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

Tackling computing's carbon footprint requires optimizing emissions across ***hardware life cycles*** (manufacturing and operational use)

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But (unlike performance, power, energy) there is a distinct lack of architectural tools and infrastructure to quantify carbon

Challenge: How do we design sustainable systems by considering the footprint across lifecycles

This work: Architectural Carbon Modeling Tools (ACT)

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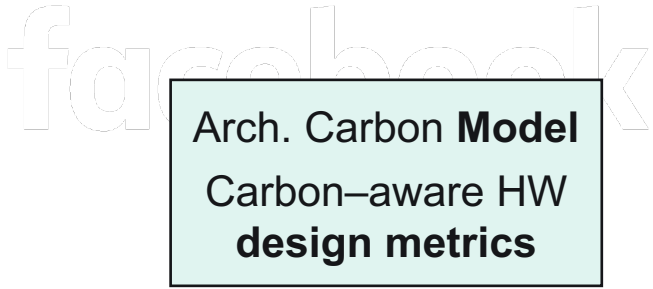

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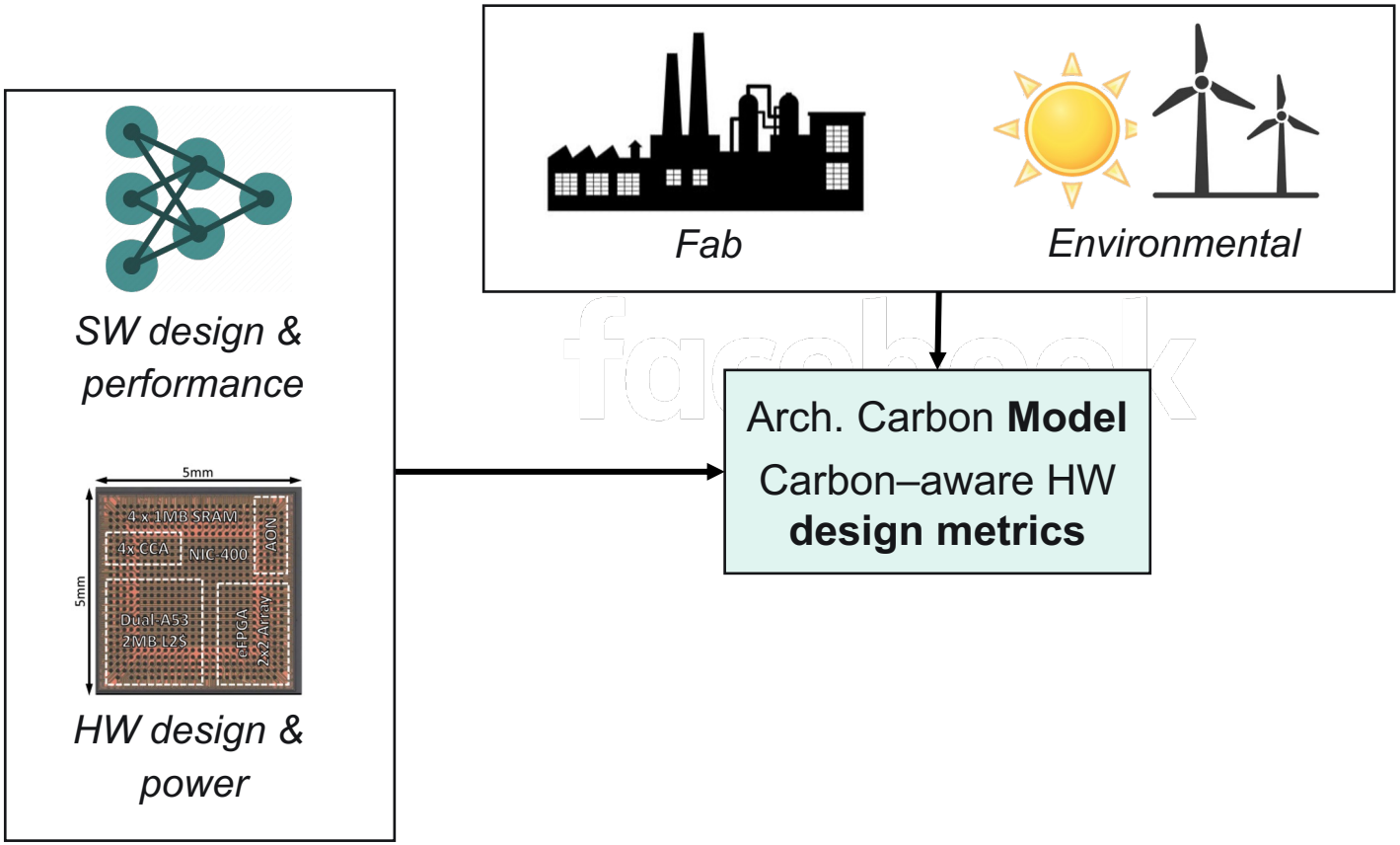

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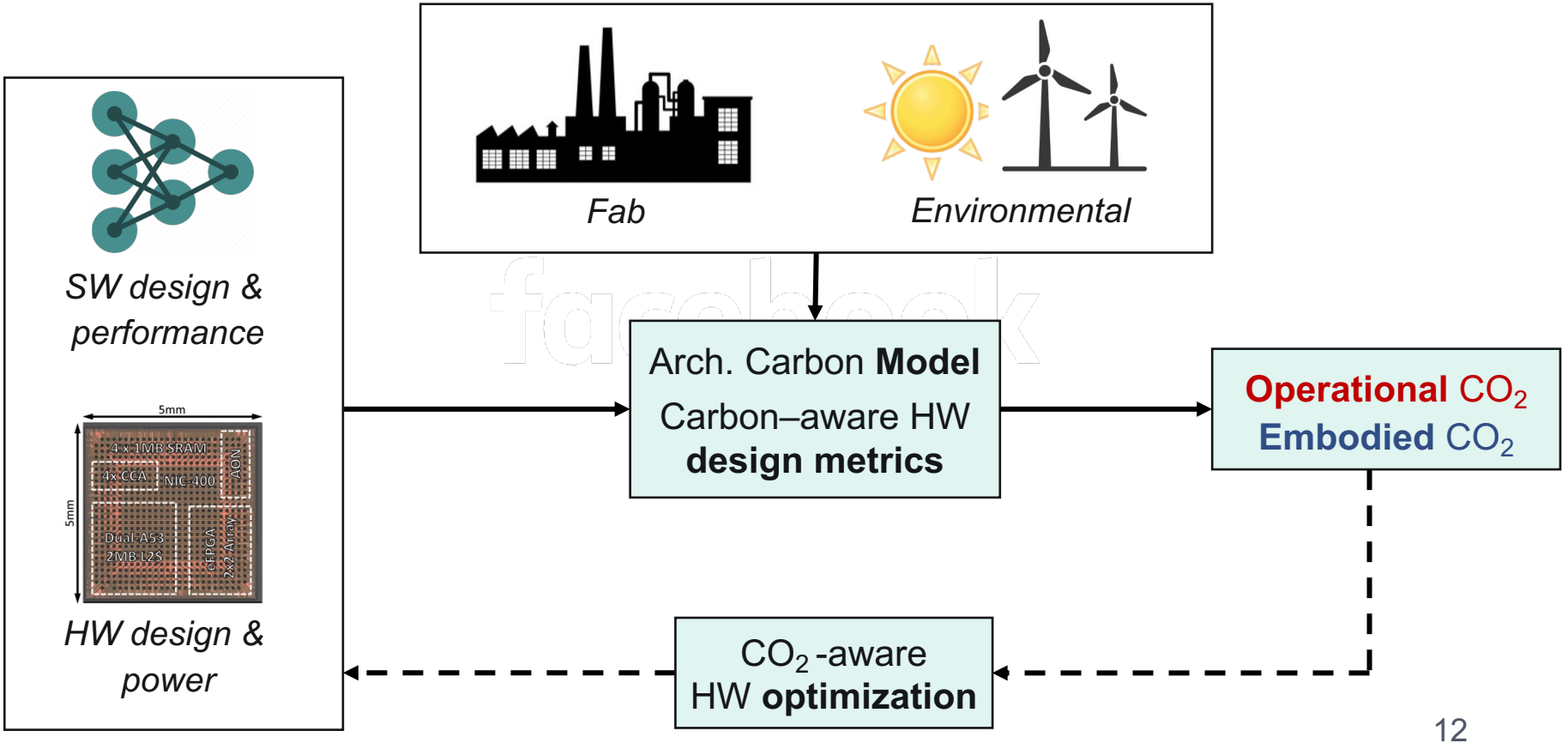

Architectural Carbon Model

Model	Hardware/software input

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$Carbon = OP_{CF} + \frac{Runtime}{Lifetime} Emb_{CF}$	**Performance/power/energy** and **lifetime** of hardware

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Architectural Carbon Model

Model	Hardware/software input
$Carbon = OP_{CF} + \frac{Runtime}{Lifetime} Emb_{CF}$	**Performance/power/energy** and **lifetime** of hardware
$OP_{CF} = CI_{use} \times Energy$	**Energy efficiency** and environment (**carbon intensity**)
$Emb_{CF} = Packaging + \sum_{r}^{SoC,Memory,Storage} Emb_r$	Overhead of **hardware manufacturing**

Embodied carbon of application processors (SoC's)

$$Emb_{soc} = Area \times \frac{\left(CI_{fab} \times Fab_{energy}\right) + Fab_{gasses} + Fab_{materials}}{Yield}$$

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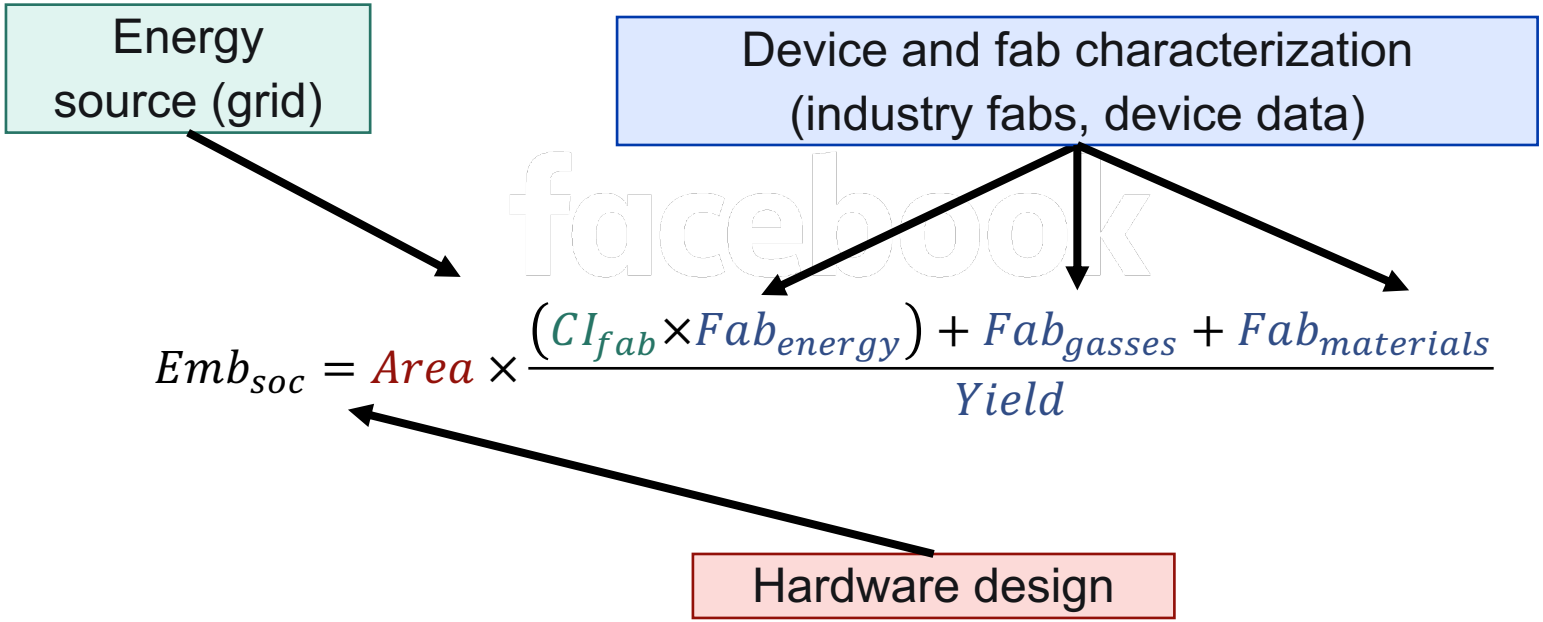

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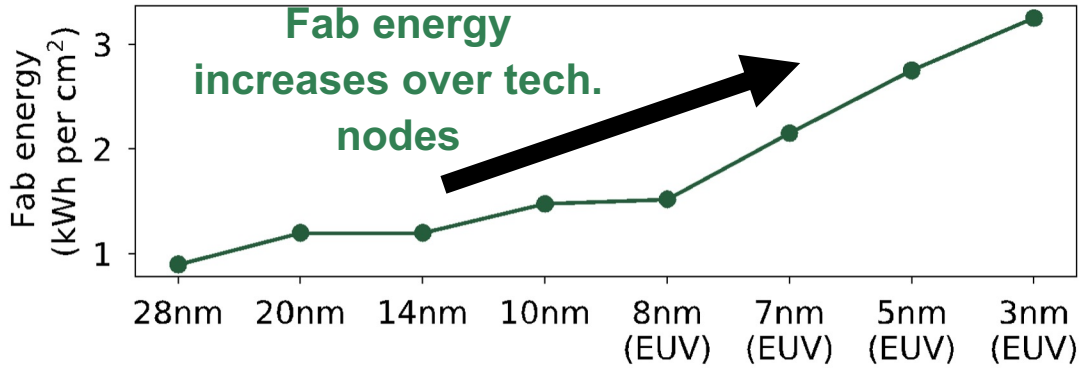

DTCO including Sustainability: Power-Performance-Area-Cost-Environmental score (PPACE) Analysis for Logic Technologies. Bardon et. al (IEDM 2020)

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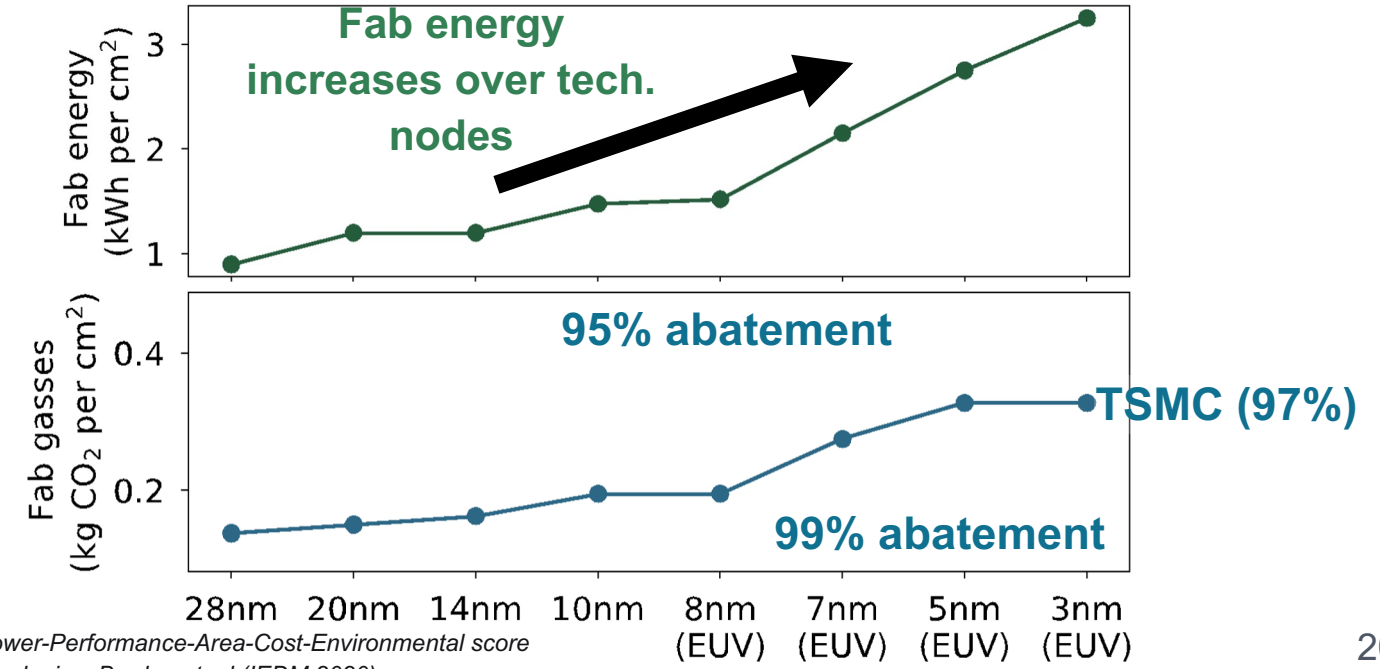

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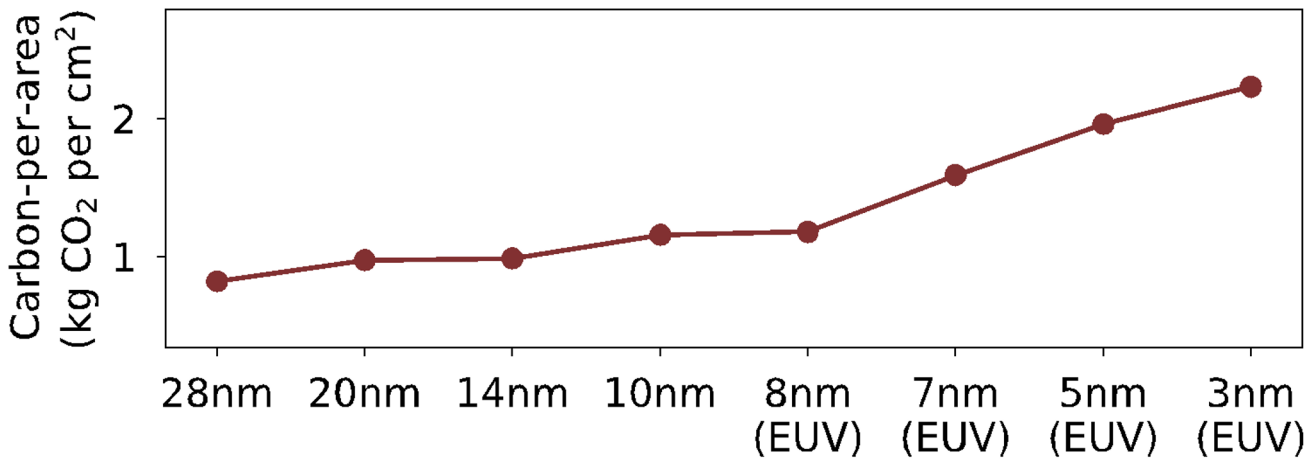

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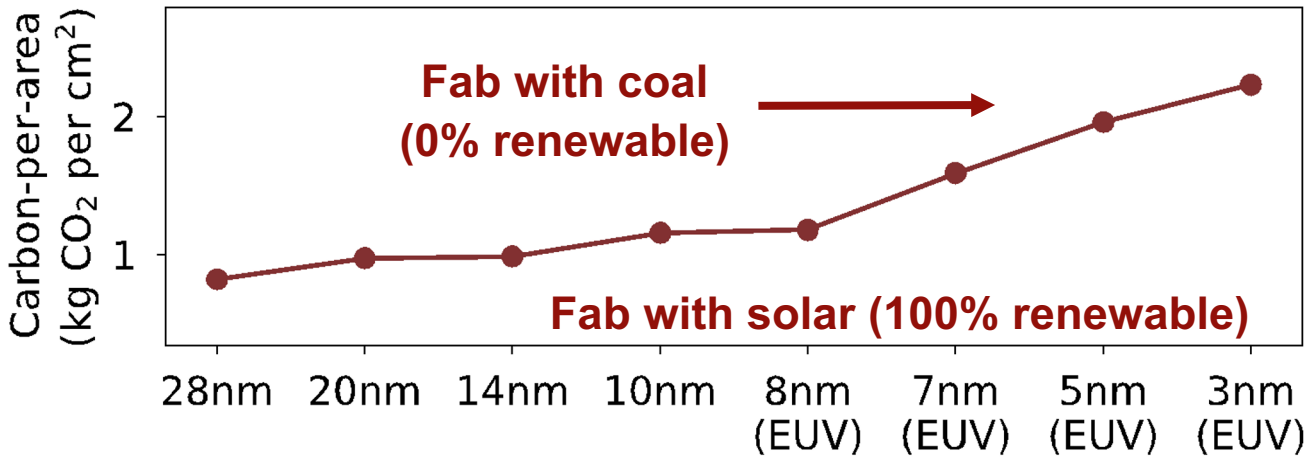

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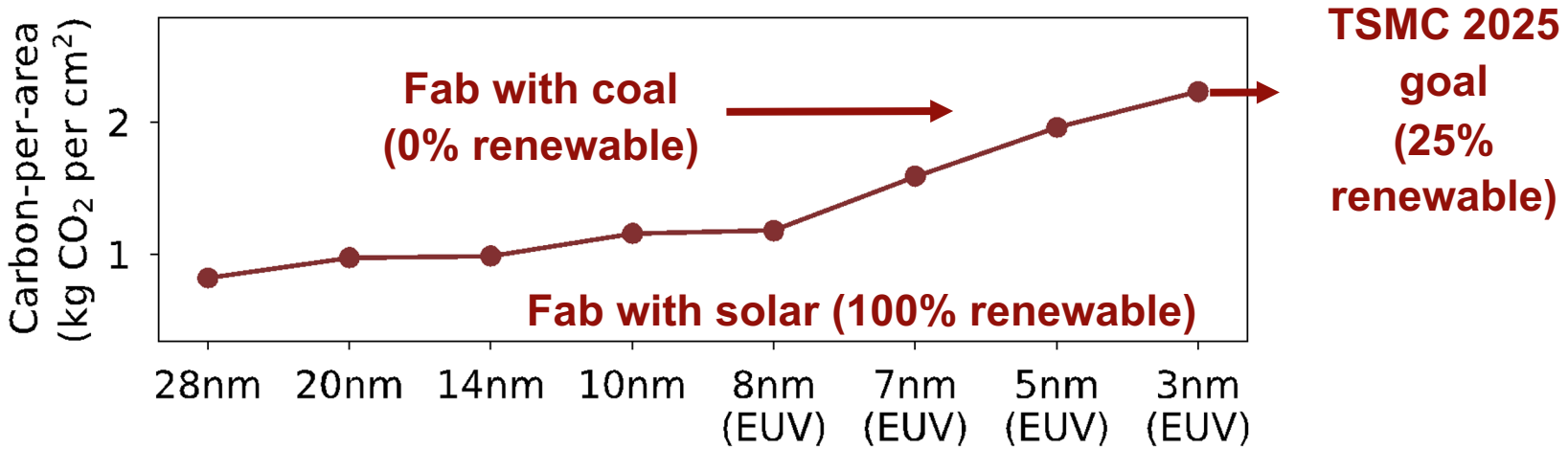

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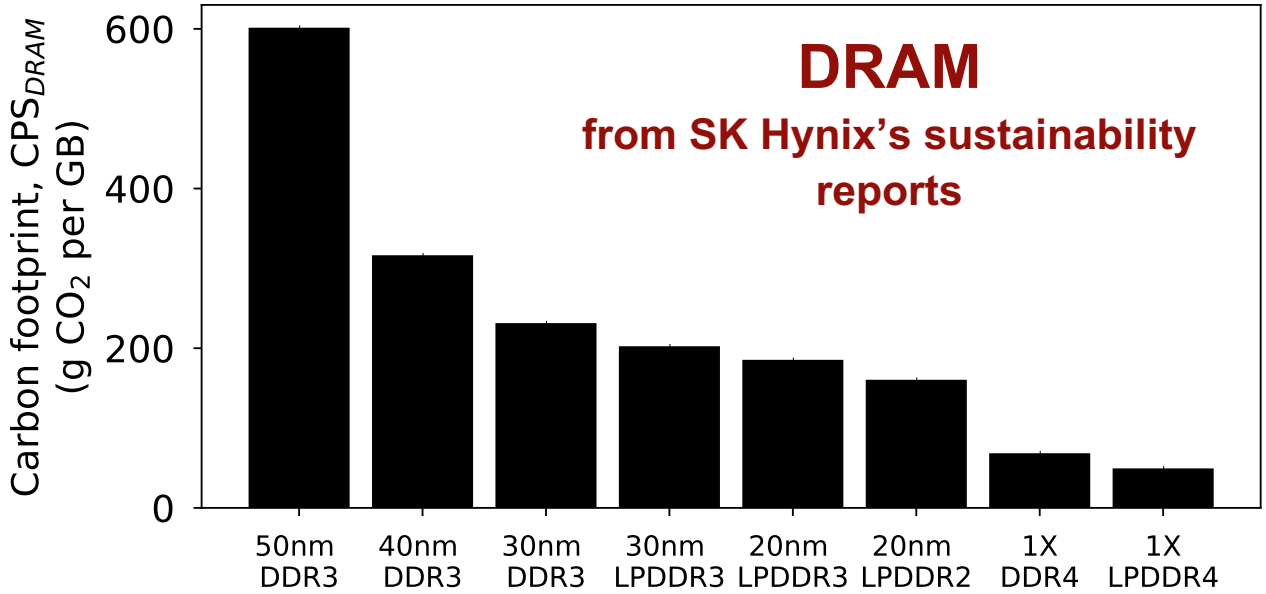
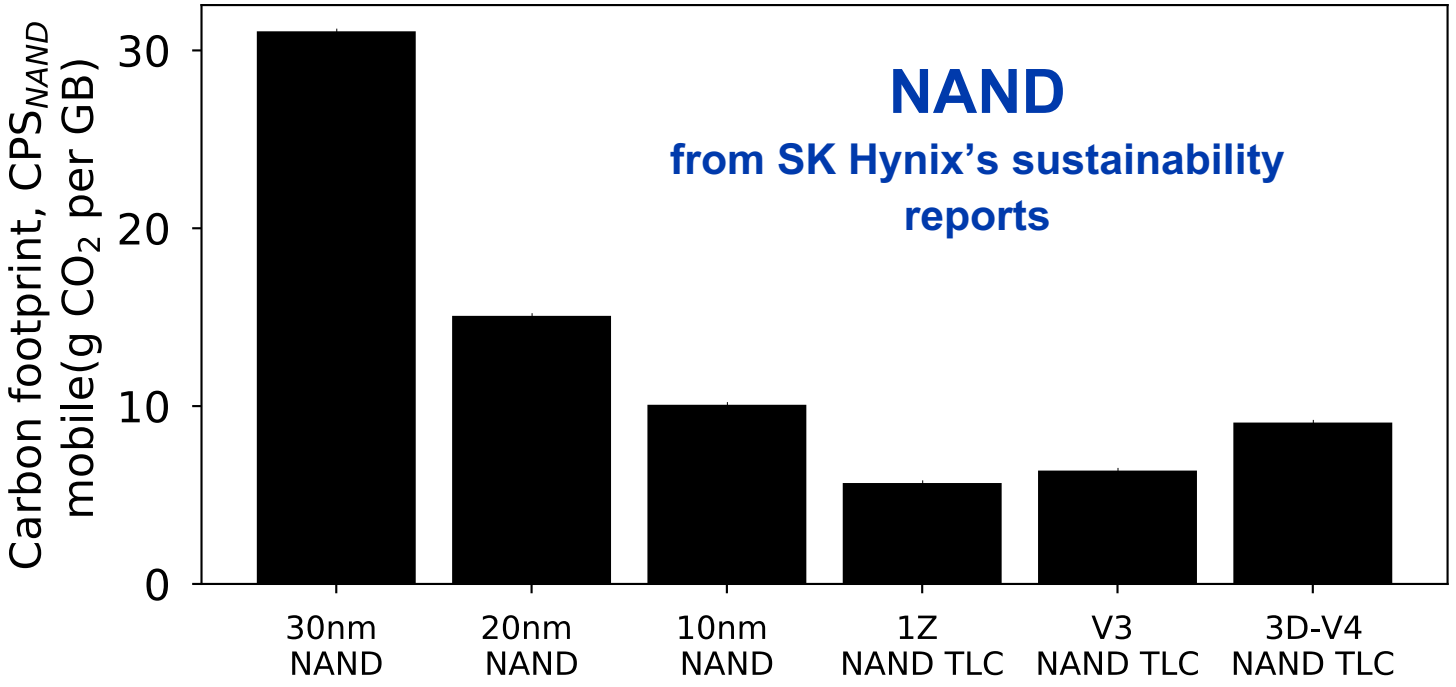
Embodied carbon of DRAM memory

$$Emb_{DRAM} = DRAM_{capacity} \times CPS_{DRAM}$$



Embodied carbon of NAND Flash storage

$$Emb_{SSD} = SSD_{capacity} \times CPS_{SSD}$$



Embodied carbon of HDD storage

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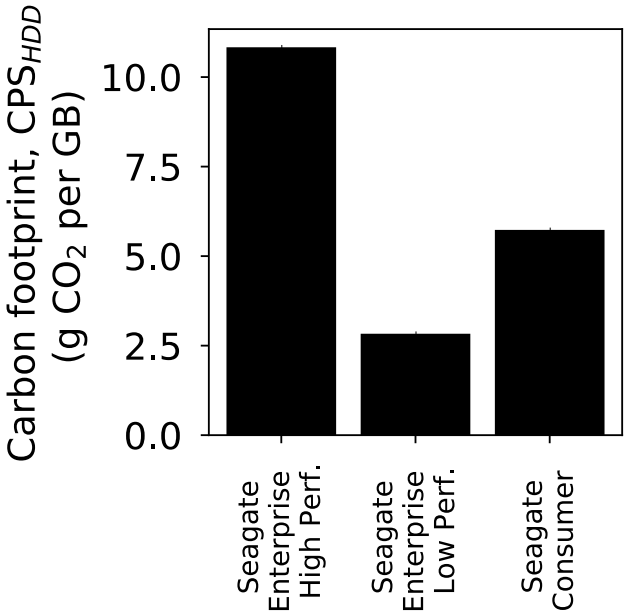

HDD

from Seagate's product environmental reports

Additional details found in the paper…

ACT parameters

Parameter	Description	Range
T	App. execution time	From SW profiling
LT	HW lifetime	1-10 years
N_r	Number of ICs	From HW design
K_r	IC packaging footprint	0.15 kg CO_2
A	IC Area	From HW design (cm^2)
p	Process node	3-28 nm
MPA	Procure materials	~0.50kg CO_2 per cm^2
EPA	Fab energy	0.8-3.5 kWh per cm^2
CI_{use}	HW CO_2 intensity	30-700 g CO_2 per kWh
CI_{fab}	Fab CO_2 intensity	30-700 g CO_2 per kWh
GPA	GHG from fab	0.1-0.5 kg CO_2 per cm^2
Y	Fab yield	0-1
CPA	CO_2 from fab	0.1-0.4 kg CO_2 per cm^2
E_{DRAM}	DRAM embodied CO_2	0-0.6 kg CO_2 per GB
E_{SSD}	SSD embodied CO_2	0-0.03 kg CO_2 per GB
E_{HDD}	HDD embodied CO_2	0-0.12 kg CO_2 per GB

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Overview of ACT

Comparing ACT to other methodologies

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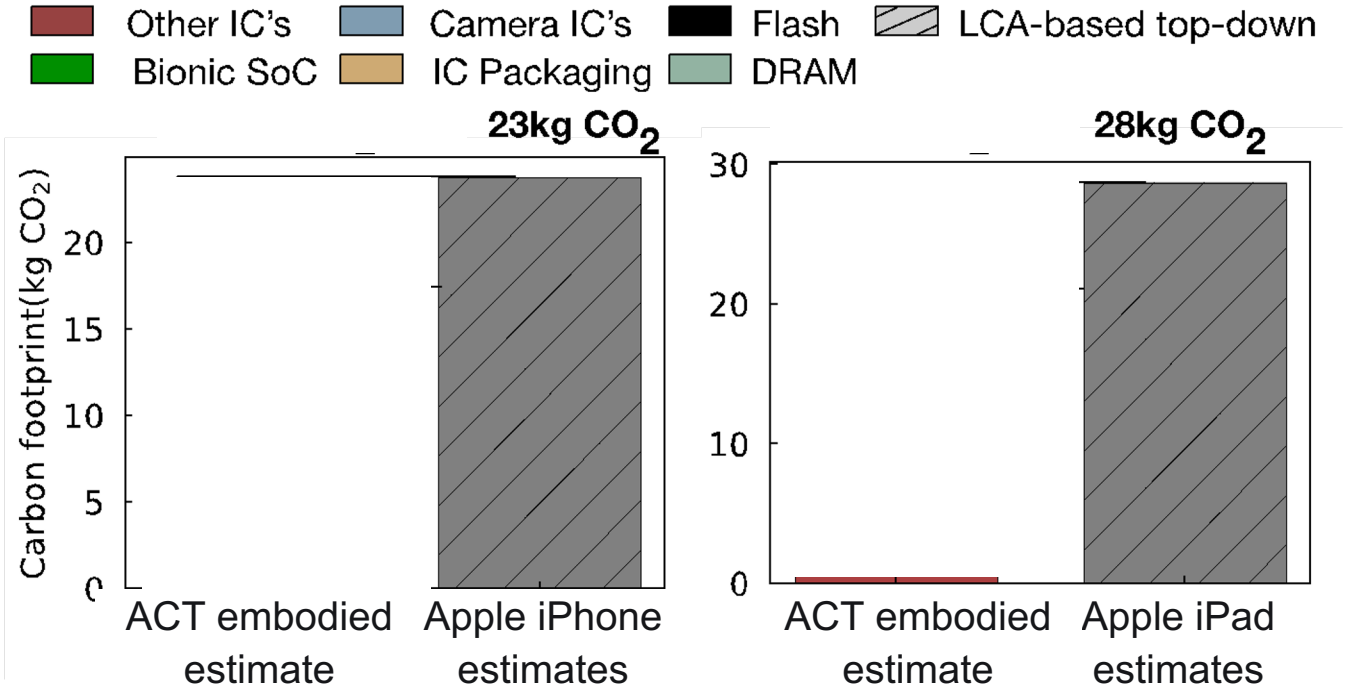
Current carbon accounting methodologies

	Description	Limitation
EIO (Economic Input/Output)	A cost-based methodology to translate component price into embodied carbon footprint	Carbon is tied directly to economic cost which is susceptible to various market effects.
Life Cycle Analysis-based tools	A database-based methodology to quantify systems' embodied emissions	Current databases are out-of-date (45nm or older technology). LCA expert take high $$ and time to conduct new system analysis.
Exergy-based analysis	A methodology based on evaluating the thermodynamic energy in devices	Does not translate directly to carbon emissions. Original exergy analyses are out-of-date.

Comparing ACT with Apple's product environmental reports



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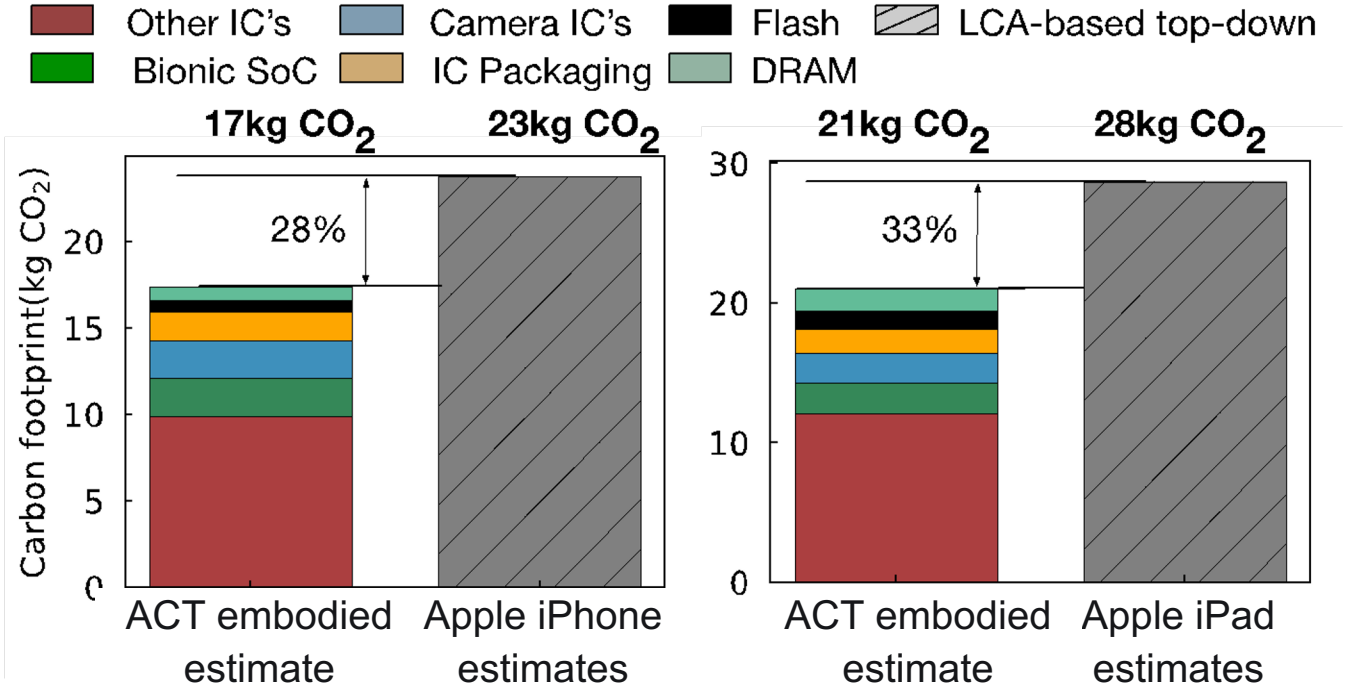

More comparisons (ACT vs. LCA's) in the paper…

	ACT vs. Dell R740 server LCA	ACT vs. Fairphone 3 mobile device LCA

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IC component	ACT vs. Dell R740 server LCA	ACT vs. Fairphone 3 mobile device LCA
Compute (processors, SoC's)	Within 2.2x	Within 1.18x
Memory	Within 1.62x	Within 2.1x
Storage	Within 1.05-2.2x	

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

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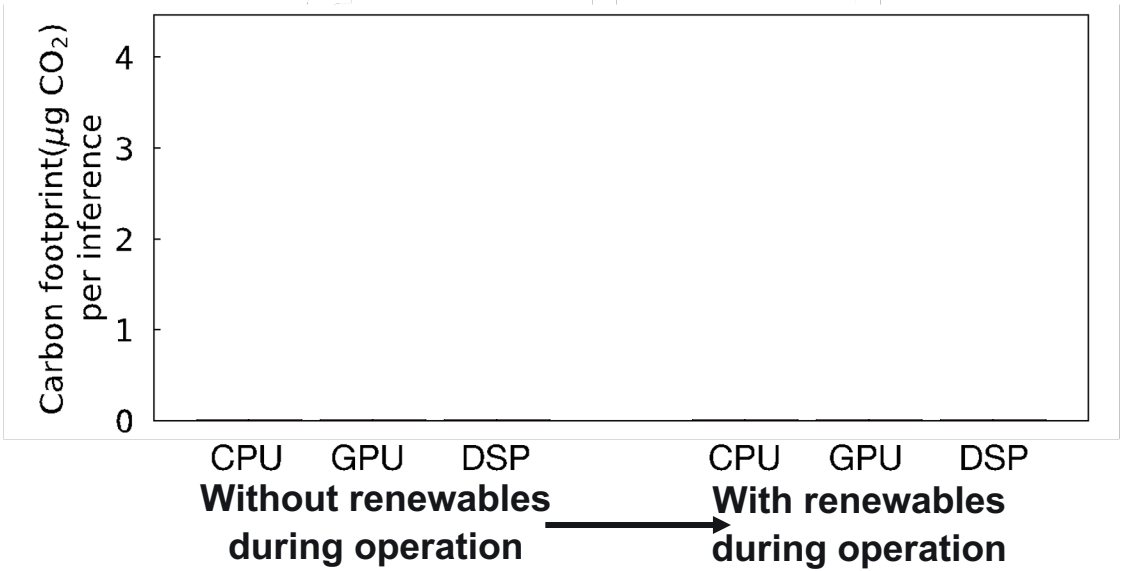
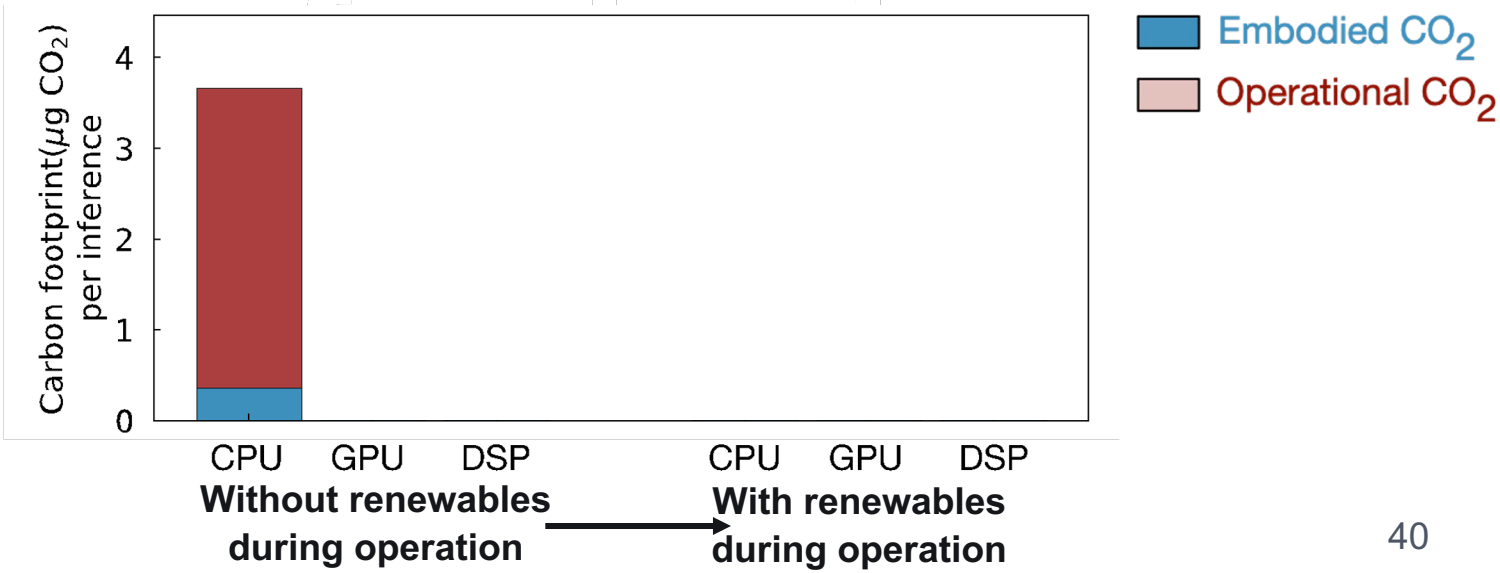


Reuse: General purpose versus custom mobile HW

AI inference case study (MobileNet) assuming 3 year hardware lifetime, and same utilization in all cases

Commodity (mobile CPU)
Specialized (mobile GPU, DSP)
→ **Architectural Carbon Model** → Carbon per inference



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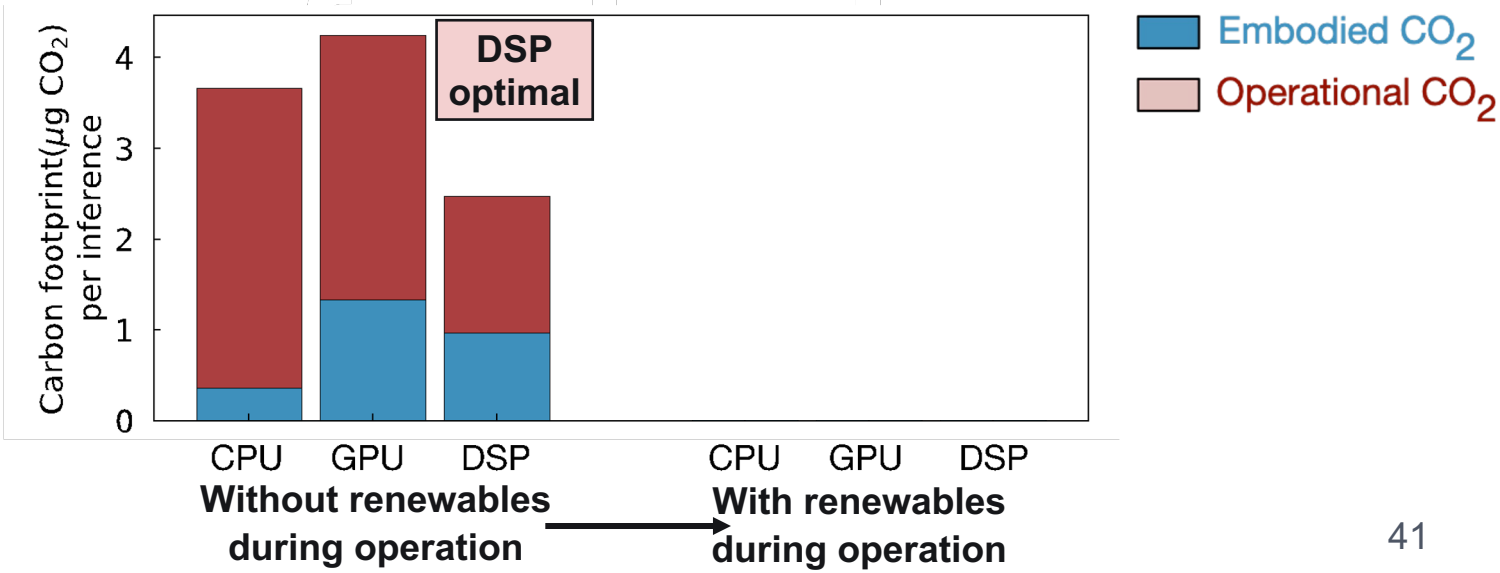

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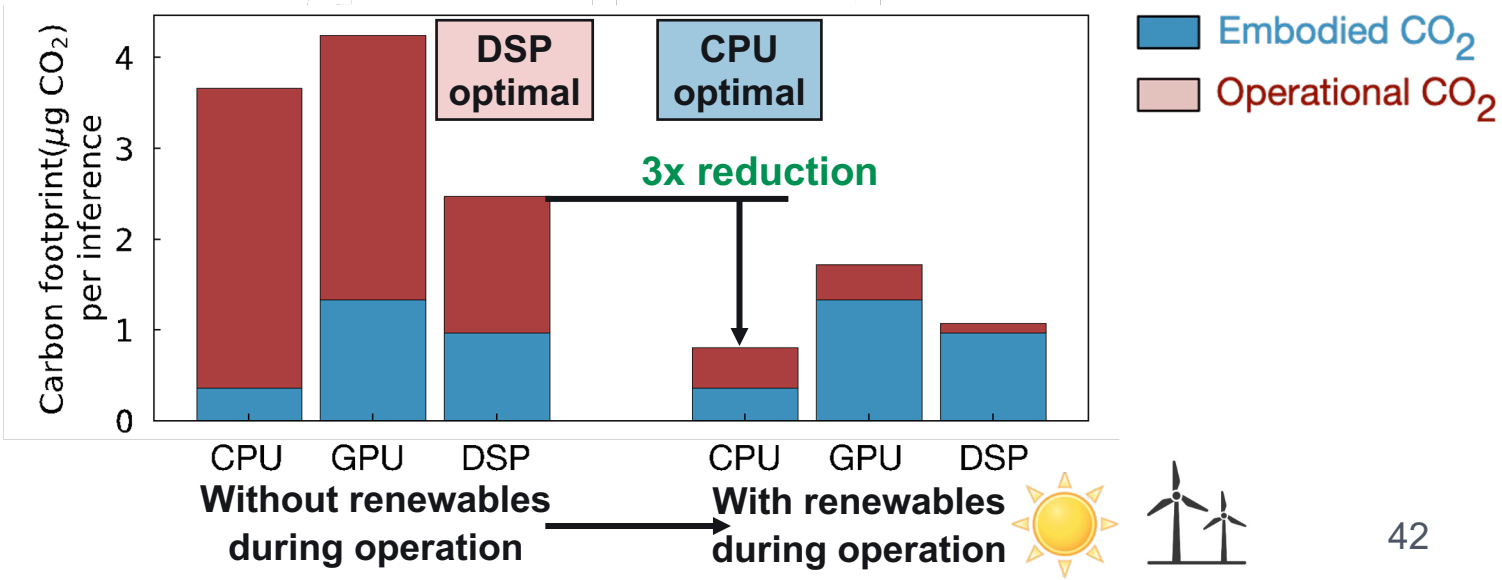

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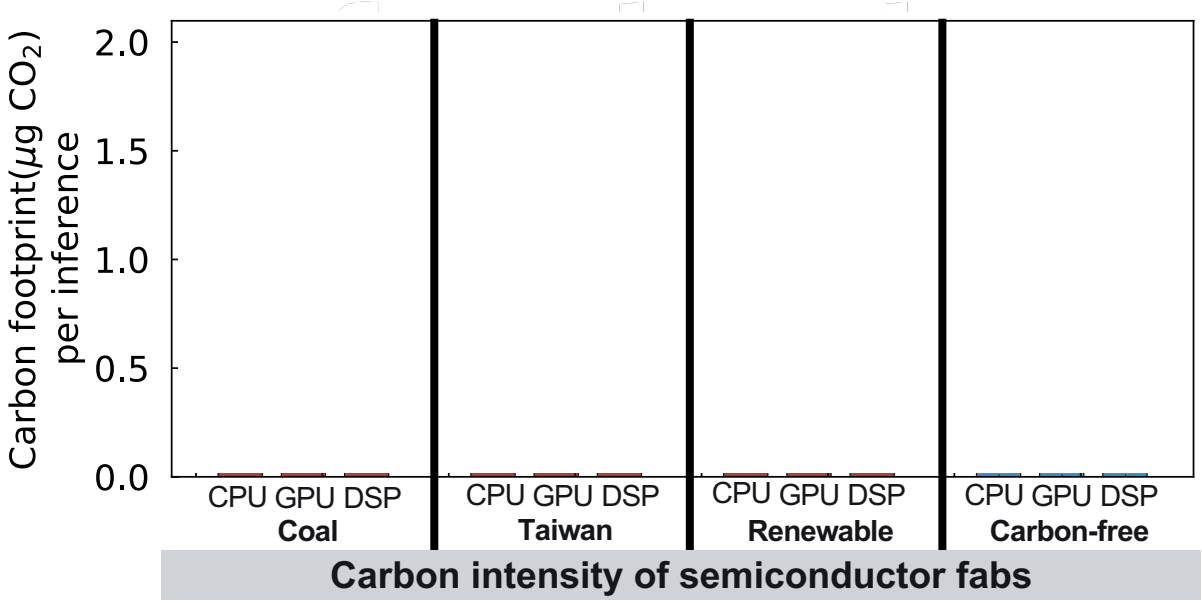

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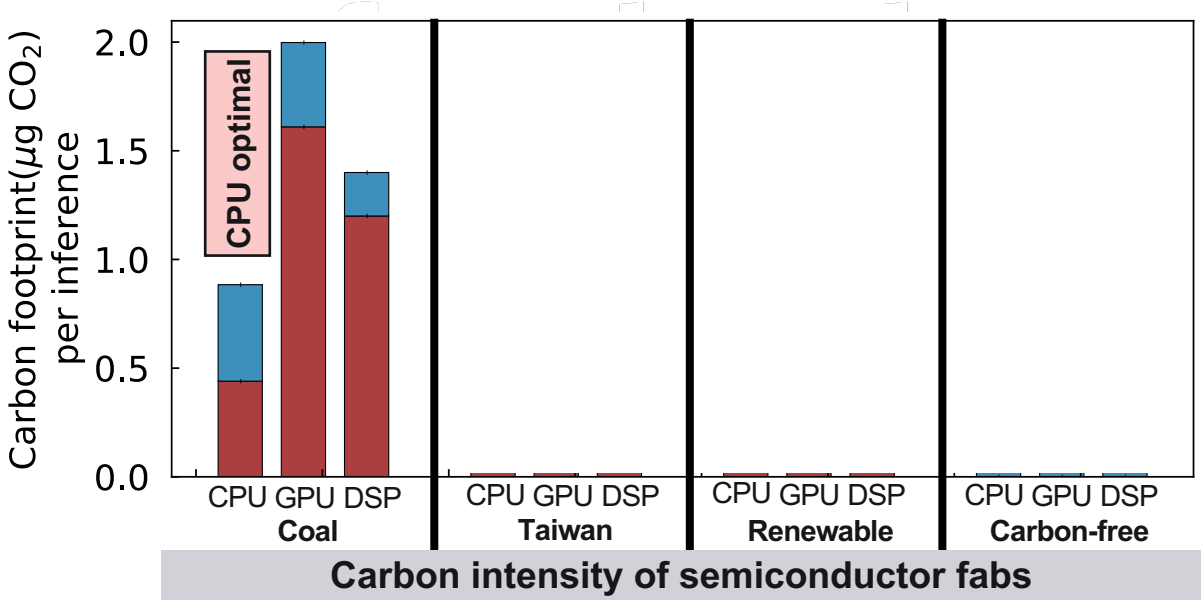

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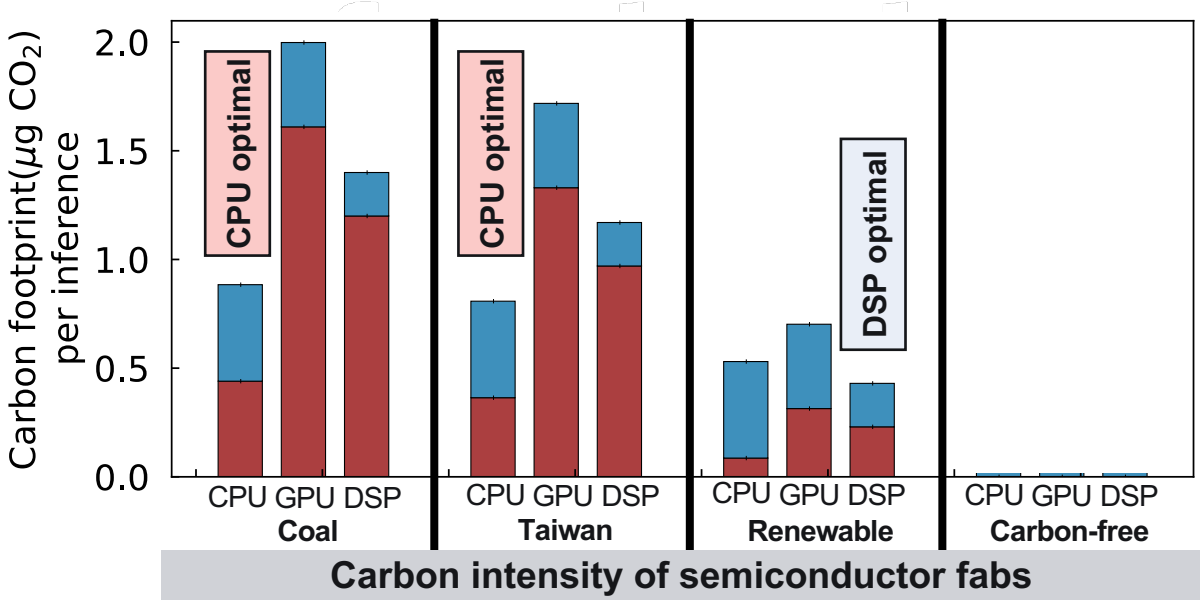

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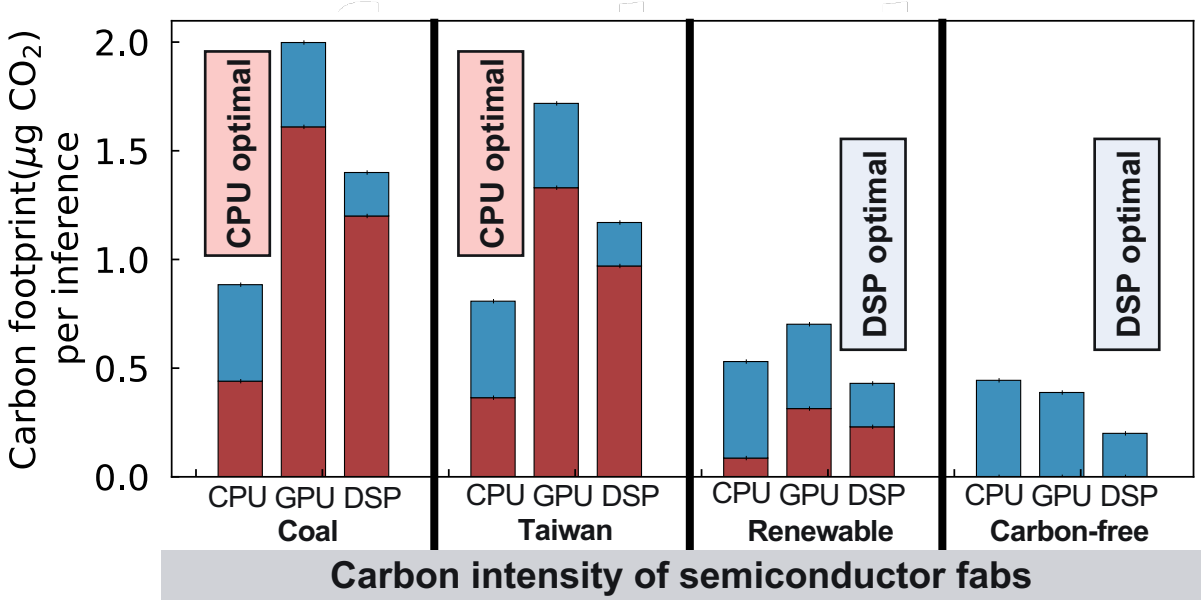

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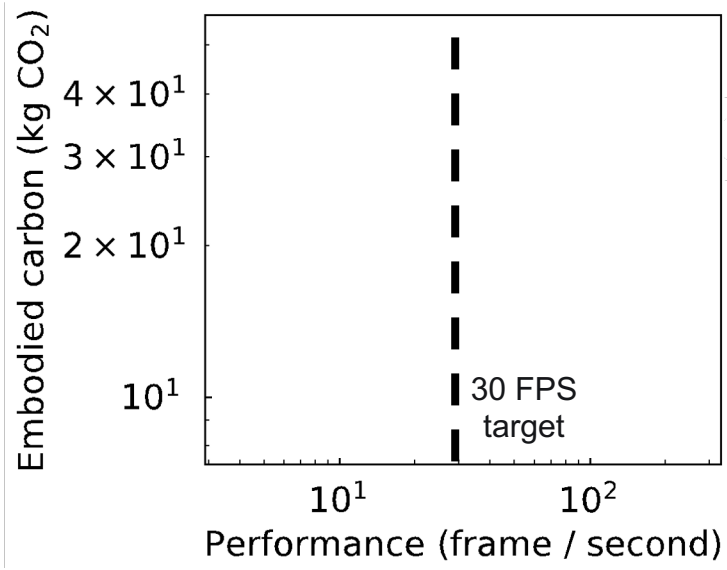

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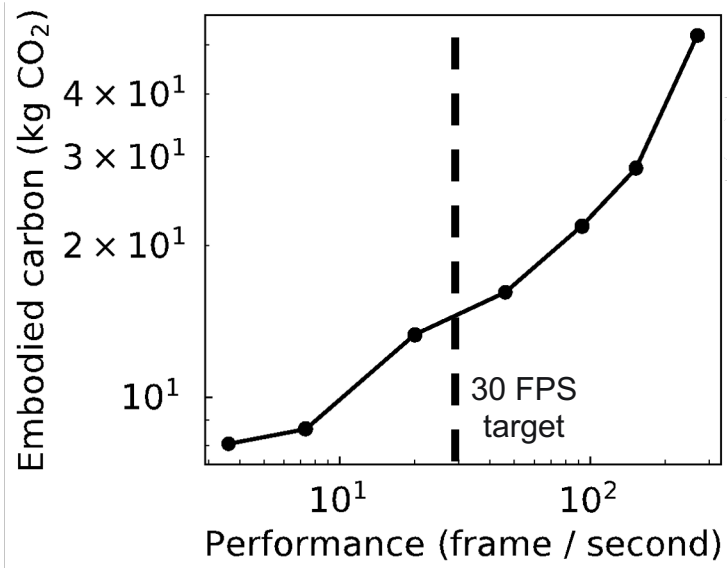
Nvidia DL Accelerator (NVDLA) → **Architectural Carbon Model** → Performance/energy vs. Carbon



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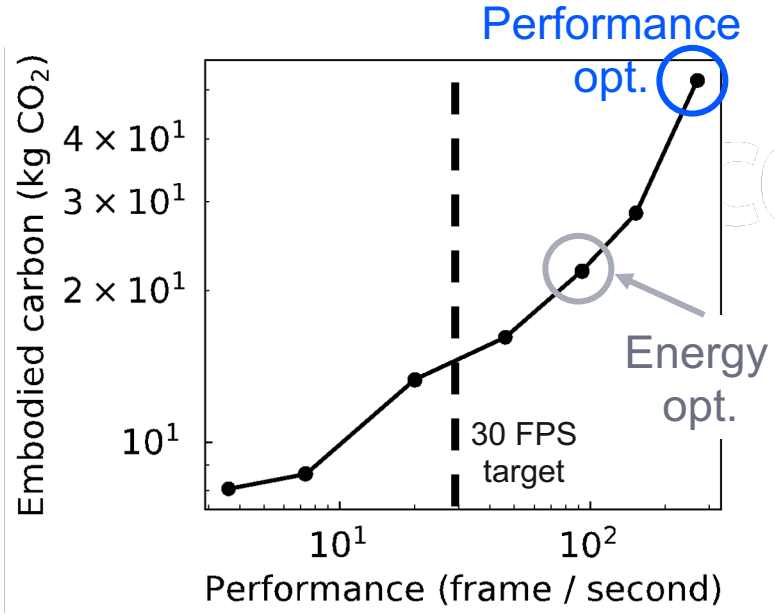

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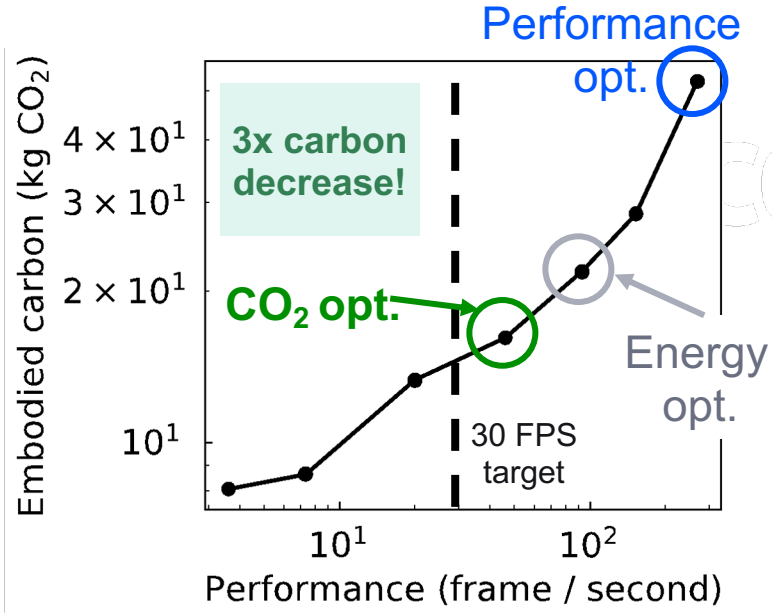

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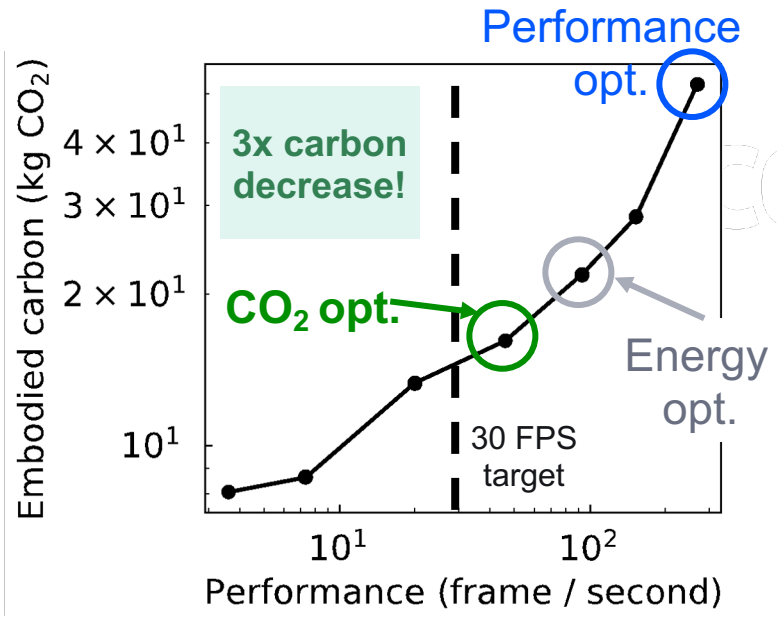

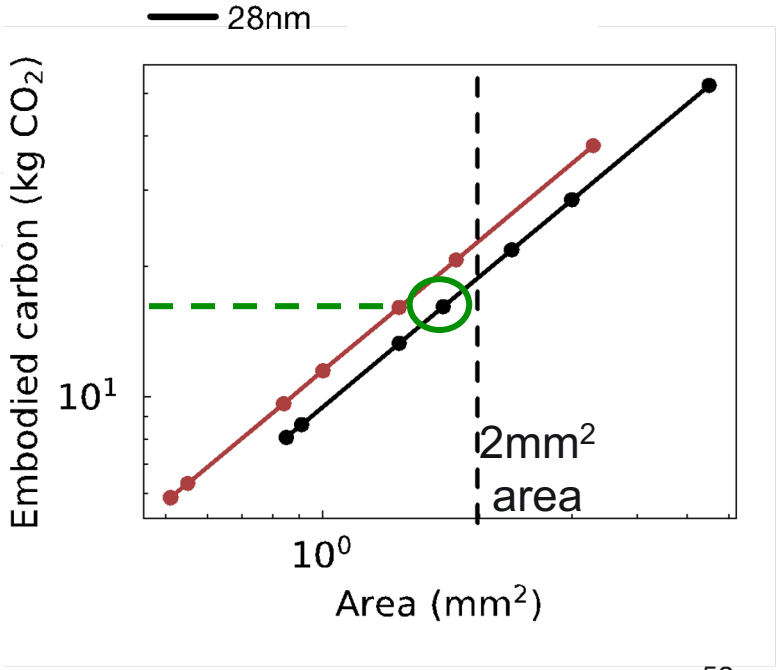

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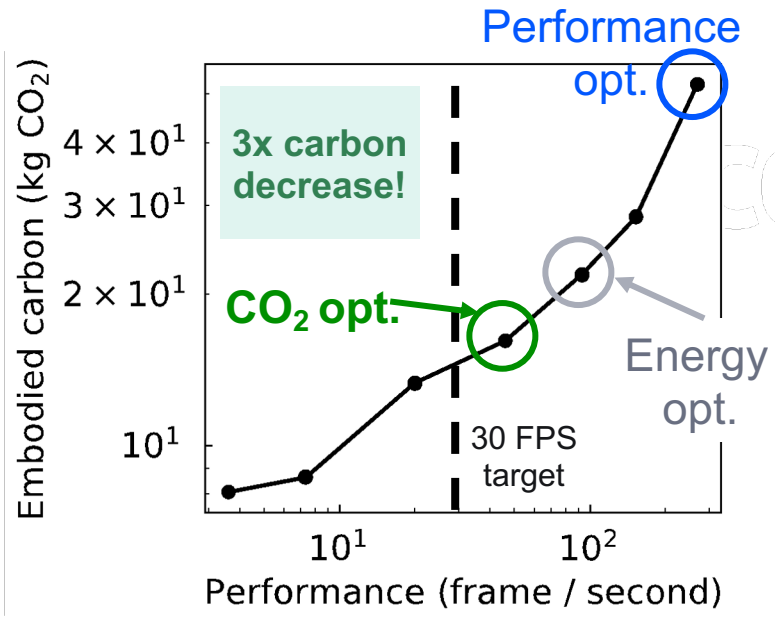

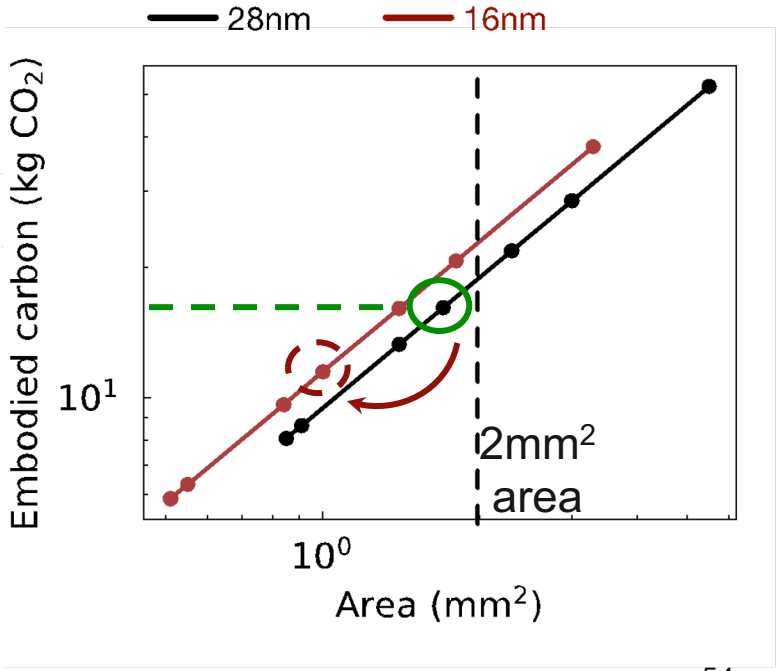

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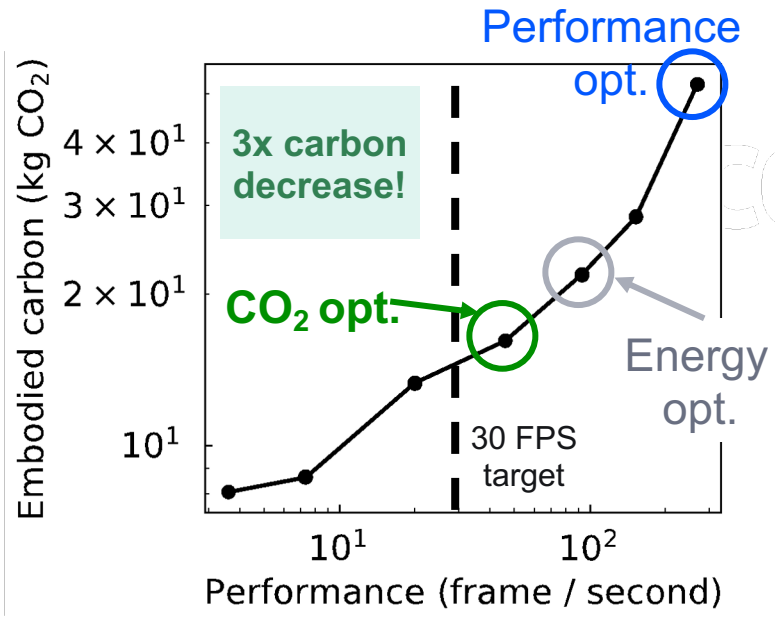

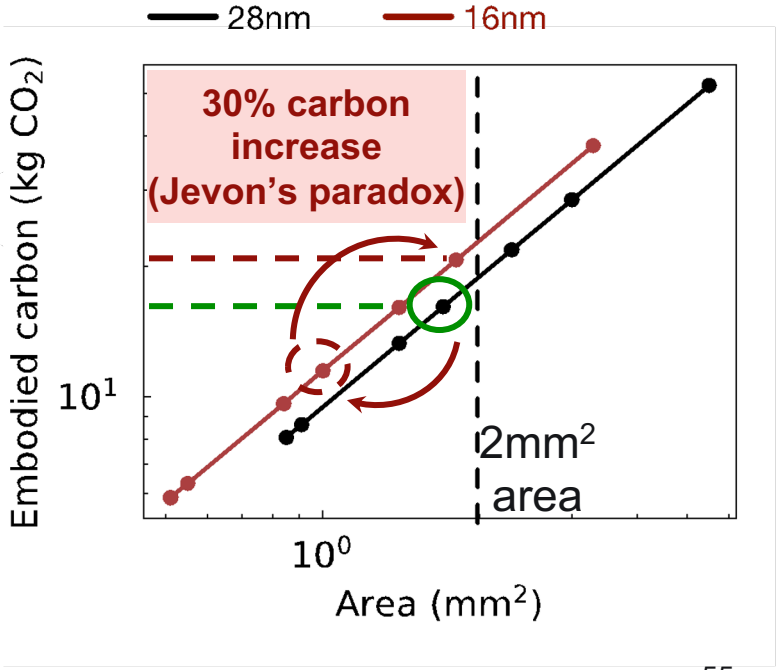

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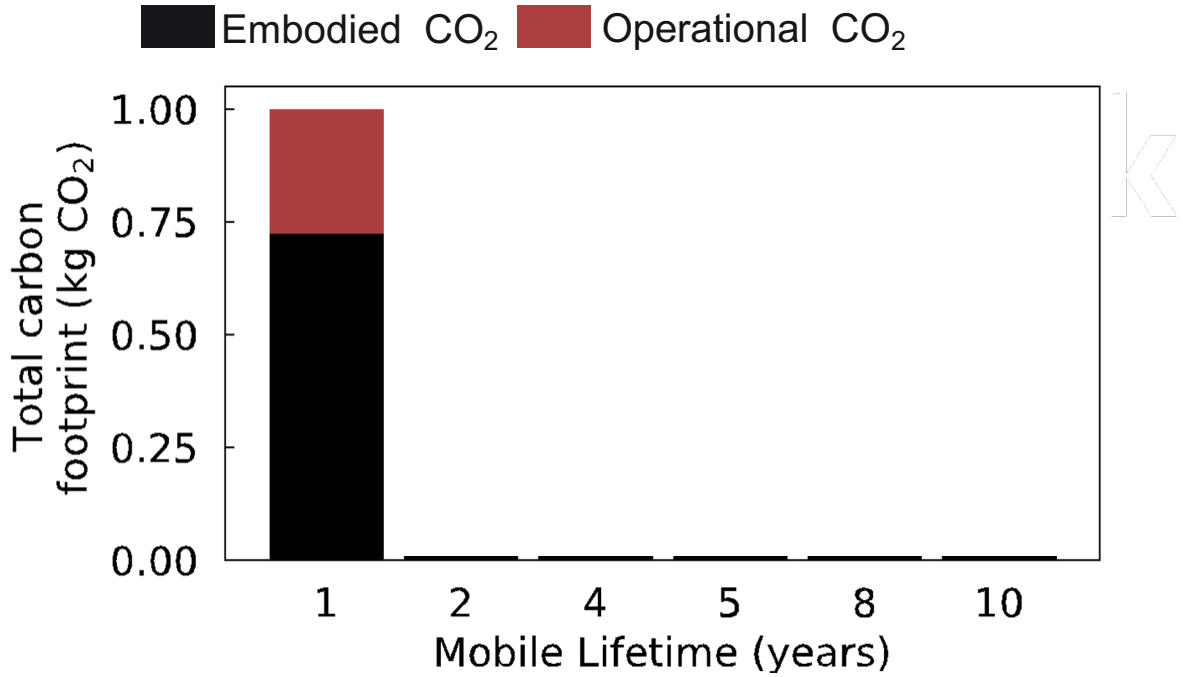
Mobile SoC's Geekbench characterization → **Architectural Carbon Model** → Operational vs. Embodied carbon



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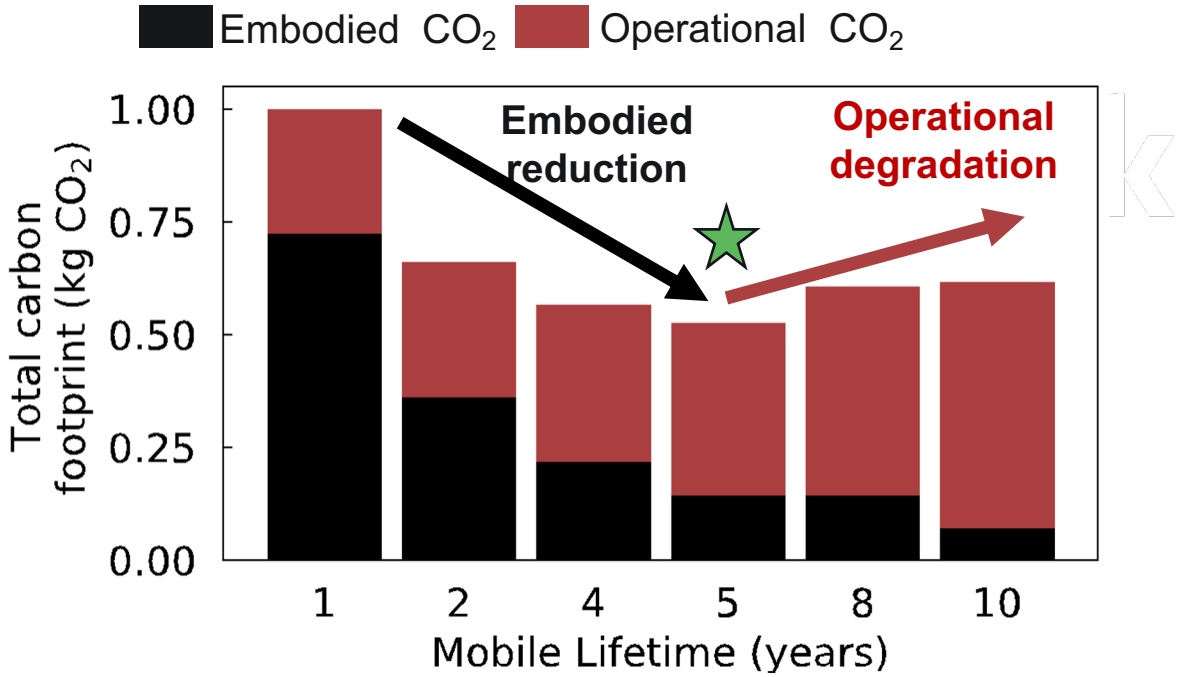

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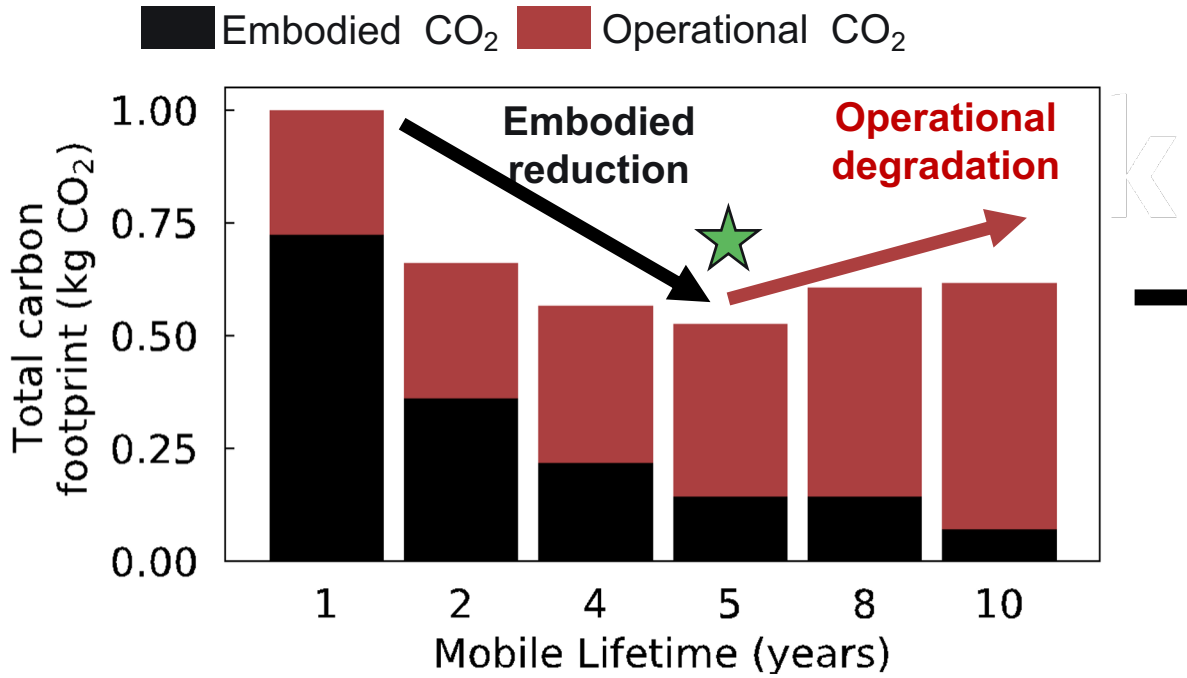
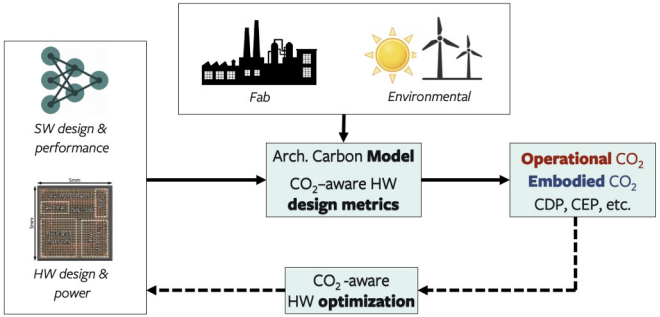


Enabling **2nd life** requires enhancing **HW reliability**

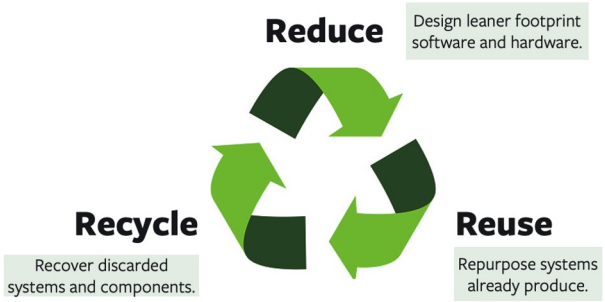
See paper for case study on storage reliability using **SSD overprovisioning**

This work: ACT

Develop the model



Case studies



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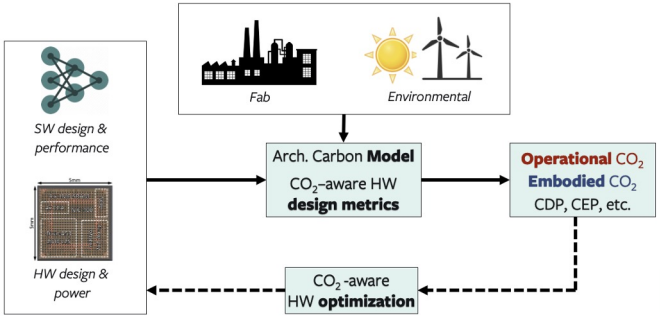
Develop the model

Case studies

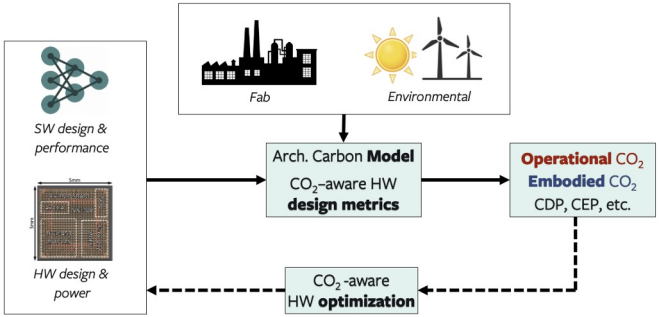


More details in the paper!

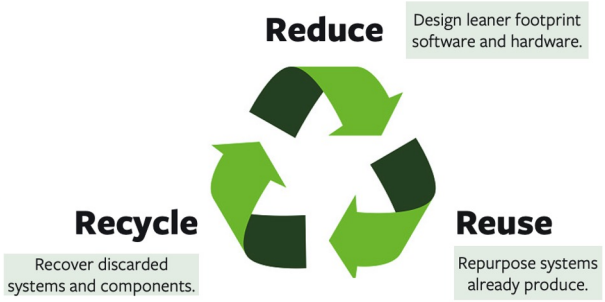
- **Modeling parameters** and industry **sources** for data
- **Carbon-aware metrics** for early DSE (e.g., EDP, CDP, CEP)
- Detailed **comparison** against industry LCA's
- Reuse case study: impact of **reconfigurable accelerators** (FPGA's)
- Recycle case study: Enabling **second life** & SSD provisioning

This work: ACT

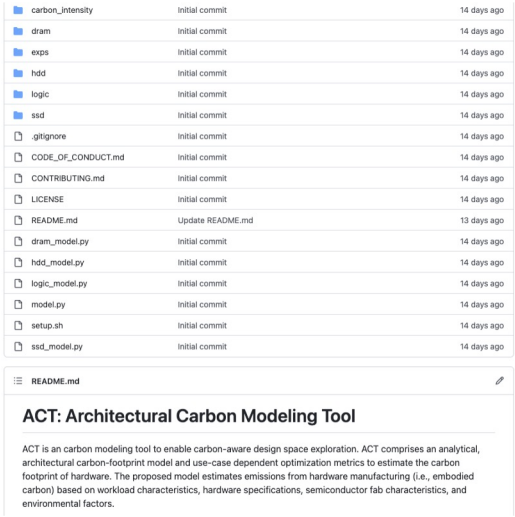
Develop the model



Case studies



Open-source!



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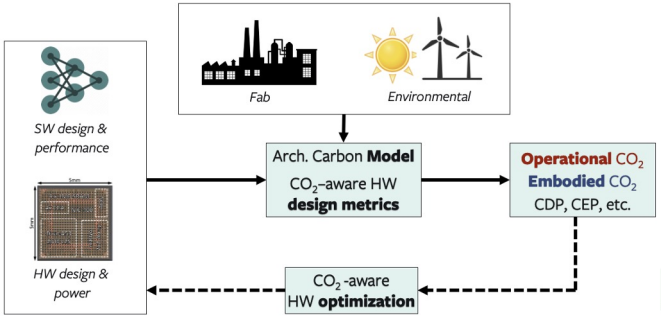
Thank you!

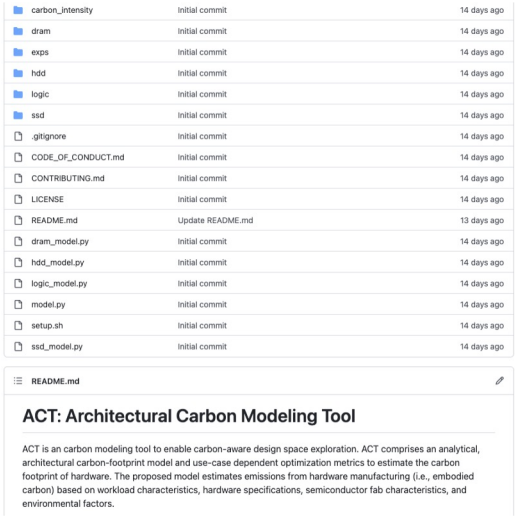
This work: ACT

Develop the model



Case studies

Open-source!



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CODE_OF_CONDUCT.md	Initial commit	14 days ago
CONTRIBUTING.md	Initial commit	14 days ago
LICENSE	Initial commit	14 days ago
README.md	Update README.md	13 days ago
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model.py	Initial commit	14 days ago
setup.sh	Initial commit	14 days ago
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README.md

ACT: Architectural Carbon Modeling Tool

ACT is an carbon modeling tool to enable carbon-aware design space exploration. ACT comprises an analytical, architectural carbon-footprint model and use-case dependent optimization metrics to estimate the carbon footprint of hardware. The proposed model estimates emissions from hardware manufacturing (i.e., embodied carbon) based on workload characteristics, hardware specifications, semiconductor fab characteristics, and environmental factors.

More details in the paper!

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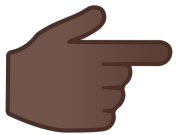
- Reuse case study: impact of **reconfigurable accelerators** (FPGA's)
- Recycle case study: SSD provisioning

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