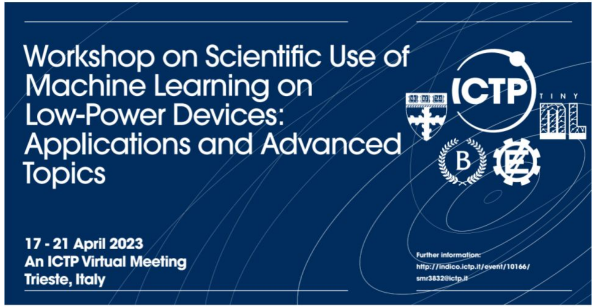
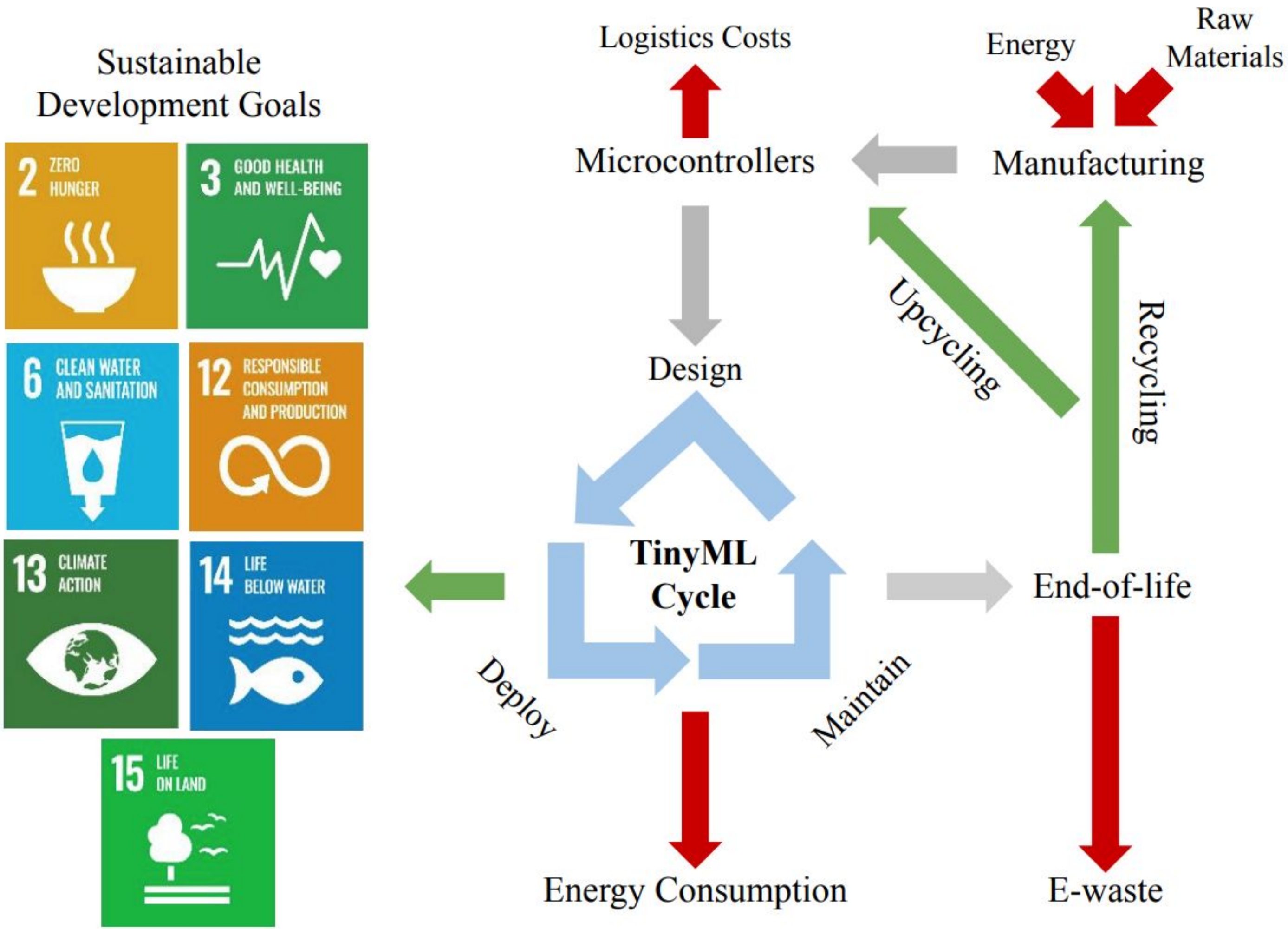


Is TinyML Sustainable?

Assessing the Environmental Impacts of Machine Learning on Microcontrollers

Brian Plancher
Barnard College, Columbia University
brianplancher.com



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

Is TinyML Sustainable?

Assessing the Environmental Impacts of Machine Learning on Microcontrollers

1. **Applications** of TinyML for Sustainability
2. Environmental Impact of an **Individual MCU**
3. Environmental Footprint of **TinyML Systems**
4. **TinyML at Scale**

Positive Effects of TinyML (1)

Environmental Footprint (2, 3)

Net Impact at Scale (4)

Applications of TinyML for Sustainability

TinyML Show and Tell

15:00 **Day Opening** *5′*

15:05 **Selected Show and Tell Talks** *5′*
Speaker: Brian PLANCHER (Barnard College, Columbia University, USA)

15:10 **Smart Poultry Farm: Tinyml-Based Disease Detection System Through Audio Signal** *20′*
Speaker: Segun ADEBAYO (Bowen University, Nigeria)

15:30 **Leveraging TinyML for Tracking Eidolon Helvum Movement Pattern and Forage Technique** *20′*
Speaker: Oluwatobi Halleluyah AWORINDE (Bowen University, Nigeria)

15:50 **Developing a "personal trainer" with TinyML** *20′*
Speaker: Ricardo CARMO (Federal University of Itajubá, Brazil)

16:10 **Sleep Apnea Detection System Using** *20′*
Speaker: Helen Neena GOVEAS (BITS Pilani, K K Birla Goa Campus, India)

16:30 **Rainfall estimation using Audio Monitoring and TinyML** *20′*
Speaker: Blessed GUDA (Carnegie Mellon University, Nigeria)

16:50 **Development of a TinyML Framework for Crop Disease Classification Tasks on Constrained Embedded Devices** *20′*
Speaker: Rehema Hamis MWAWADO (Sokoine University of Agriculture, Tanzania)

17:10 **Word recognition in Kichwa using audio and low-power devices: a machine learning approach for alert applications** *20′*
Speaker: Karina ORTEGA AVILÉS (Escuela Superior Politécnica del Litoral, Ecuador)

17:30 **DTMF Demodulation: A Brief Investigation of Machine Learning for Digital Signal Process** *20′*
Speaker: Umar Hadiza YUSUF (Carnegie Mellon University, Nigeria)

17:50 **Day Closing** *10′*

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

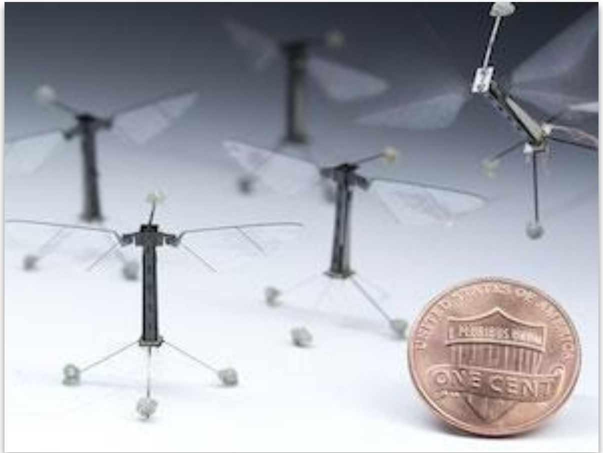
RESOLVE's AI camera transmits notifications of elephant detection and can **run for more than 1.5 years** on a single battery.

Credit: Tim Cole

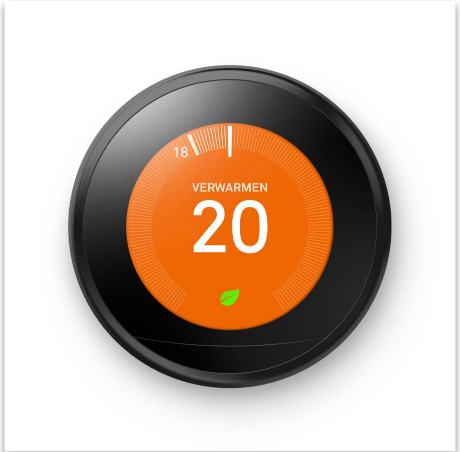
To prevent collisions with whales in busy waterways, Google deployed a TinyML model on hydrophones to alert ships.

Climate Action
(SDG #13)

Credit: Ribbit Network



Credit: Wyss Institute at Harvard University



Credit: Google Nest

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

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

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

Environmental Impact of an Individual MCU

How might you be able to quantify the environmental impact of an MCU?

- End of Life
- Logistics
- Use
- Raw Materials
- Production: Other
- Production: Energy Consumption

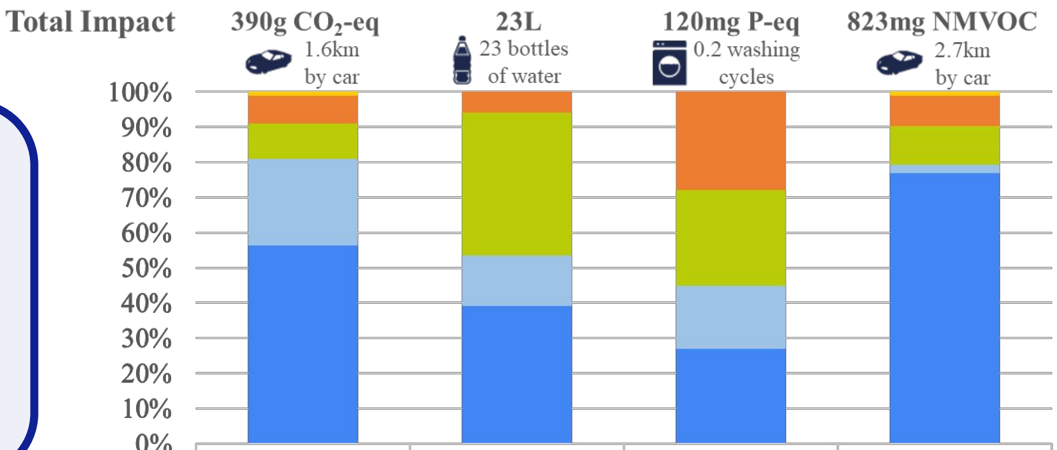
life.augmented

- Climate Change
- Water Demand
- Freshwater Eutrophication
- Protochemical Oxidant Formation

https://www.st.com/content/st_com/en/about/sustainability/sustainable-technology.html

Energy Consumption During Production Dominates the Small Footprint

Reuse of old MCUs would greatly improve their sustainability!



	Climate Change	Water Demand	Freshwater Eutrophication	Protochemical Oxidant Formation
End of Life	<1%	<1%	<1%	<1%
Logistics	1%	<1%	<1%	1%
Use	8%	6%	28%	8%
Raw Materials	10%	41%	27%	10%
Production: Other	25%	15%	18%	2%
Production: Energy Consumption	56%	39%	27%	71%

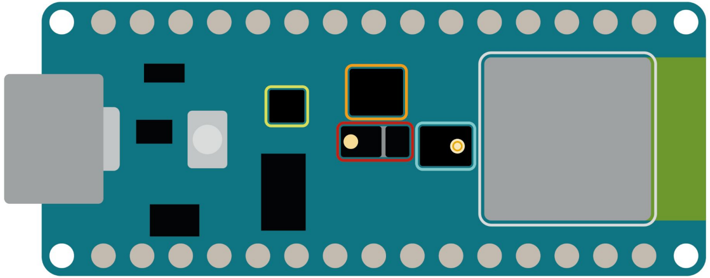
Environmental Footprint of TinyML Systems

Real TinyML Systems are more than just an MCU!

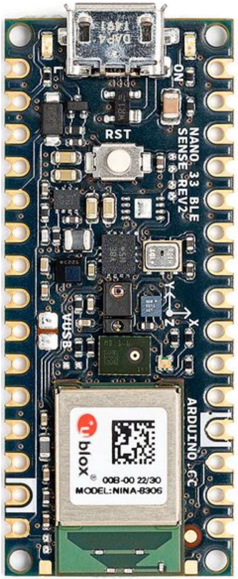
What else is in a TinyML System?

Sensors, Casing, Power Supply, and more!

Real TinyML Systems are more than just an MCU!



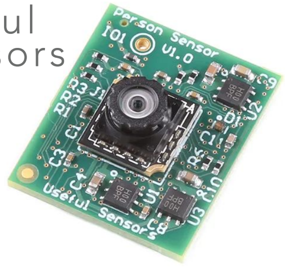
- Color, brightness, proximity and gesture sensor
- Digital microphone
- Motion, vibration and orientation sensor
- Temperature, humidity and pressure sensor
- Arm Cortex-M4 microcontroller and BLE module



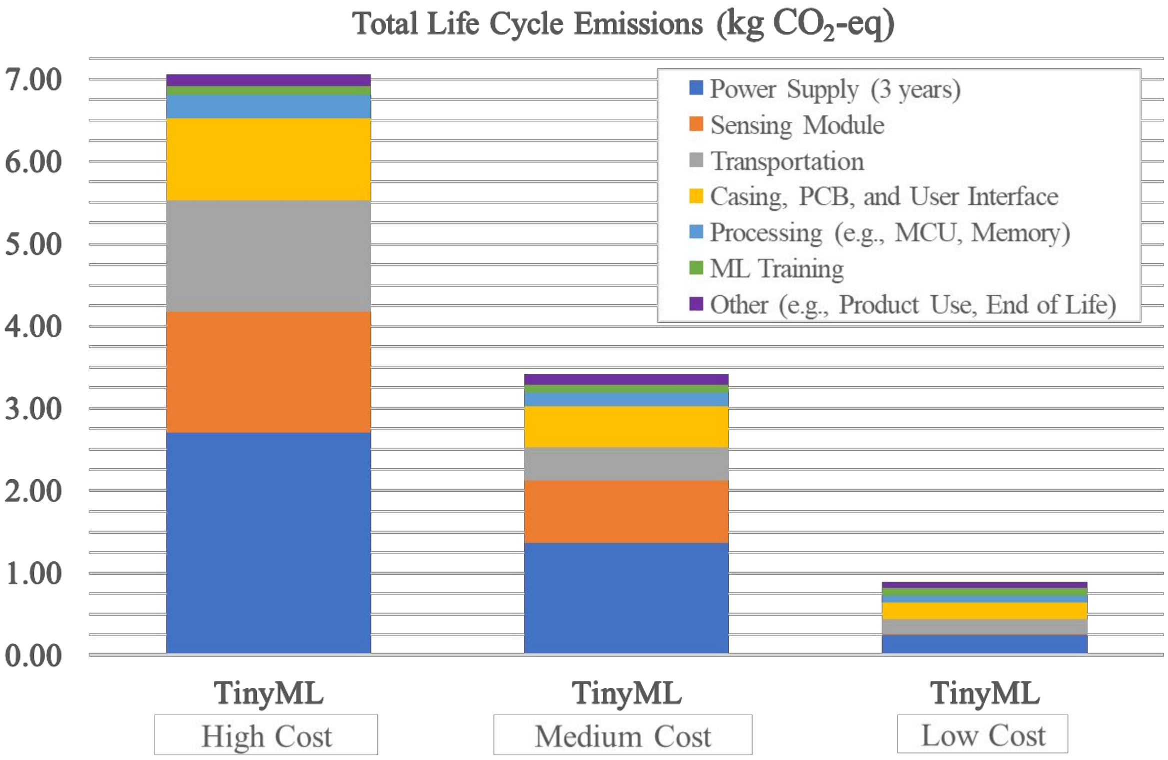
Building Representative Systems

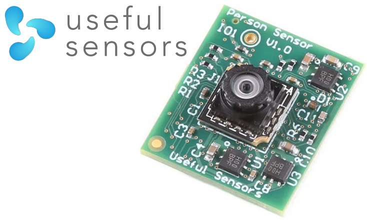
Cost Level	High Cost	Medium Cost	Low Cost
Application	Image Classification		Keyword Spotting
Size	Large	Compact	Compact

useful sensors

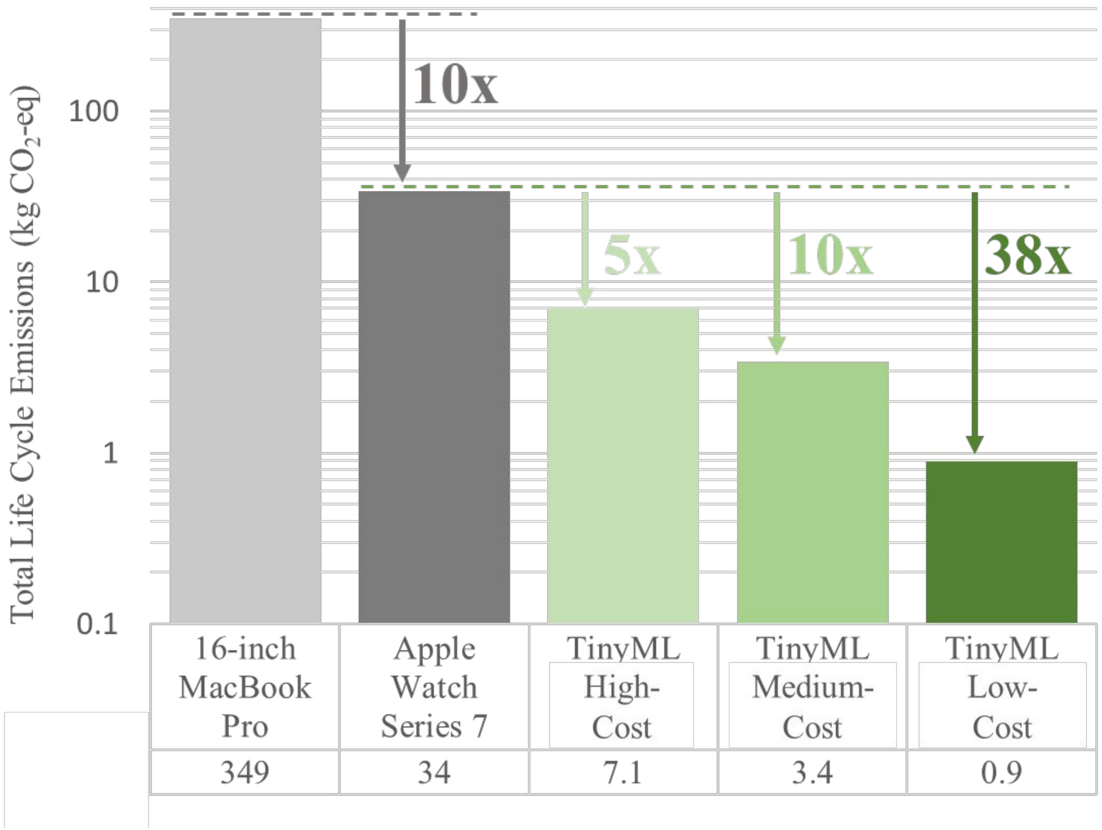


Building Representative Systems



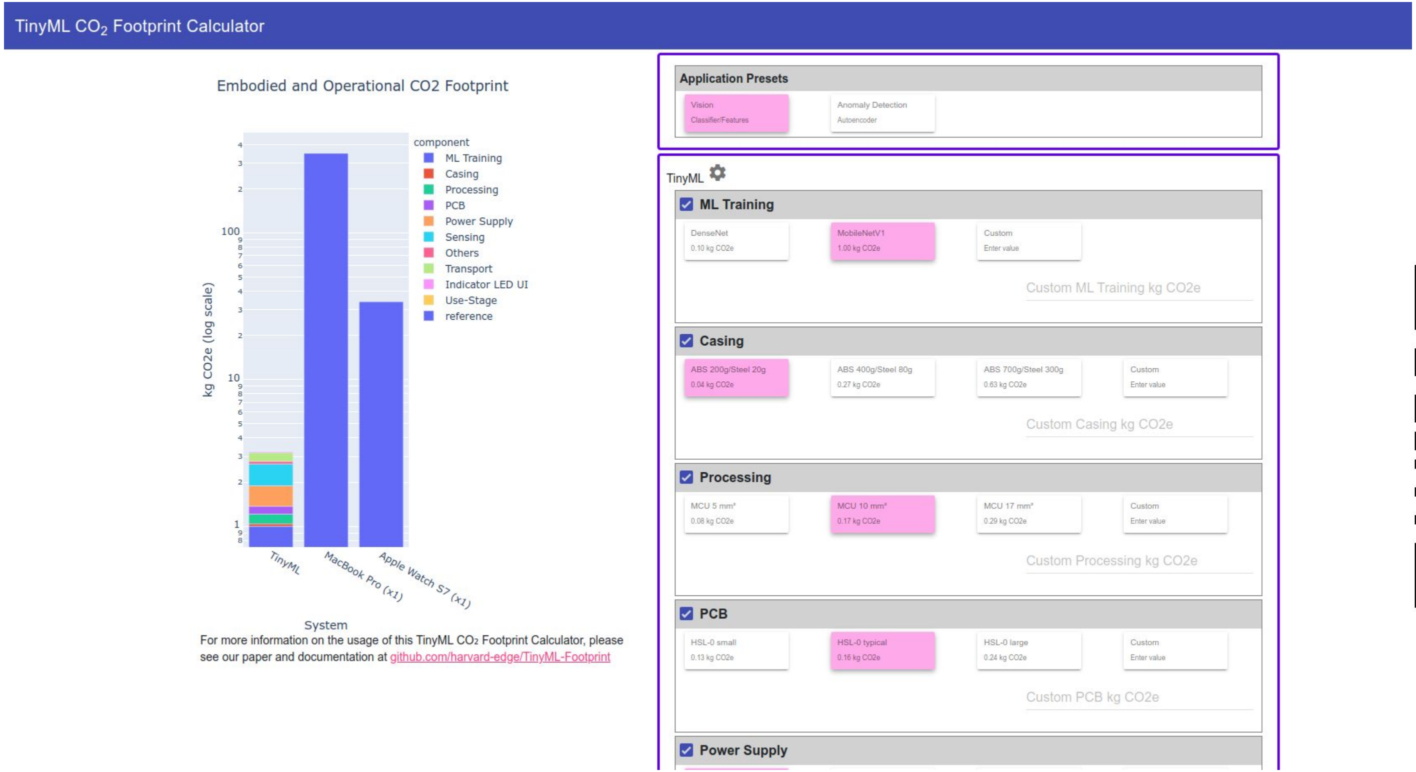


TinyML Systems in Context



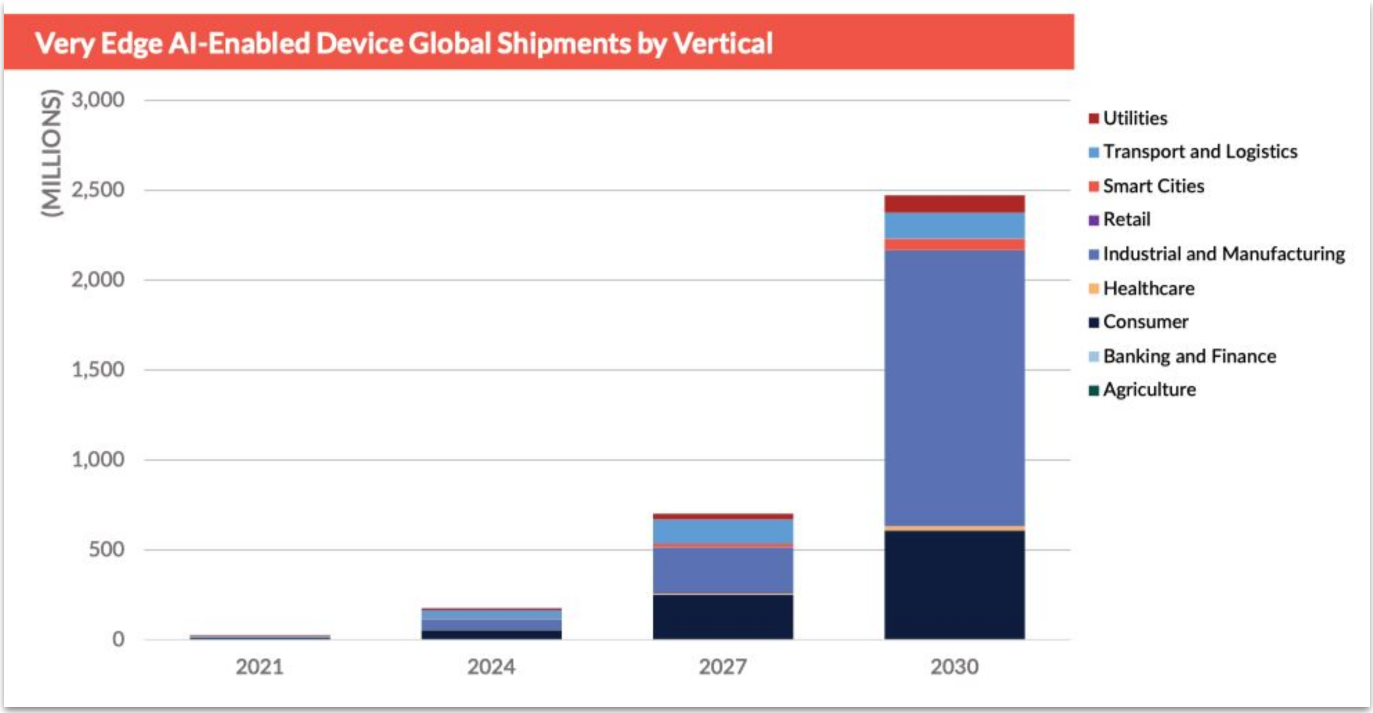
5x to 38x Savings over a 3-year lifespan!

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



TinyML at Scale

TinyML Market Forecast



Source: ABI Research: TinyML

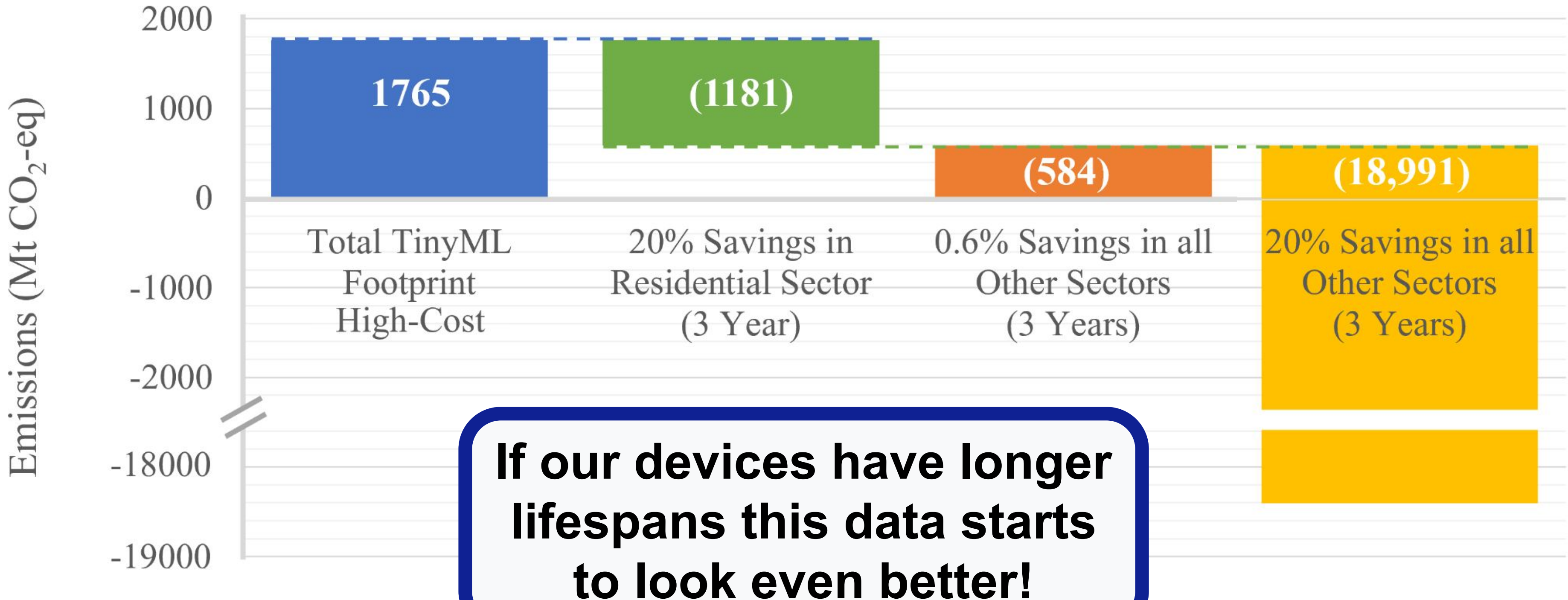
How many TinyML Devices are there?

There are around **250bn MCUs** deployed today and around **15bn IoT** devices

IoT Device Growth					
	~15 Billion	>50 Billion	>100 billion	>250 Billion	>1 Trillion
Linear	2023	2041	2067	2144	2531
Exponential	2023	2032	2036	2043	2053

https://www.statista.com/statistics/1183457/iot-connected-devices-worldwide/

What if we scale to 250bn devices?



If our devices have longer lifespans this data starts to look even better!

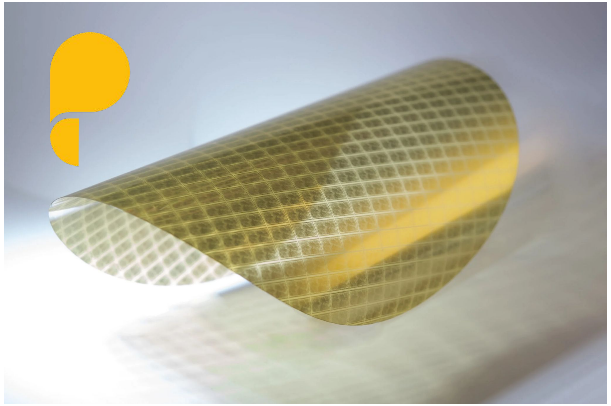
Limitations and Areas for Future Study

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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https://arxiv.org/abs/2301.11899