Challenges in Building the Carbon Footprint Model for Large-Scale GPU Systems

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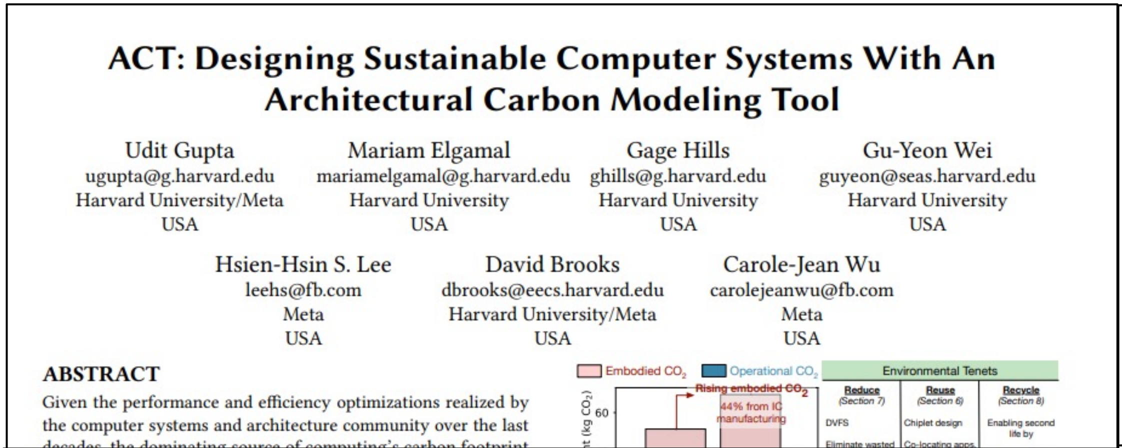
Carbon footprint has become an important topic in systems research



ACT: Designing Sustainable Computer Systems With An Architectural Carbon Modeling Tool

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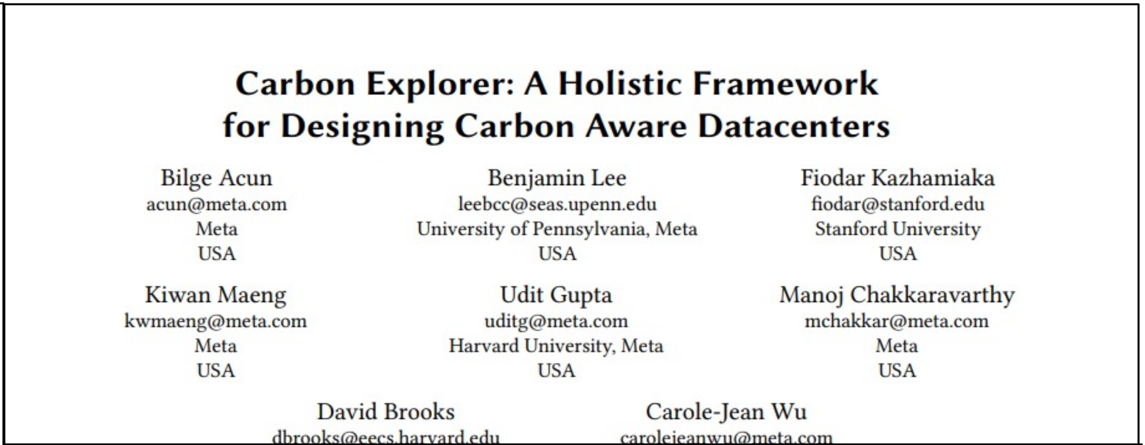
ABSTRACT

Given the performance and efficiency optimizations realized by the computer systems and architecture community over the last decades, the dominating source of computing's carbon footprint



Carbon Explorer: A Holistic Framework for Designing Carbon Aware Datacenters

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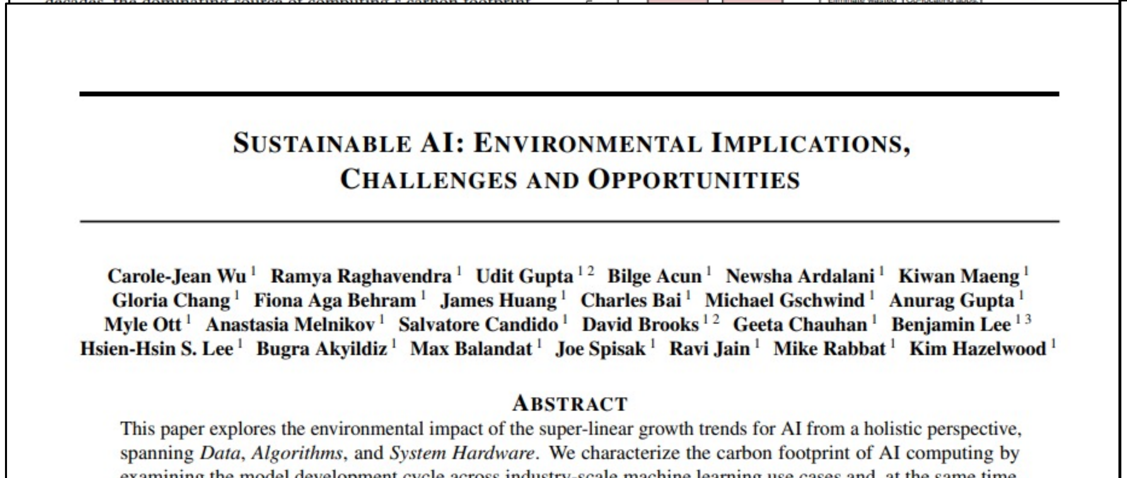

SUSTAINABLE AI: ENVIRONMENTAL IMPLICATIONS, CHALLENGES AND OPPORTUNITIES

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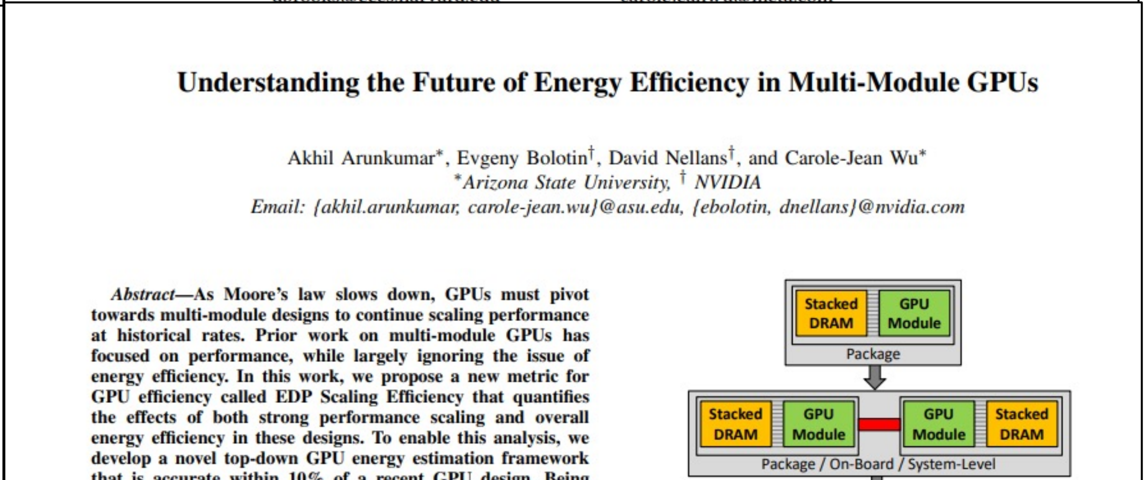
ABSTRACT

This paper explores the environmental impact of the super-linear growth trends for AI from a holistic perspective, spanning *Data*, *Algorithms*, and *System Hardware*. We characterize the carbon footprint of AI computing by examining the model development cycle across industry-scale machine learning use cases and, at the same time



Understanding the Future of Energy Efficiency in Multi-Module GPUs

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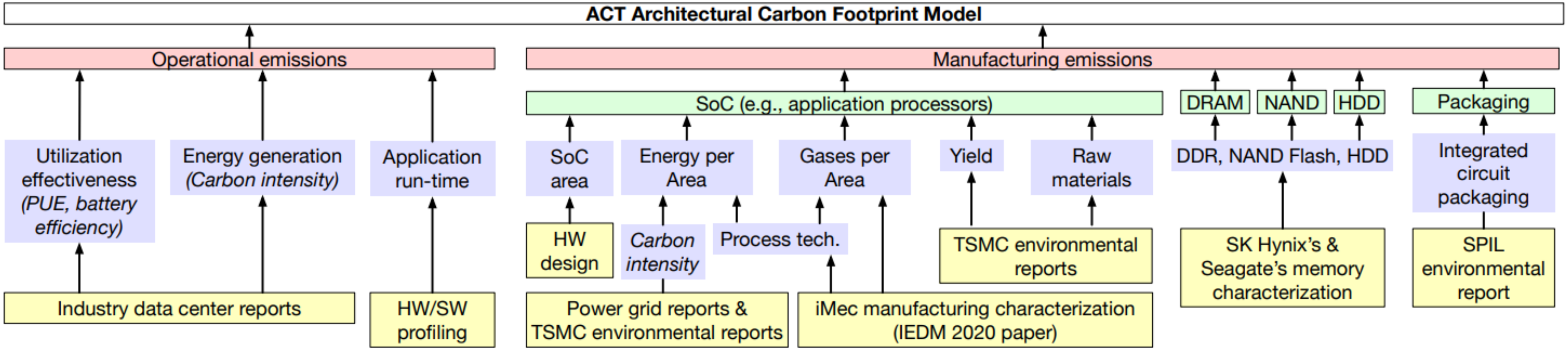
Abstract—As Moore's law slows down, GPUs must pivot towards multi-module designs to continue scaling performance at historical rates. Prior work on multi-module GPUs has focused on performance, while largely ignoring the issue of energy efficiency. In this work, we propose a new metric for GPU efficiency called EDP Scaling Efficiency that quantifies the effects of both strong performance scaling and overall energy efficiency in these designs. To enable this analysis, we develop a novel top-down GPU energy estimation framework that is accurate within 10% of a recent GPU design. Being

Carbon footprint modeling: the ACT approach

- ACT (Gupta et. Al., ISCA’22) is a carbon footprint modeling tool. It organizes the carbon emission of a system into two categories
  - **Embodied carbon**
  - **Operational carbon**



ACT Architectural Carbon Footprint Model
Operational emissions
Manufacturing emissions
SoC (e.g., application processors)
DRAM
NAND
HDD
Packaging
Utilization effectiveness (PUE, battery efficiency)
Energy generation (Carbon intensity)
Application run-time
SoC area
Energy per Area
Gases per Area
Yield
Raw materials
DDR, NAND Flash, HDD
Integrated circuit packaging
HW design
Carbon intensity
Process tech.
TSMC environmental reports
SK Hynix’s & Seagate’s memory characterization
SPIL environmental report
Industry data center reports
HW/SW profiling
Power grid reports & TSMC environmental reports
iMec manufacturing characterization (IEDM 2020 paper)

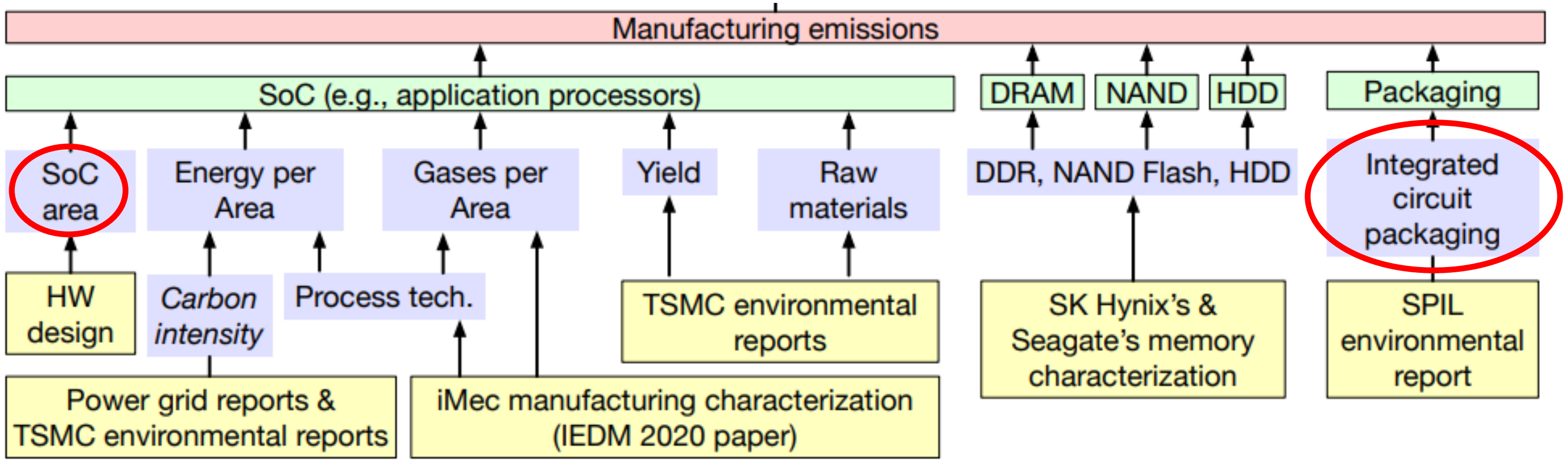
Gupta, Udit, Mariam Elgamal, Gage Hills, Gu-Yeon Wei, Hsien-Hsin S. Lee, David Brooks, and Carole-Jean Wu. "ACT: Designing sustainable computer systems with an architectural carbon modeling tool." In *Proceedings of the 49th Annual International Symposium on Computer Architecture*, pp. 784-799. 2022.

Goal of this presentation

Share our experience and the challenges we encountered while using the ACT tool to model the carbon footprint of a large-scale GPU-accelerated HPC system

Embodied footprint modeling challenge I

- **Difficult to obtain information related to carbon footprint modeling from vendors' product datasheet**, for example
  - Number of ICs packaged on a NVIDIA GPU card
  - Die area of Intel Xeon processors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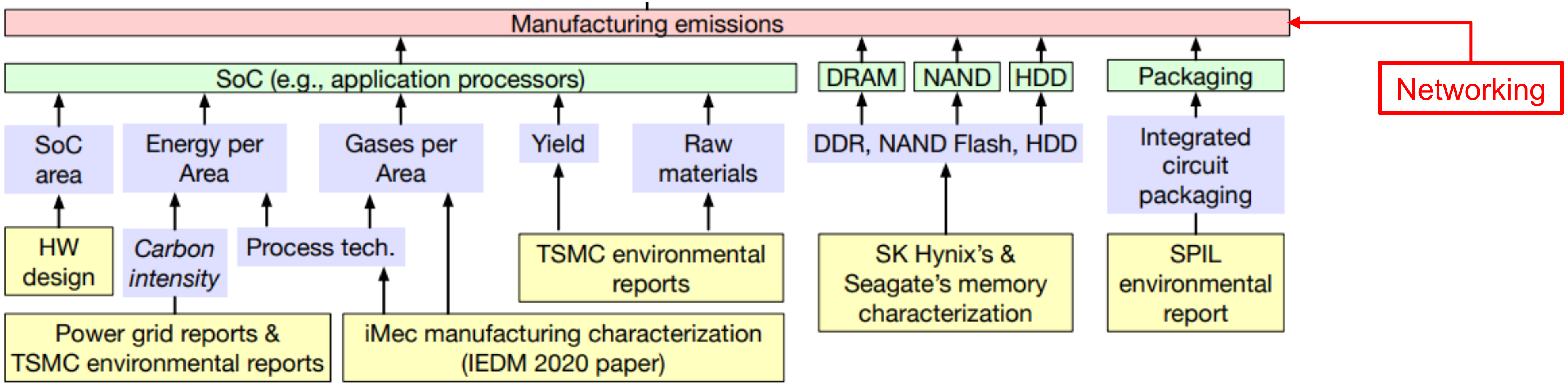
Embodied footprint modeling challenge 2

- ACT's model works well for a single device, e.g., desktop, phone
- But **lacks extensibility to large scale distributed systems**
  - For example, the network fabrics for inter-node communication



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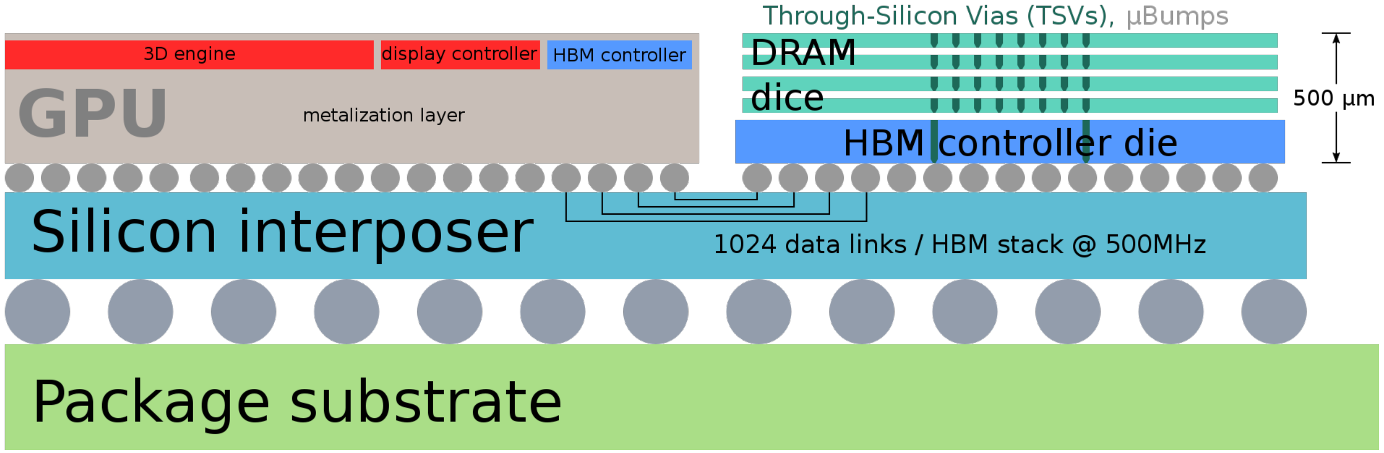
Networking

Embodied footprint modeling challenge 3

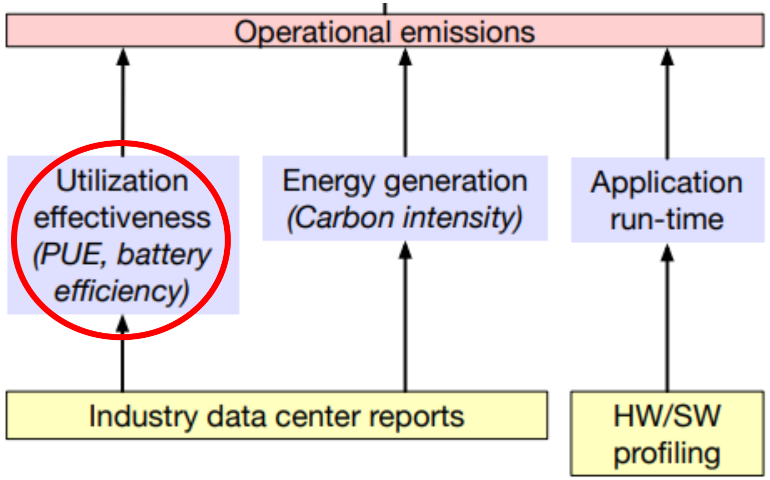
- **Need for GPU-specific features to model GPU-accelerated systems**
  - ACT models GPUs like CPUs – based on the processor’s die area
  - Modern GPUs use FinFET technology compared to traditional CMOS
  - GPUs such as NVIDIA V100 use HBM2 memory that is stacked vertically and integrated into the same package with the GPU cores
    - Unlike CPUs that use DDR4/DDR5 discrete memory chips



https://en.wikipedia.org/wiki/High_Bandwidth_Memory

Operational carbon footprint challenge I

- **Need for systematic power monitoring tool**
  - We need to monitor CPU/GPU power at node level
  - Use this to estimate operational energy
  - Then convert to emitted carbon using real-time carbon intensity
  - Good to have a universal software suite that can be used in any datacenter in any location



Operational emissions

Utilization effectiveness *(PUE, battery efficiency)*

Energy generation *(Carbon intensity)*

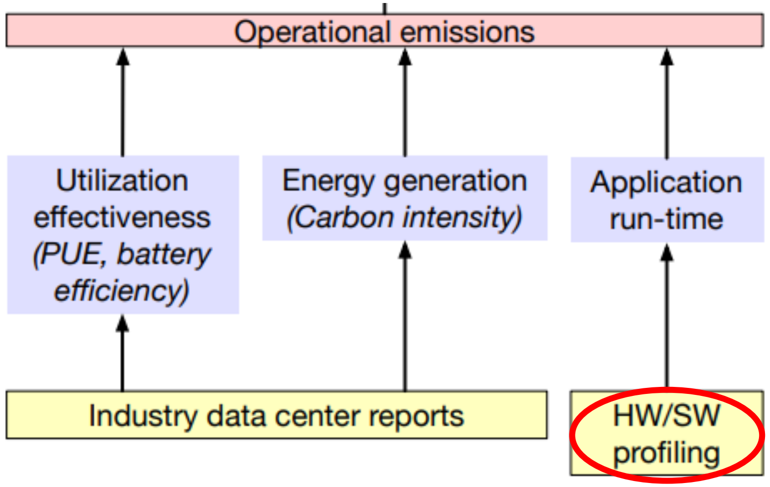
Application run-time

Industry data center reports

HW/SW profiling

Operational carbon footprint challenge 2

- **Difficult to estimate operational carbon emission on the next-generational system**
  - When making system upgrade decisions, need to build carbon footprint model for the next generational system
  - But the HW/SW profiling for operational carbon is difficult to obtain from new hardware in the future
  - System operators also usually do not have information about the user workload


Operational emissions
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Summary and recommendations

- **Hardware manufacturers**
  - Provide more data to customers from the carbon perspective
- **Embodied carbon modeling**
  - Extension to audiences from HPC and distributed system field is needed
- **Operational carbon modeling**
  - Need for universal and systematic monitoring tool
  - Would be helpful for system operators to record history of previous hardware upgrades for reference

Feel free to reach out!
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Acknowledgements

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Thank you!