


Workshop on Widening
Access to TinyML Network by
Establishing Best Practices in
Education



3 - 7 July 2023
An ICTP Meeting
Trieste, Italy

Further information:
<http://indico.ictp.it/event/10185/>
smr3851@ictp.it

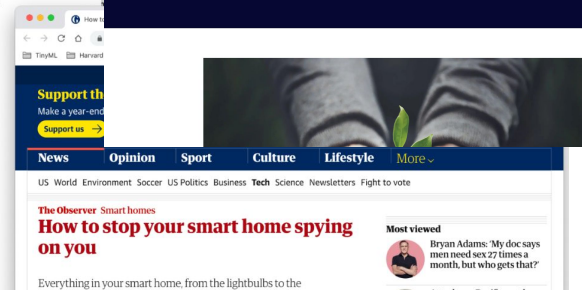
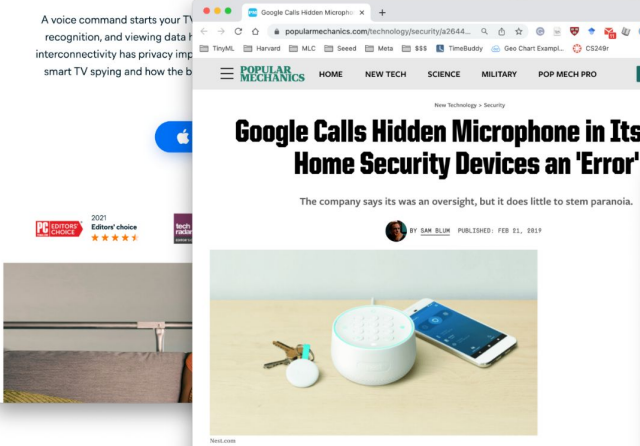
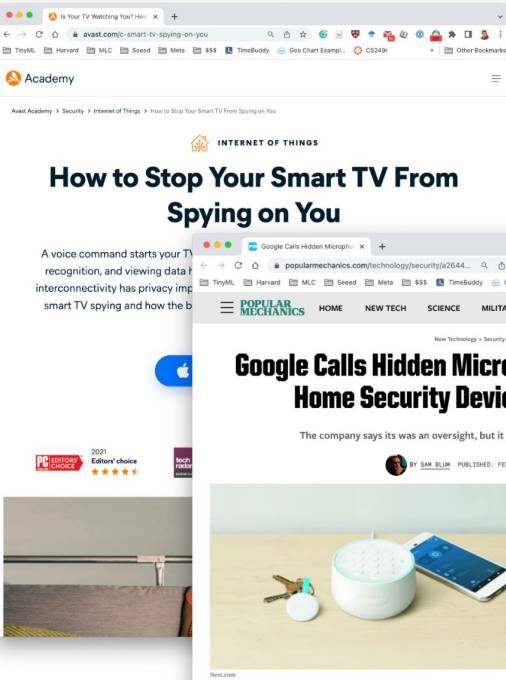
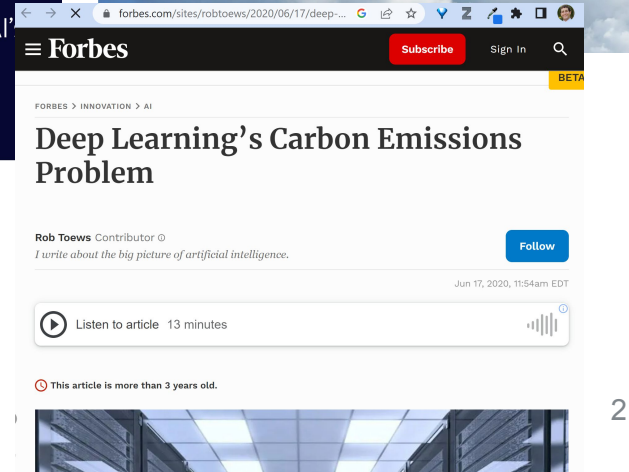
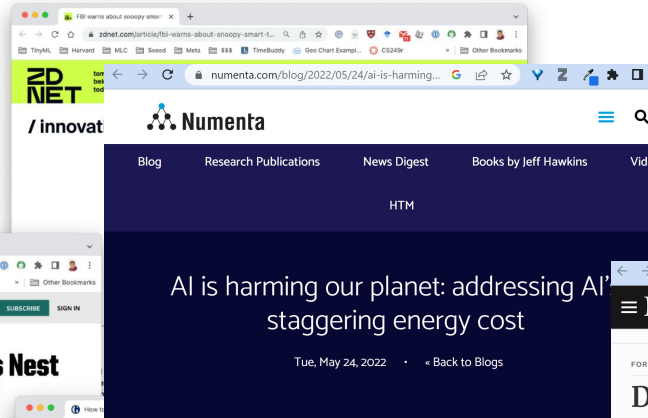
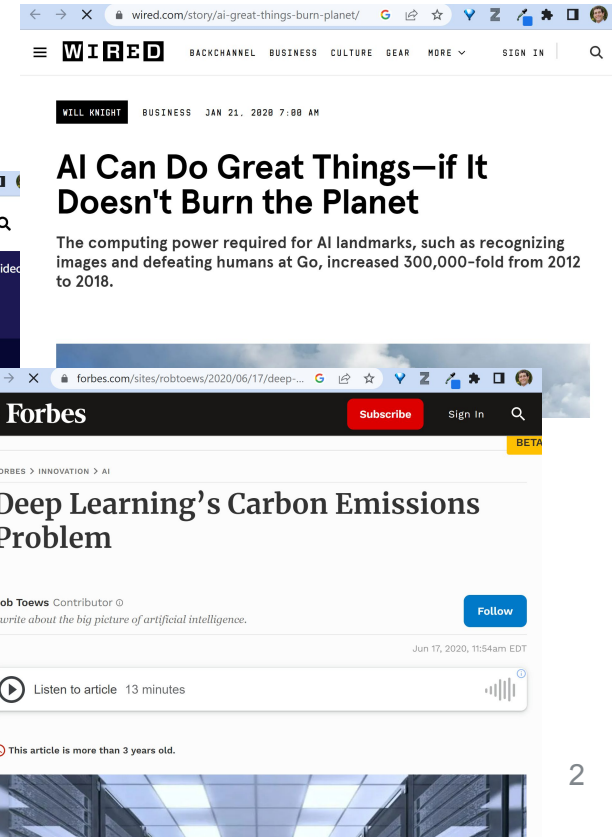
Responsible AI via Sustainable and Privacy Preserving EdgeML



Brian Plancher
Barnard College, Columbia University
brianplancher.com



How can we adapt our approach to EdgeML to support **Responsible AI** future?



Responsible AI via Sustainable and Privacy Preserving EdgeML

1. What is a (**Datasheet** for a) **Machine Learning Sensor?**
2. **Applications** of TinyML for Sustainability
3. Environmental Footprint of **TinyML Systems at Deployed Scale**

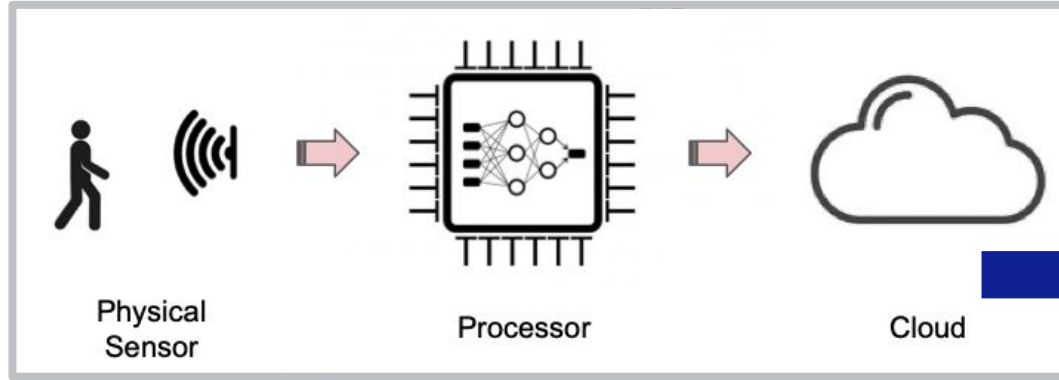
**Our Suggested
Transparent
Paradigm**

**Positive Effects
of TinyML**

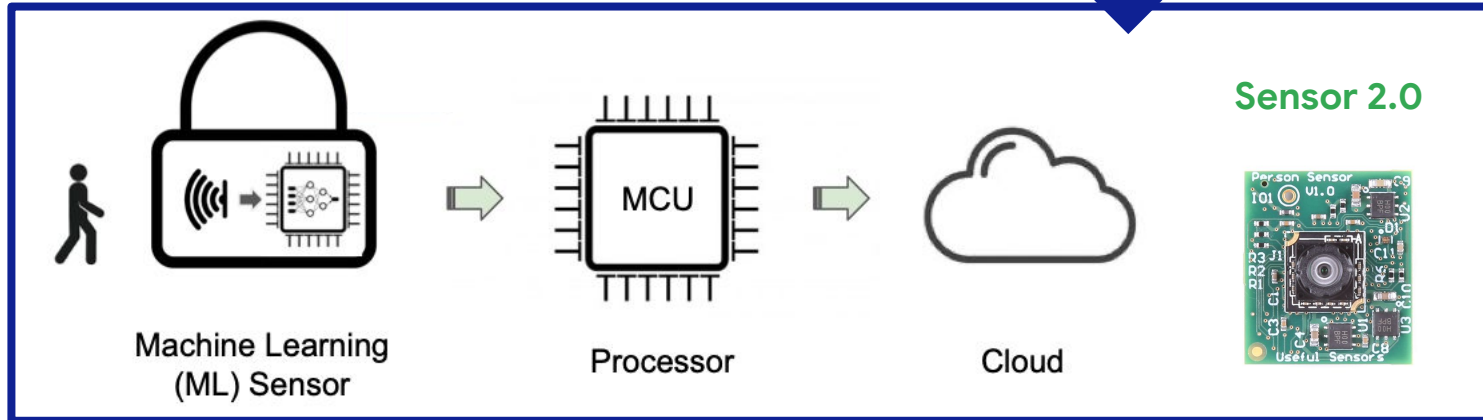
**Environmental
Footprint at Scale**

What is a (Datasheet for a) Machine Learning Sensor?

What is a Machine Learning Sensor?



**Privacy
by Design**



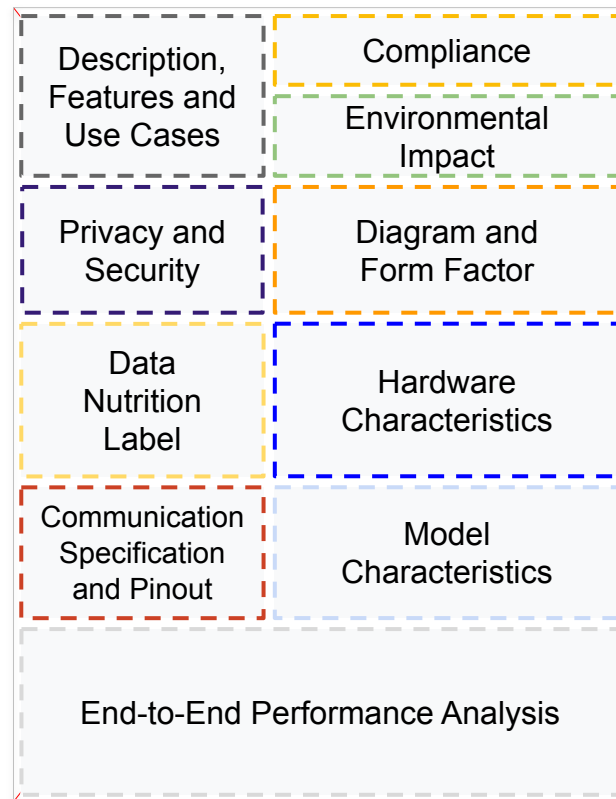
We suggest **transparency** as a core value to overcome these challenges.

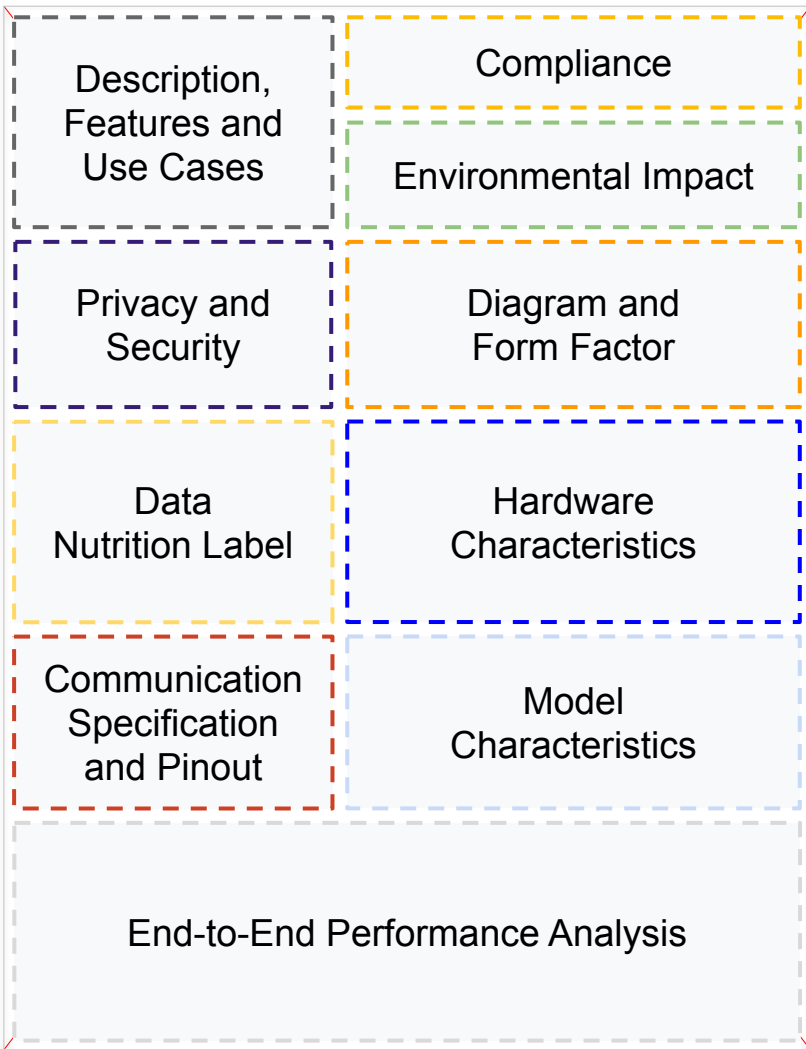
Datasheets for Machine Learning Sensors

Matthew Stewart^{1*} Pete Warden^{2,5} Yasmine Omri¹ Shvetank Prakash¹ Joao Santos¹
Shawn Hymel⁴ Benjamin Brown¹ Jim MacArthur¹ Nat Jeffries⁵ Brian Plancher³
Vijay Janapa Reddi¹

¹Harvard University ²Stanford University ³Barnard College, Columbia University
⁴Edge Impulse ⁵Useful Sensors

arxiv.org/abs/2306.08848

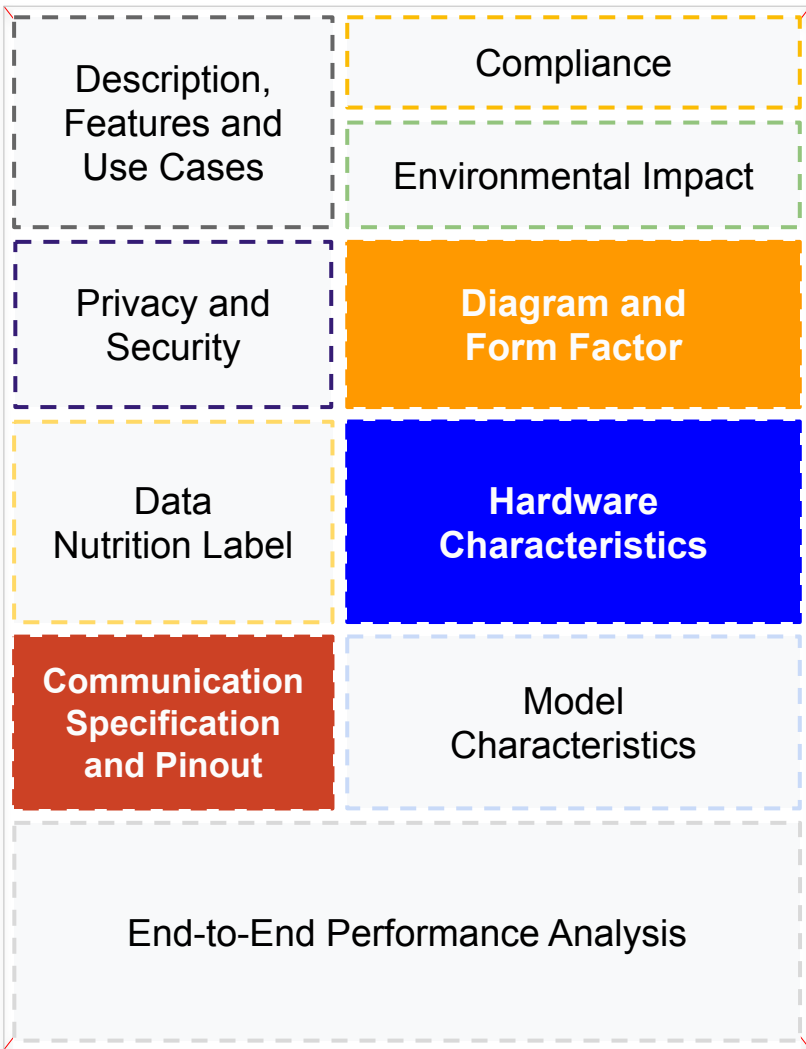




ML Sensor Datasheets

Have 3 Goals:

1. Raise the level of **abstraction**
2. Transparent at the **hardware, data, model, and end-to-end layers**
3. Support **Responsible** Use

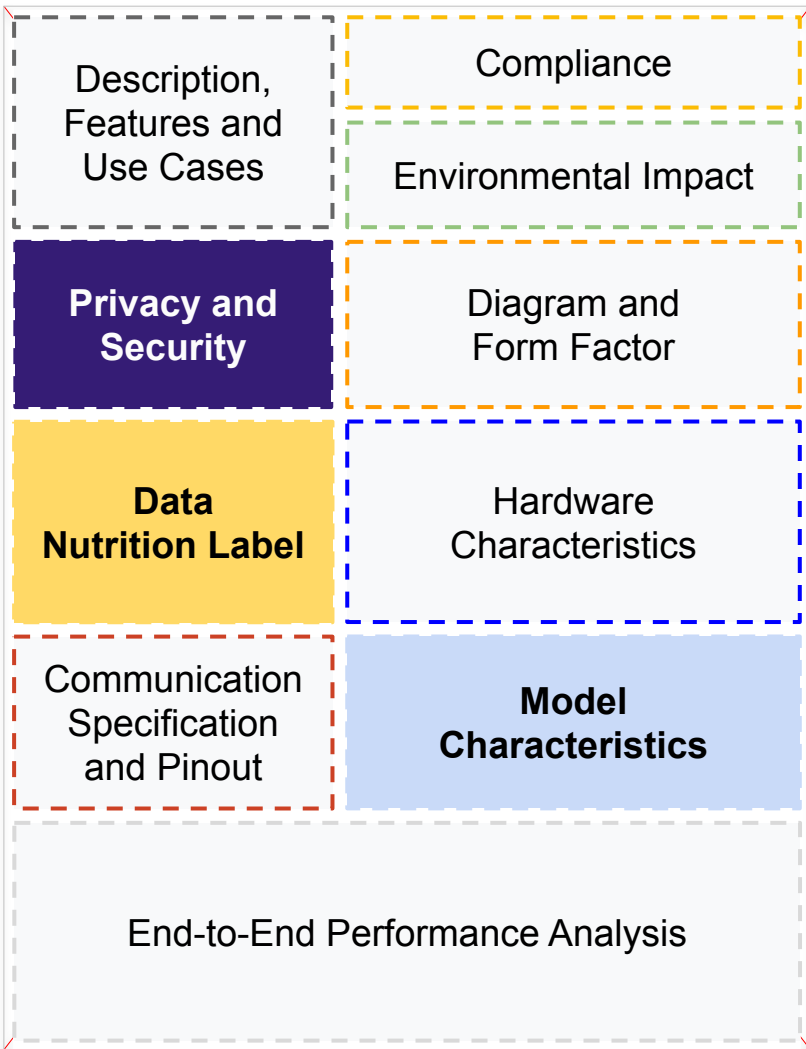


ML Sensor Datasheets

Have 3 Goals:

1. Raise the level of abstraction
2. Transparent at the **hardware**, data, model, and end-to-end layers
3. Support Responsible Use

Standard Sensor Datasheet



ML Sensor Datasheets

Have 3 Goals:

1. Raise the level of abstraction
2. Transparent at the hardware, **data, model**, and end-to-end layers
3. Support **Responsible** Use

**Responsible
Machine Learning
Analysis**

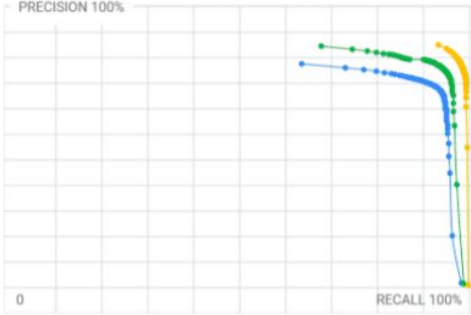
Responsible Machine Learning Analysis

Source: datanutrition.org



Aggregated Human Data
Quality Review
Ethical Review
About Humans
Commercial License
Multi-source Funded
Not Actively Updated
Multi-source Data
No Subpopulations

Dataset Nutrition Label



PRECISION 100%

RECALL 100%

● Open Images ● Face Detection Dataset Benchmark
● Labeled Faces in the Wild

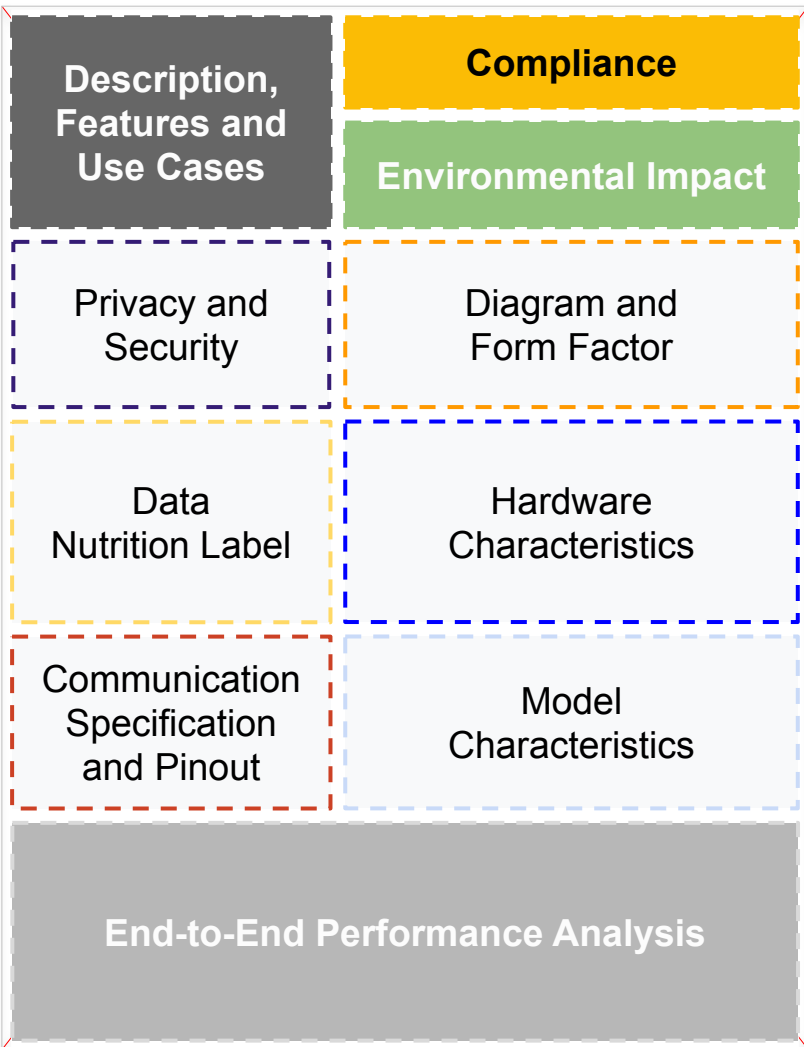
Model performance:
Measured with [Precision-Recall \(PR\)](#) and [Area Under the PR Curve \(PR-AUC\)](#). Download raw performance results data [here](#). Disaggregated performance measured with [Recall](#), which captures how often the model misses faces with specific characteristics. Equal recall across subgroups corresponds to the [“Equality of Opportunity” fairness criterion](#).

Performance evaluated on:

- A subset of [Open Images](#)
- [Face Detection Data Set and Benchmark](#)
- [Labeled Faces in the Wild](#)

Model Characteristics

Source: modelcards.withgoogle.com

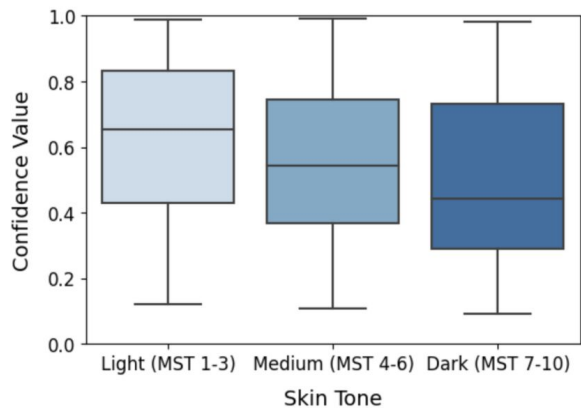
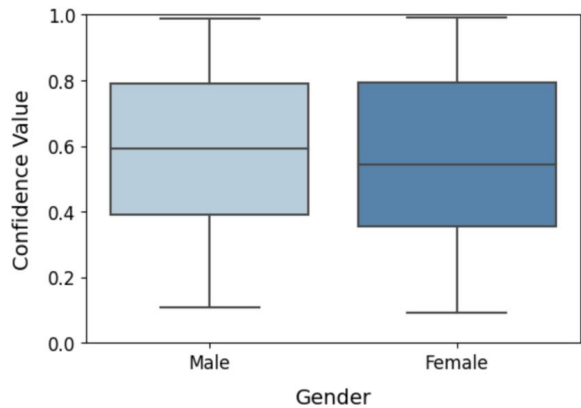
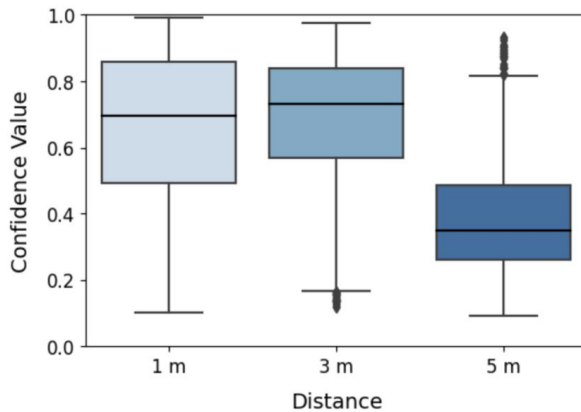
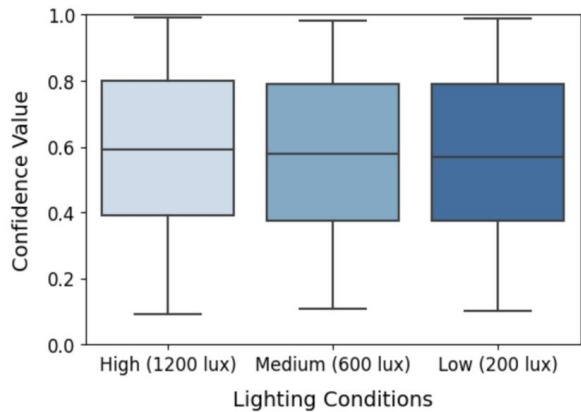


ML Sensor Datasheets

Have 3 Goals:

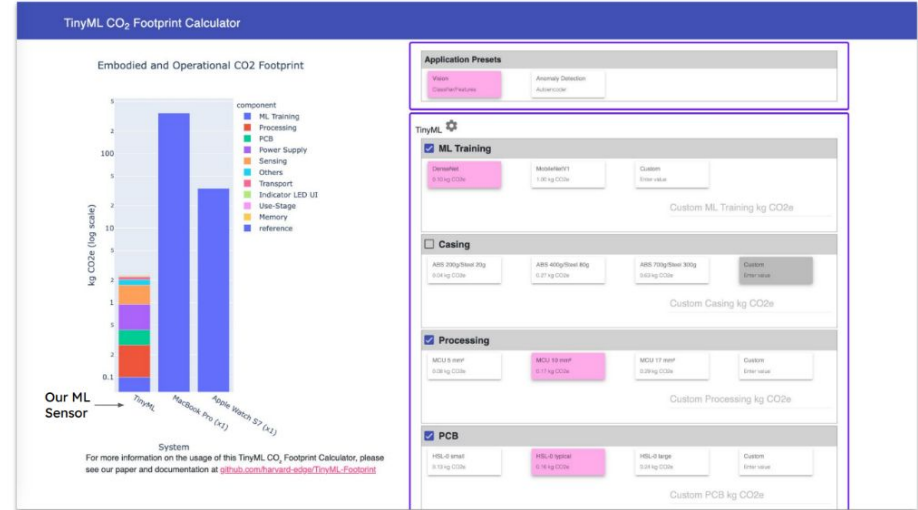
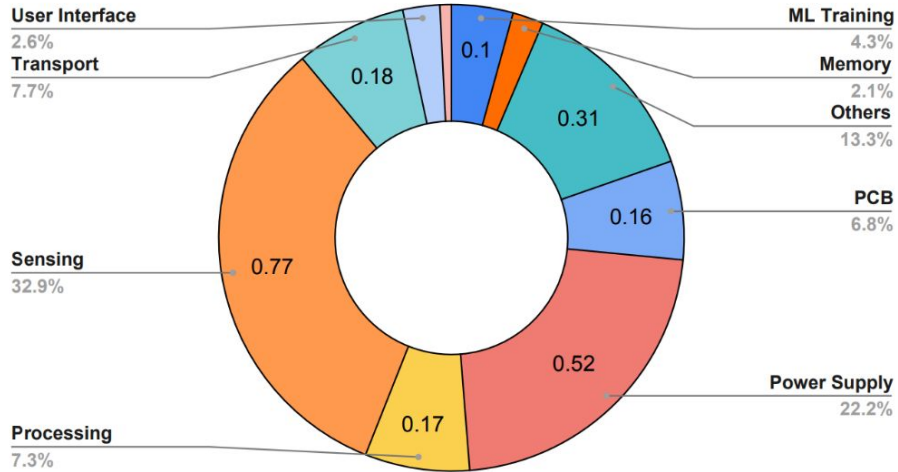
1. Raise the level of **abstraction**
2. Transparent at the hardware, data, model, and **end-to-end layers**
3. Support **Responsible** Use

**Overall System
Analysis**



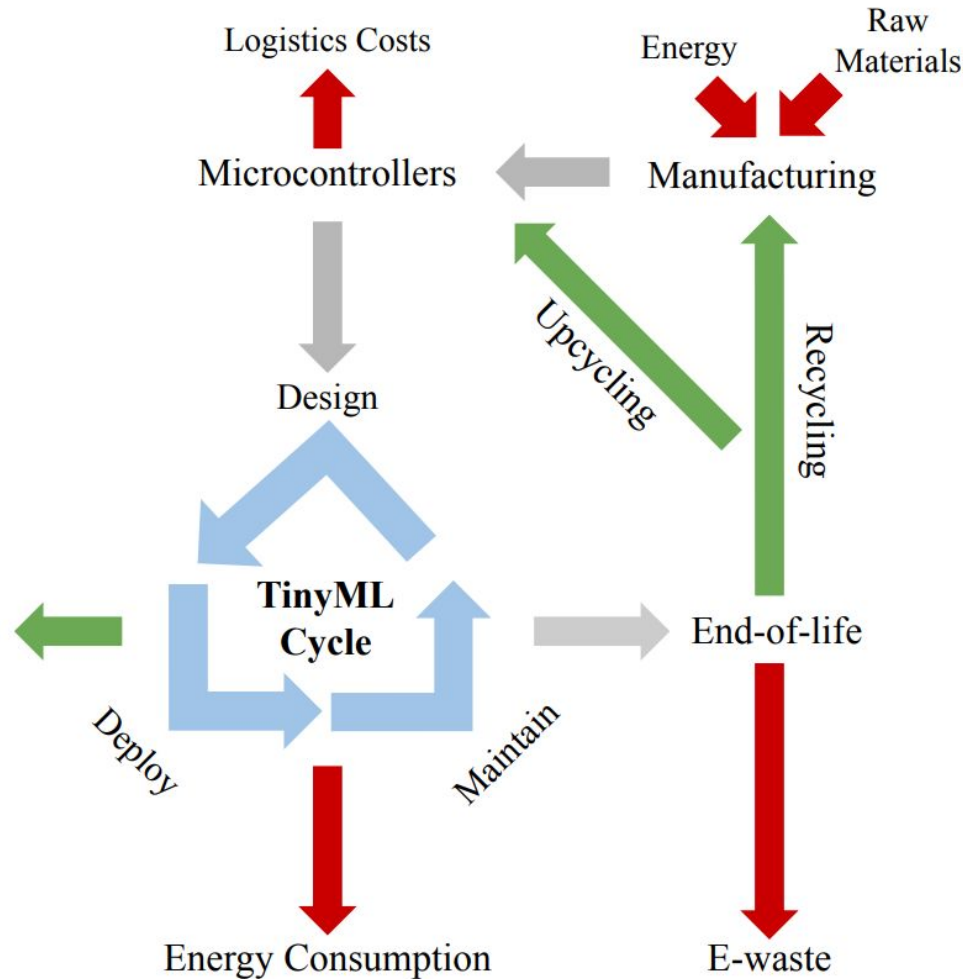
End-to-End
Responsible
Performance
Analysis

Environmental Impact



Lets Explore this Impact
in More Detail

Sustainable Development Goals



TinyML can support the SDGs but comes with costs. **What is the net impact?**

Applications of TinyML for Sustainability

Zero Hunger & Good Health and Well-Being

(SDG #2 & #3)



Credit: PlantVillage Nuru

Nuru, an ML app more accurate than humans at detecting plant diseases. Increased a farmer's sales by 55% & **yields by 146%**.



Credit: Crop Angel Ltd

Tiny drones can provide targeted pesticide applications that **reduce use to 0.1%** of conventional blanket spraying.



Credit: Sinhyu/Getty Images

Using Edge Impulse, a system was prototyped to identify mosquitoes by wing beats sounds with **88.3% accuracy**.

Life on Land & Below Water

(SDG #14 & #15)



Credit: Rainforest Connection

Rainforest Connection uses **recycled smartphones** for **solar-powered** listening devices to warn of **deforestation** efforts



Credit: RESOLVE and Bivash Pandav

RESOLVE's AI camera transmits notifications of elephant detection and can **run for more than 1.5 years** on a single battery.



Credit: Tim Cole

To prevent collisions with whales in busy waterways, Google deployed a TinyML model on hydrophones to alert ships.

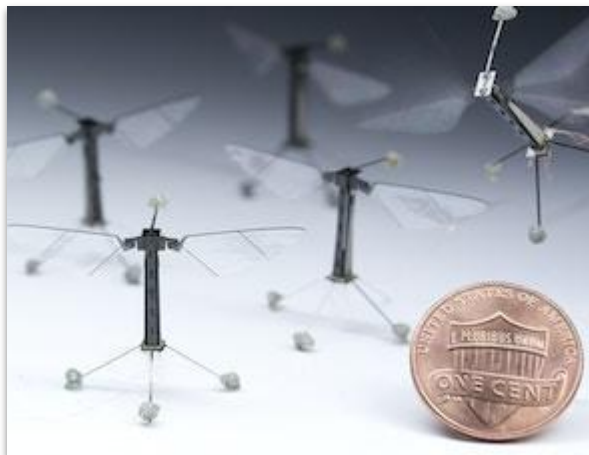
Climate Action

(SDG #13)



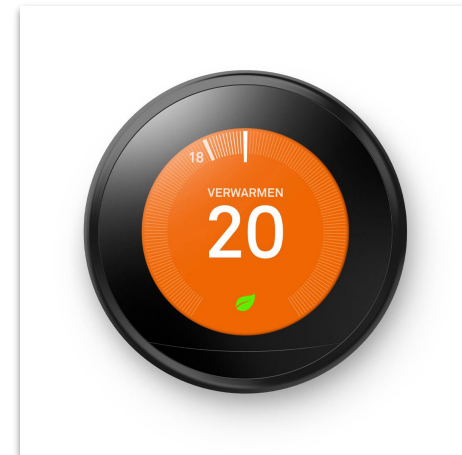
Credit: Ribbit Network

Ribbit Network is **crowdsourcing world's largest greenhouse gas emissions dataset** through distributed intelligent sensors



Credit: Wyss Institute at Harvard University

TinyML can help provide intelligence to **tiny robots like the Robobee** that can be used as artificial pollinators.

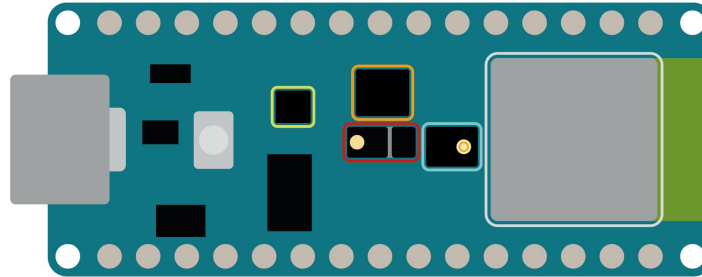
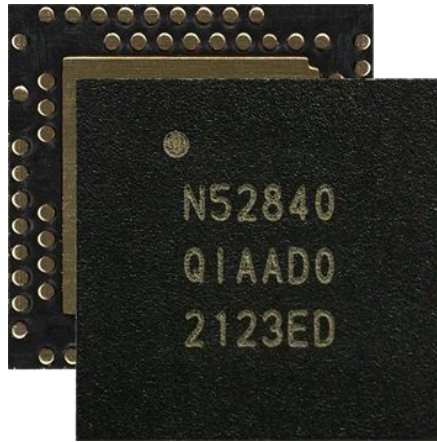


Credit: Google Nest

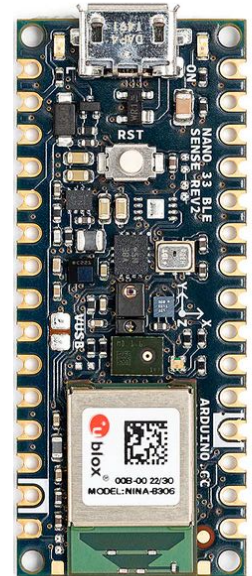
Smart HVAC systems show a **20-40% reduction in building energy usage**.

Environmental Footprint of TinyML Systems

Real TinyML Systems are more than just an MCU!

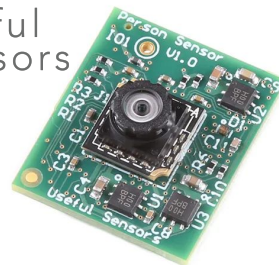


- ◆ Color, brightness, proximity and gesture sensor
- ◆ Digital microphone
- ◆ Motion, vibration and orientation sensor
- ◆ Temperature, humidity and pressure sensor
- ◆ Arm Cortex-M4 microcontroller and BLE module

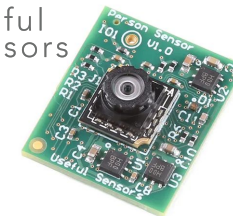
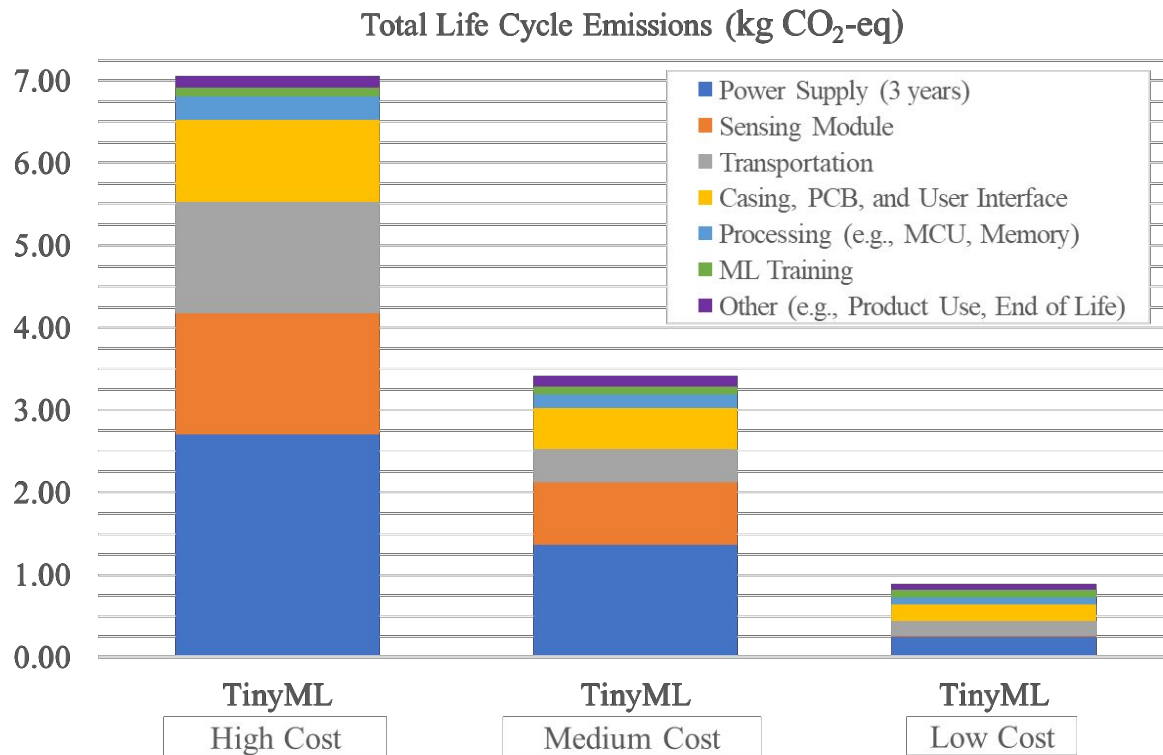


Building Representative Systems

Cost Level	High Cost	Medium Cost	Low Cost
Application	Image Classification		Keyword Spotting
Size	Large	Compact	Compact



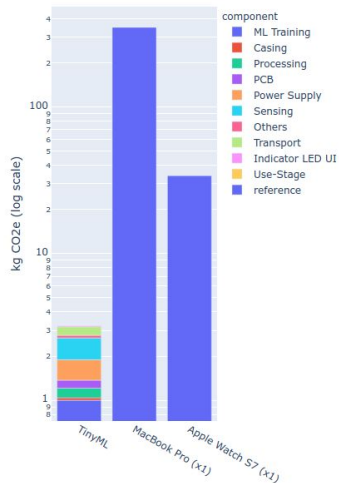
Building Representative Systems



harvard-edge.github.io/TinyML-Footprint/

TinyML CO₂ Footprint Calculator

Embodied and Operational CO₂ Footprint



System

For more information on the usage of this TinyML CO₂ Footprint Calculator, please see our paper and documentation at github.com/harvard-edge/TinyML-Footprint

Application Presets

Vision Classifier*Features Anomaly Detection Autocoder

TinyML ⚙️

ML Training

DenseNet 0.10 kg CO₂e MobileNetV1 1.00 kg CO₂e Custom Enter value

Custom ML Training kg CO₂e

Casing

ABS 200g/Steel 20g 0.04 kg CO₂e ABS 400g/Steel 80g 0.27 kg CO₂e ABS 700g/Steel 300g 0.63 kg CO₂e Custom Enter value

Custom Casing kg CO₂e

Processing

MCU 5 mm² 0.08 kg CO₂e MCU 10 mm² 0.17 kg CO₂e MCU 17 mm² 0.29 kg CO₂e Custom Enter value

Custom Processing kg CO₂e

PCB

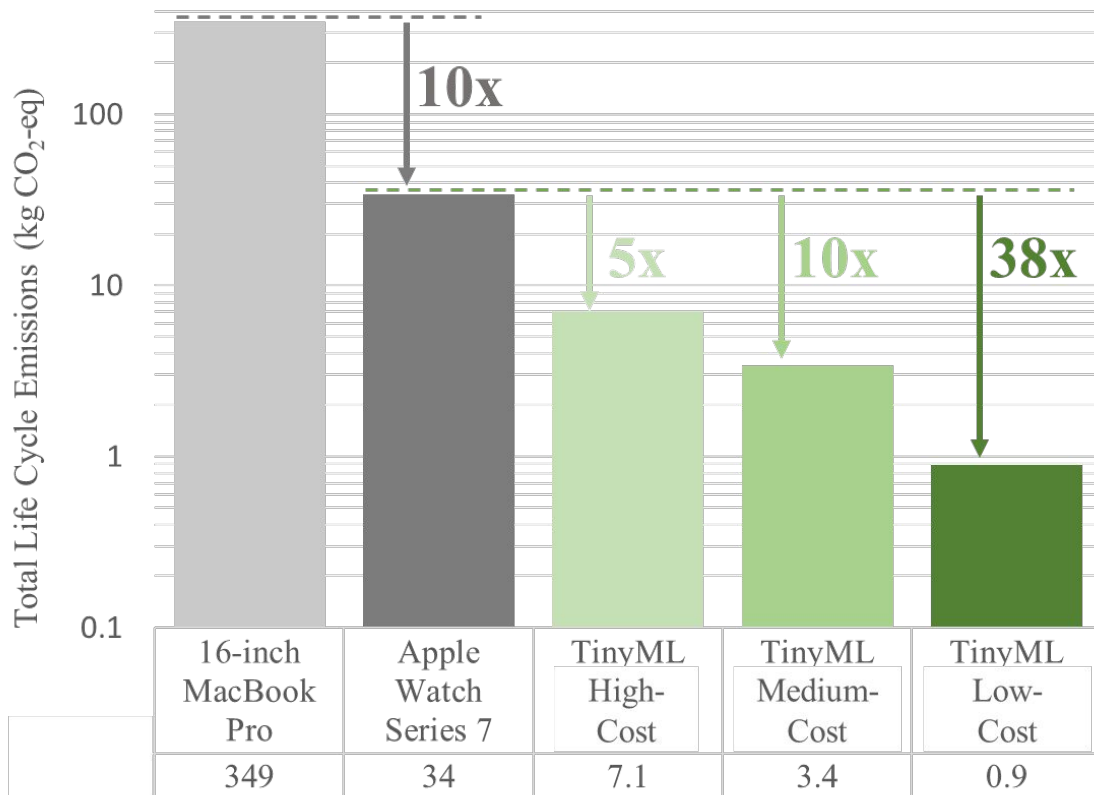
HSL-0 small 0.13 kg CO₂e HSL-0 typical 0.16 kg CO₂e HSL-0 large 0.24 kg CO₂e Custom Enter value

Custom PCB kg CO₂e

Power Supply



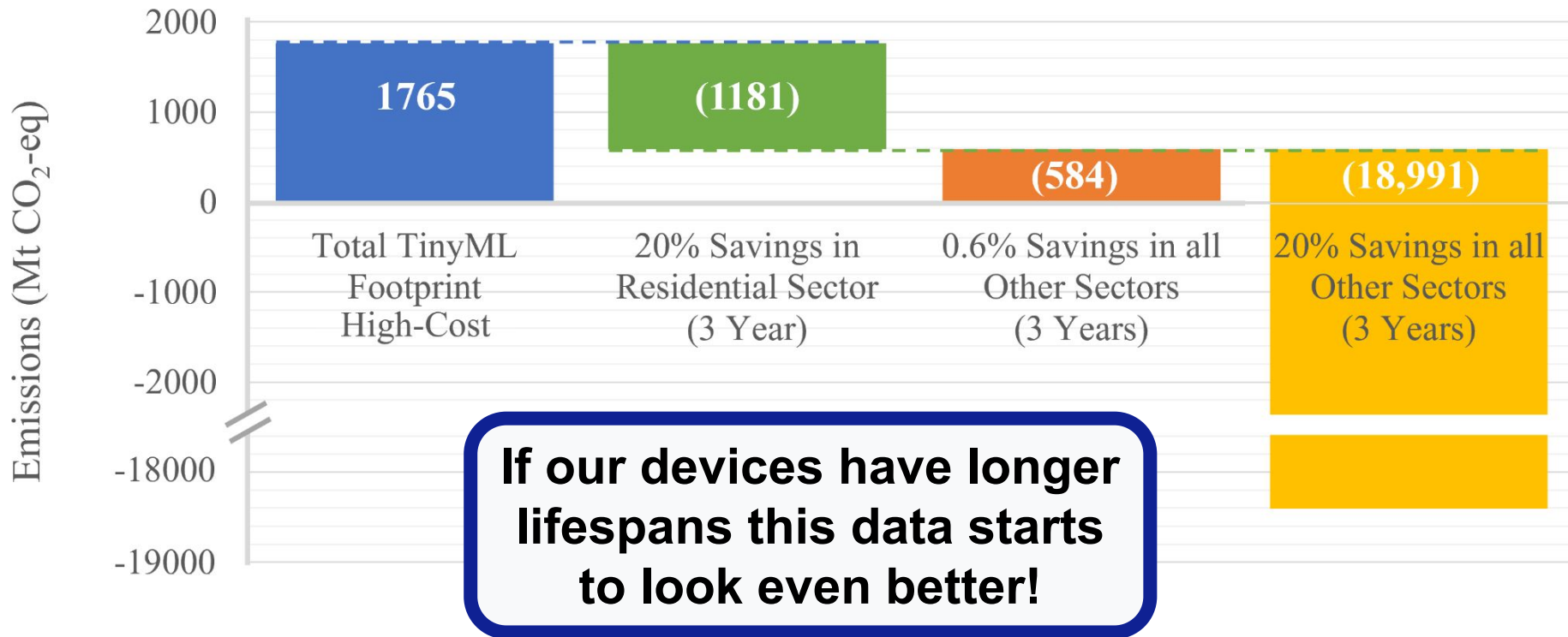
TinyML Systems in Context



**5x to 38x
Savings
over a
3-year
lifespan!**

Environmental Footprint of TinyML Systems at **Deployed Scale**

What if we scale to 250bn devices?



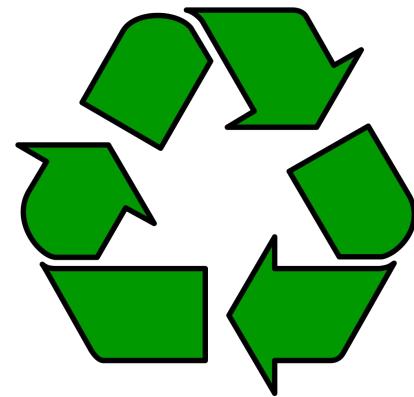
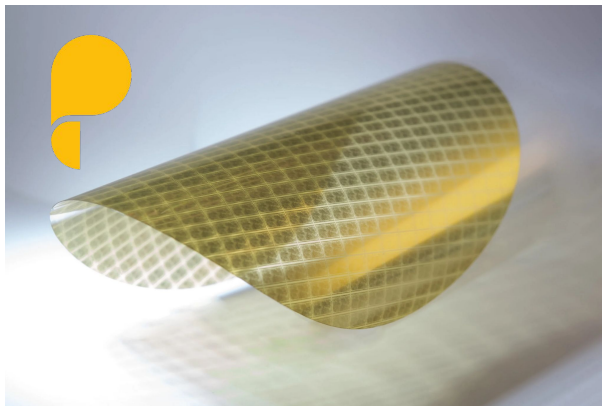
Limitations and Areas for Future Study

What about the net impact of factors **beyond carbon**?

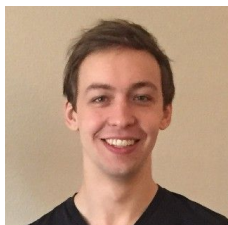
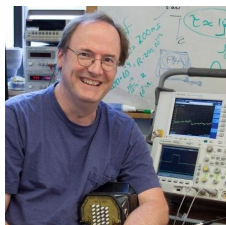
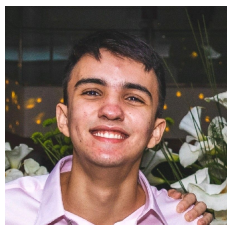
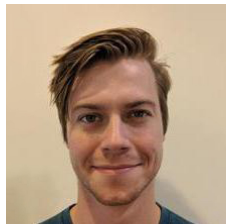
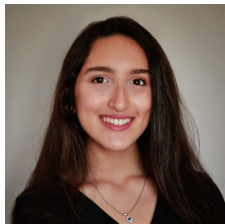
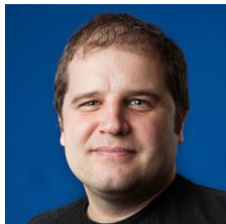
What about **Jevons' Paradox**?

What about the **human costs**?

How can **emerging technologies** help?




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