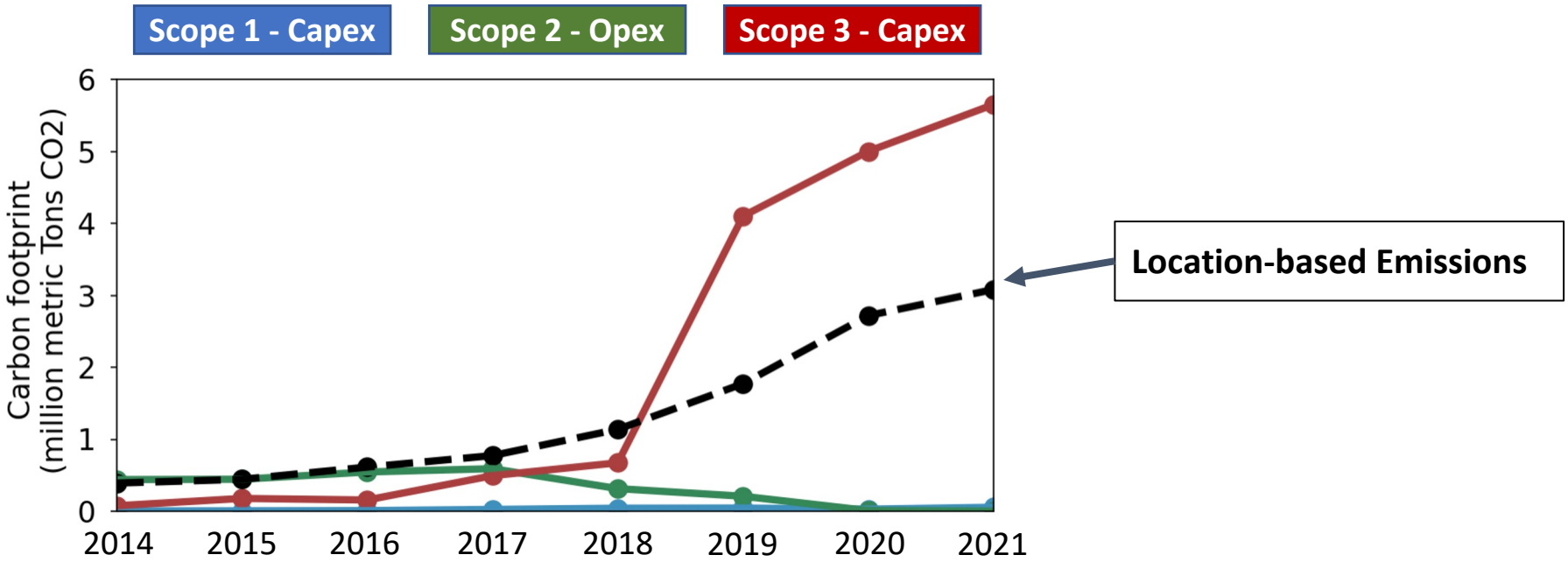


Scope 2 emissions come from *opex-related* activities
Scope 1 and Scope 3 emissions come from *capex-related* activities

Historical analysis of Facebook's carbon footprint



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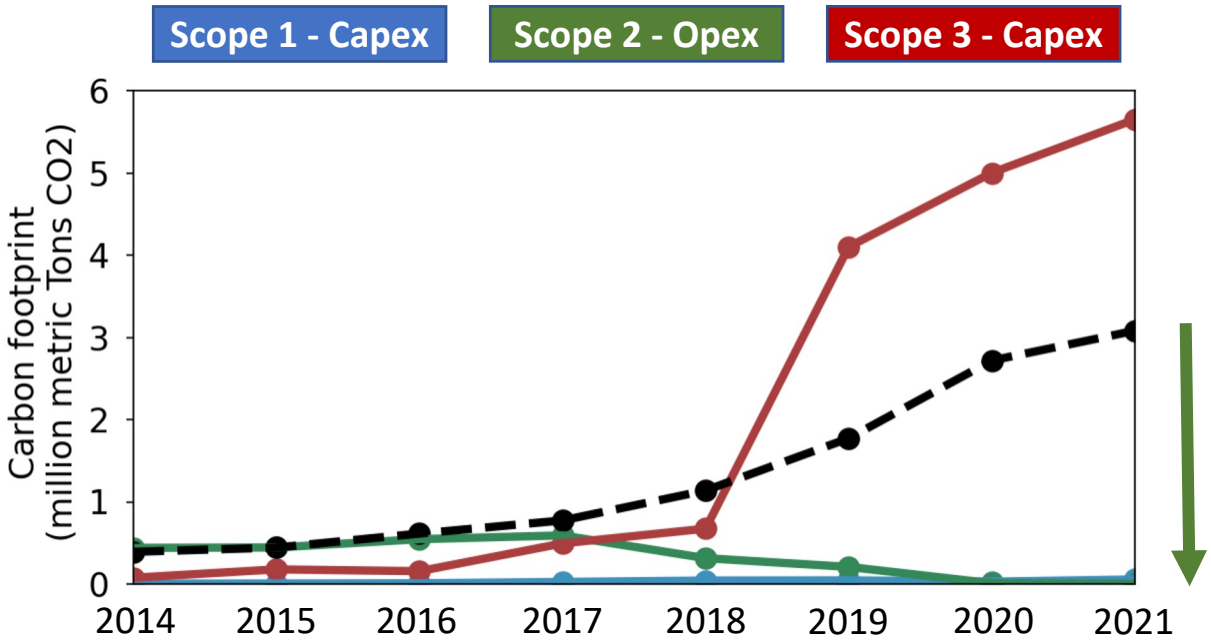

Impact of renewable energy in data centers

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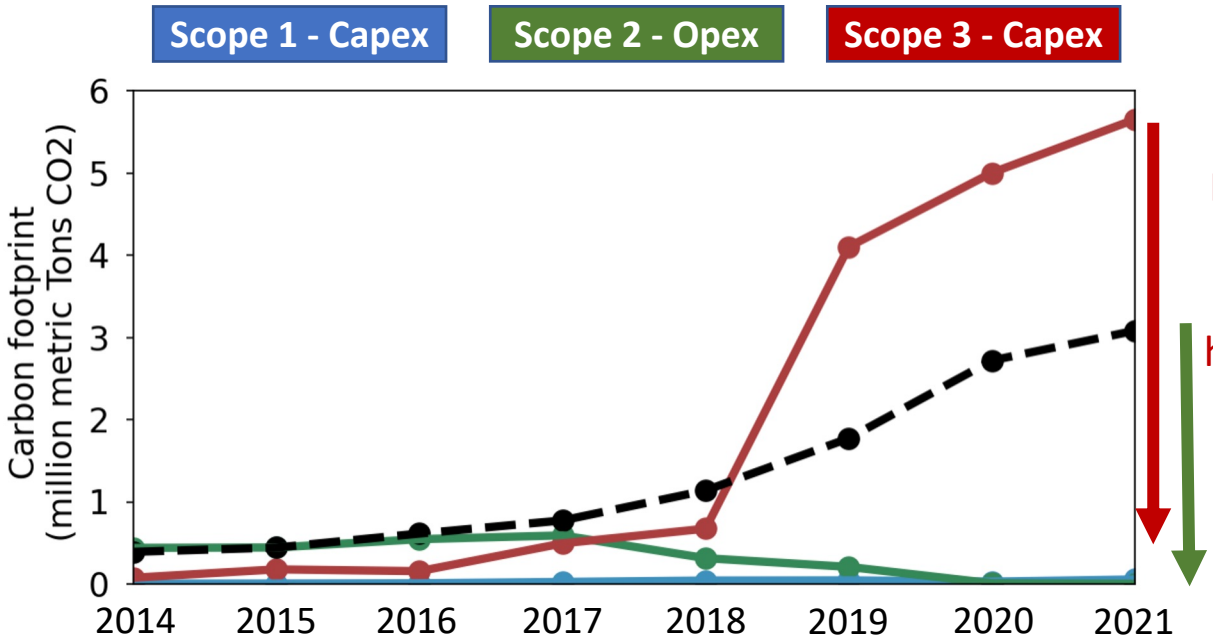

Scope 3 (capex) dominates Facebook's carbon emissions.

49% of Scope 3 comes from hardware, infrastructure, data center construction

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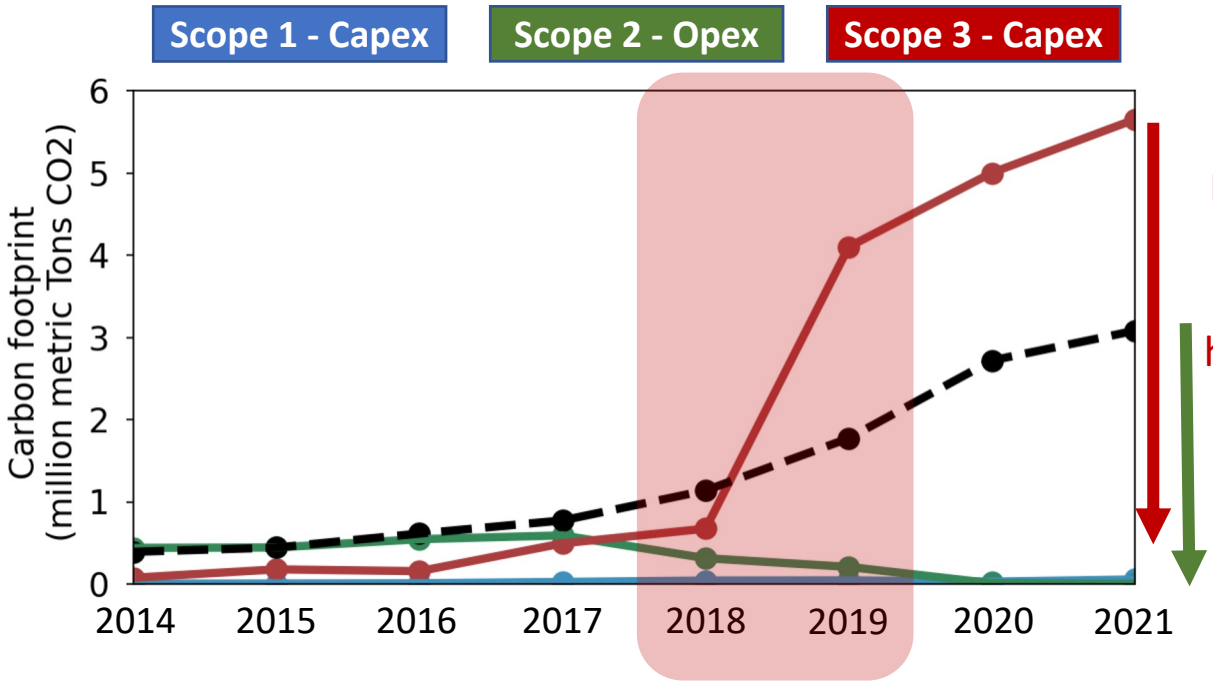

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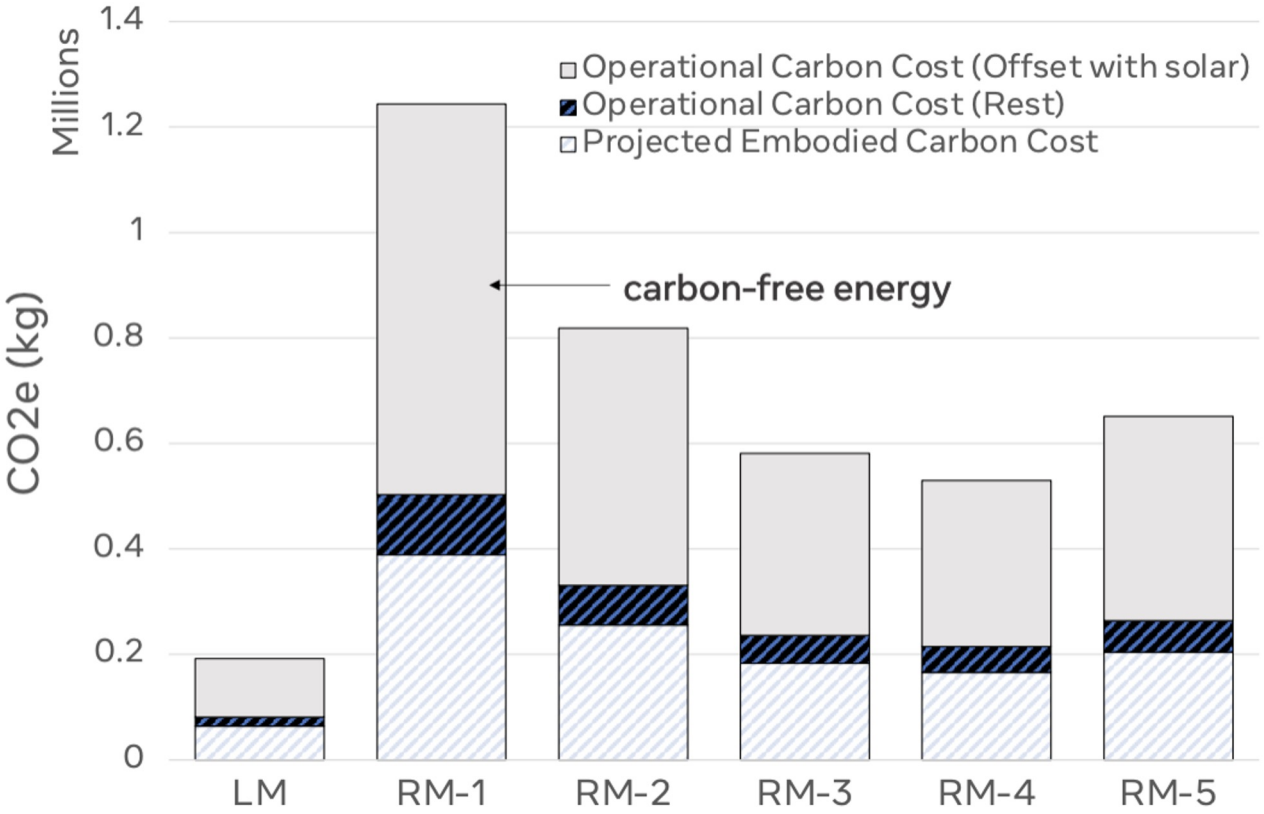
Crucial to look at emissions across HW cycle



Economic incentives and carbon sequestration

How Microsoft is using an internal carbon fee to reach its carbon negative goal

March 24, 2022 • 2 min read

Share

Elizabeth Willmott

Carbon Program Director, Microsoft

Thought leadership, Sustainability

Microsoft: **$100/tCO2e** to incentivize reductions

- Projecting future *annual* cost of over **$1 billion**

Google: Estimates **$50-$300/tCO2e** as carbon sequestration scales up to **20%** of the cost of a server!

https://cloudblogs.microsoft.com/industry-blog/sustainability/2022/03/24/how-microsoft-is-using-an-internal-carbon-fee-to-reach-its-carbon-negative-goal/
https://www.youtube.com/watch?v=W7uTbxCxmPg

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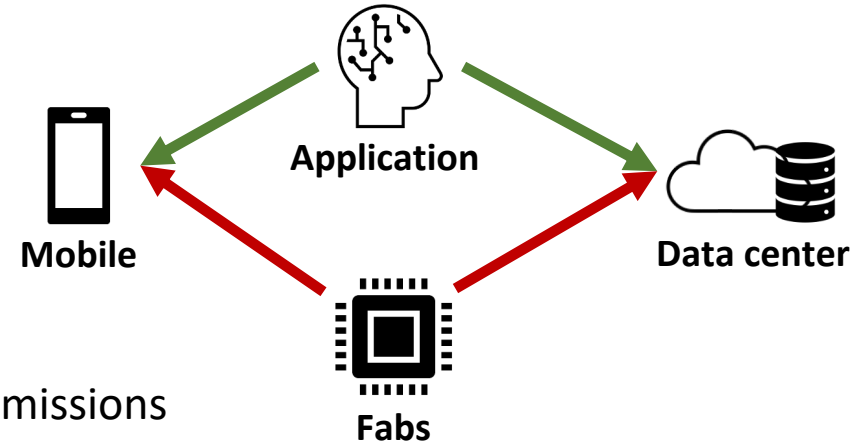

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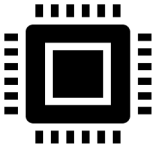
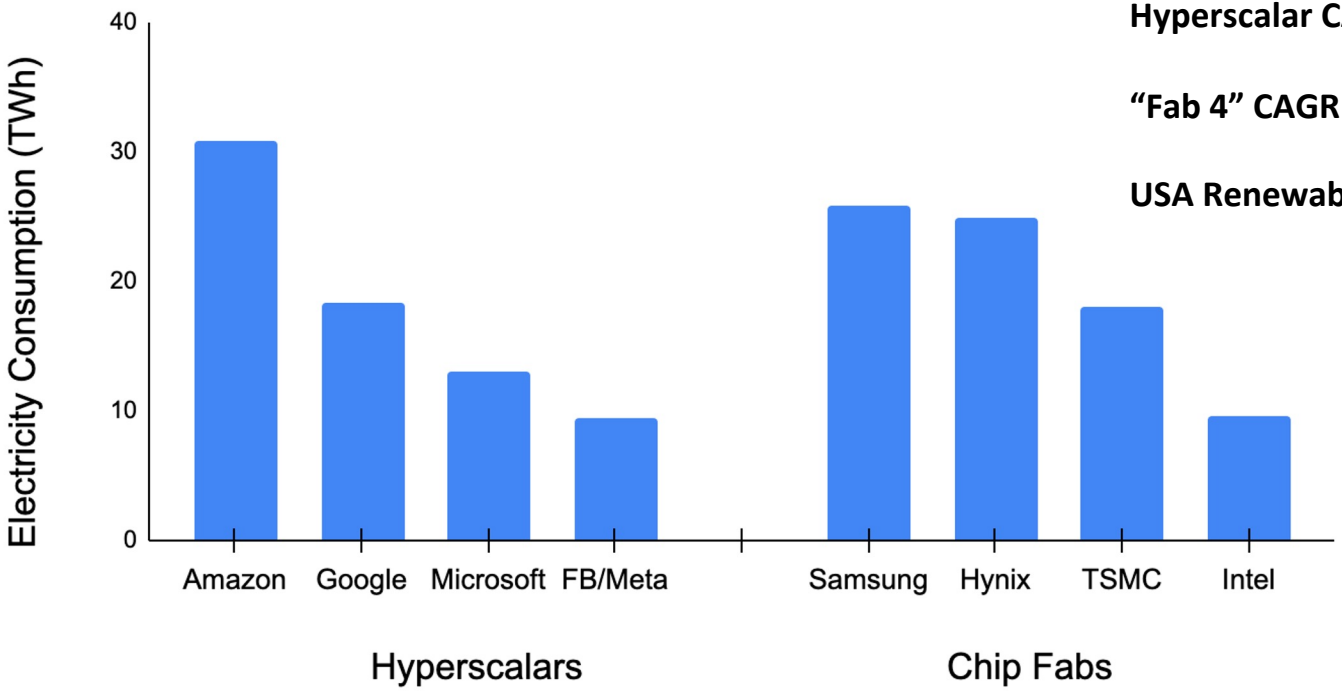


Understanding the breakdown of semiconductor manufacturing

Chip manufacturing is energy intensive



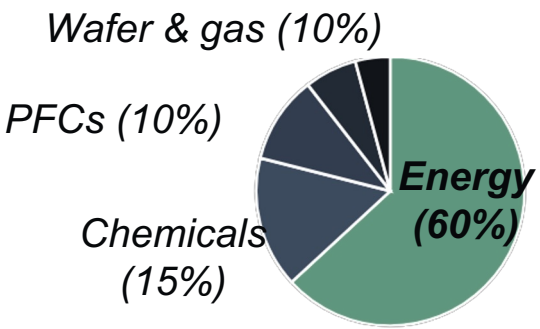
Hyperscalar CAGR 25% since 2015

“Fab 4” CAGR 11% since 2015

USA Renewables CAGR 7% since 2015

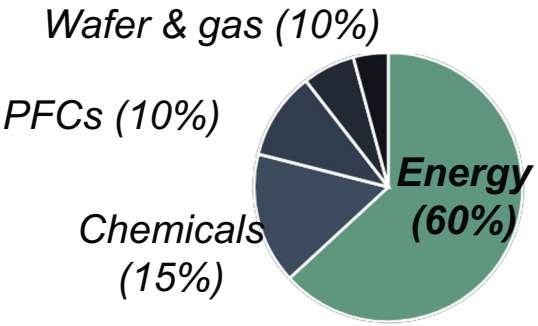
Source: 2021 corporate sustainability reports

Semiconductor fab

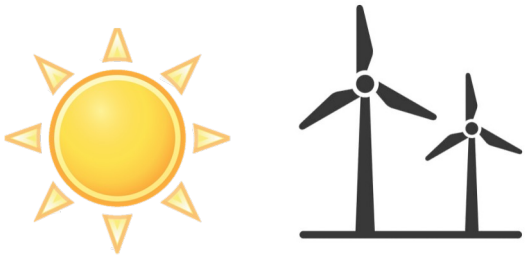


Gupta et. al. Chasing Carbon: The Elusive Environmental Footprint of Computing (HPCA 2021)

Semiconductor fab



***100% Renewable** powered semiconductor fab*



*Reduces manufacturing footprint by **2.5x***

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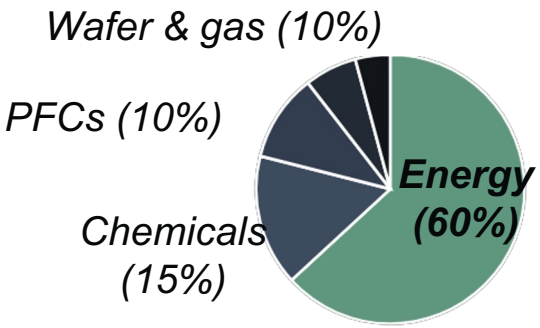
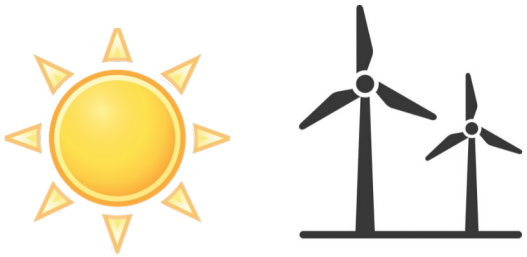
“Green” powered fabs are not enough

Semiconductor fab



TSMC plans for
25% renewable by 2025 and
100% renewable by 2050.

***100% Renewable** powered semiconductor fab*



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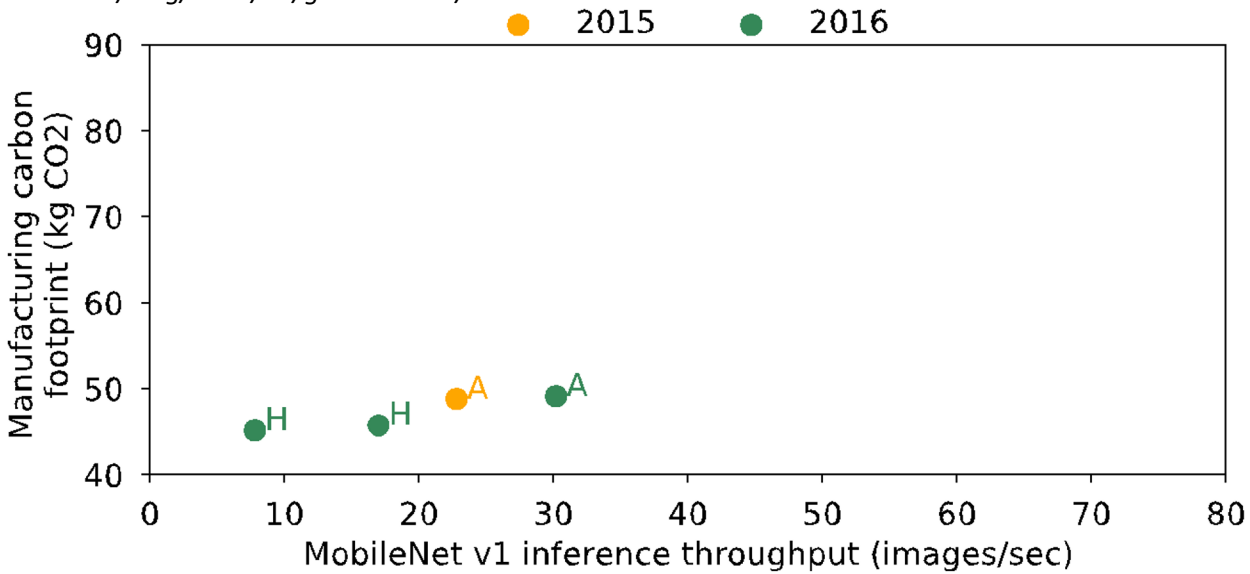
We must elevate carbon as a first order design target and constraint alongside performance, power, energy, and area

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

Performance versus manufacturing footprint

Data from industry (Apple, Google, Huawei) life cycle analyses and GeekBench performance measurements
https://www.geekbench.com/blog/2019/09/geekbench-5/



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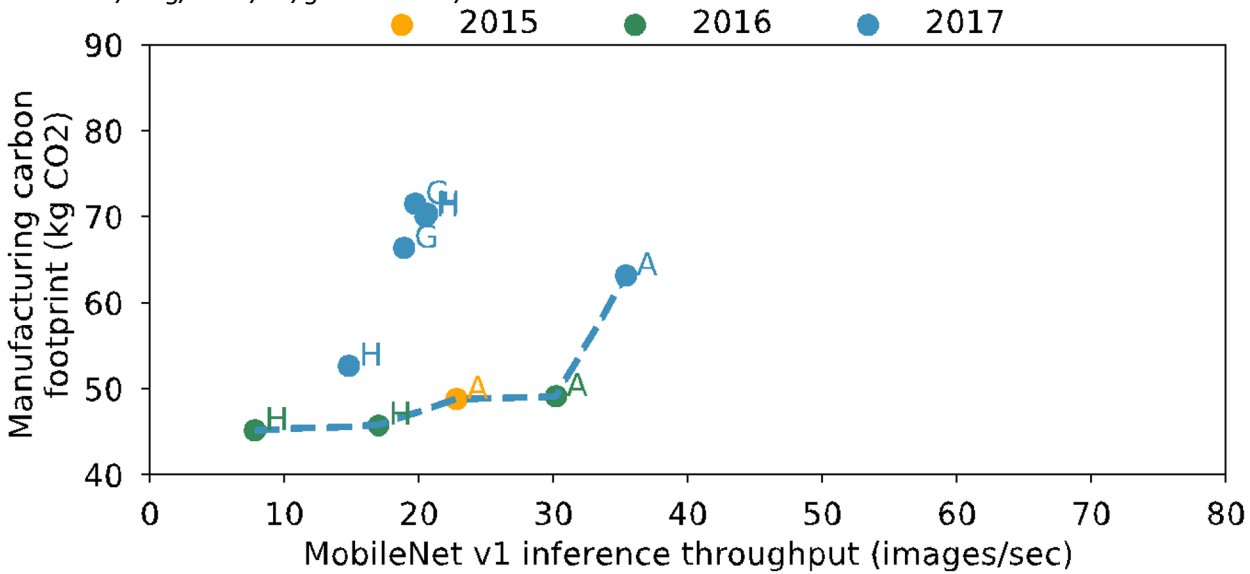

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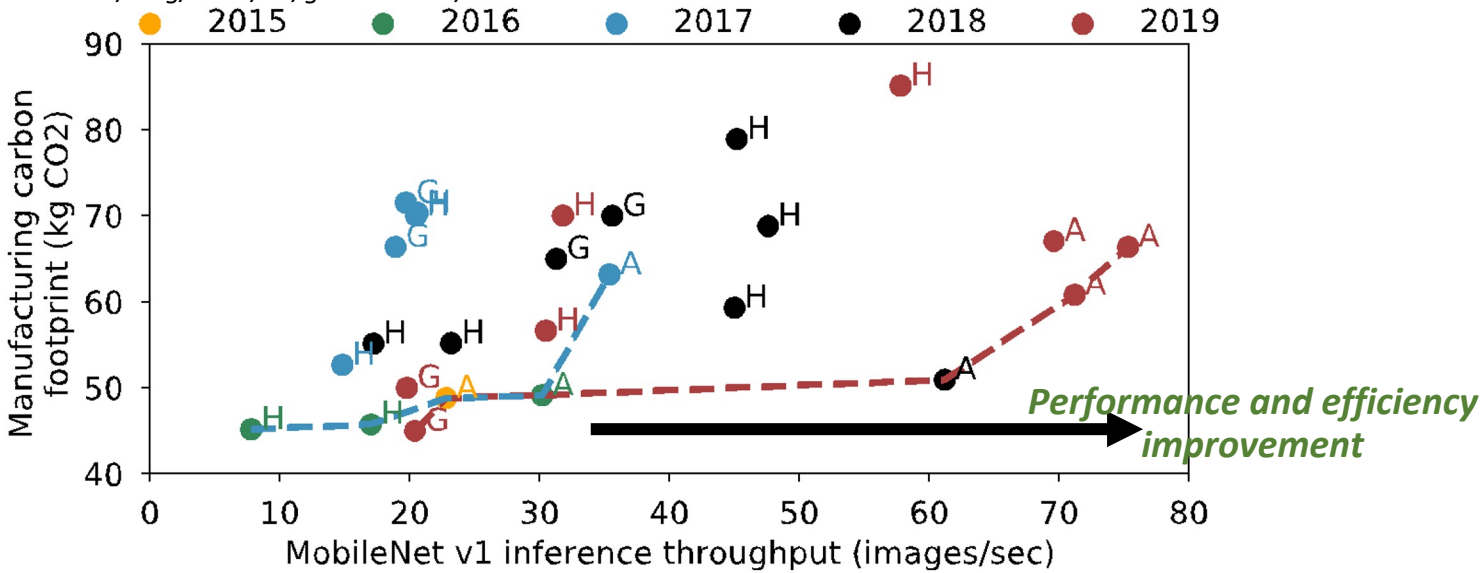

Between 2017 and 2019 the Pareto frontier has shifted to the right prioritizing performance.

Designing sustainable systems requires shifting the frontier down.

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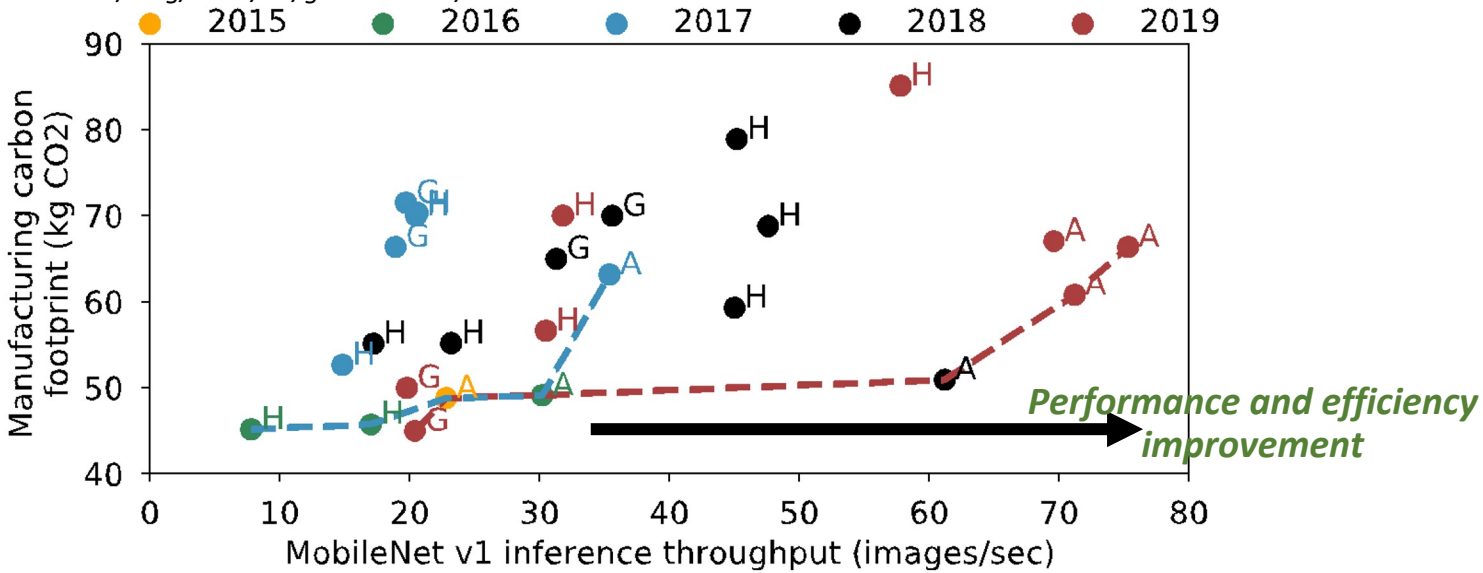

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