



Towards Netzero for the IC industry

Emily Gallagher

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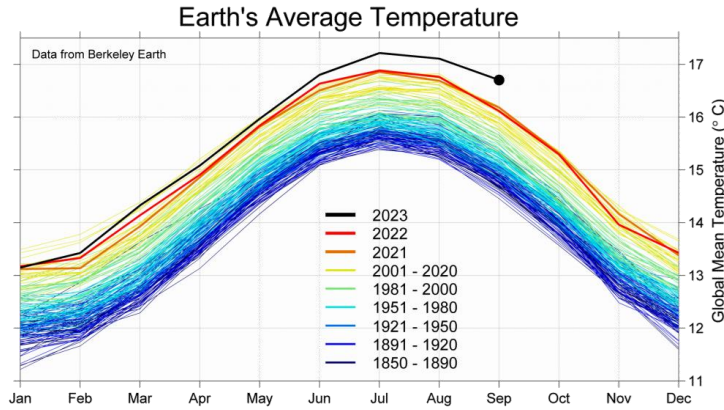
POWERED BY **imec**

The background is a dark blue field filled with a complex, low-poly geometric pattern of various shapes and sizes. A single, larger cube is positioned in the upper center, outlined with a bright blue, glowing wireframe. The overall aesthetic is futuristic and digital.

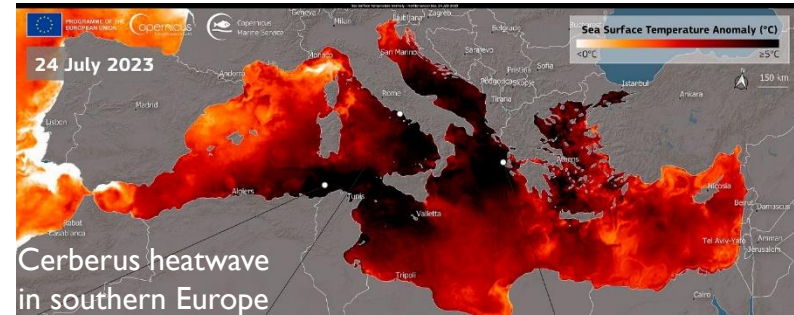
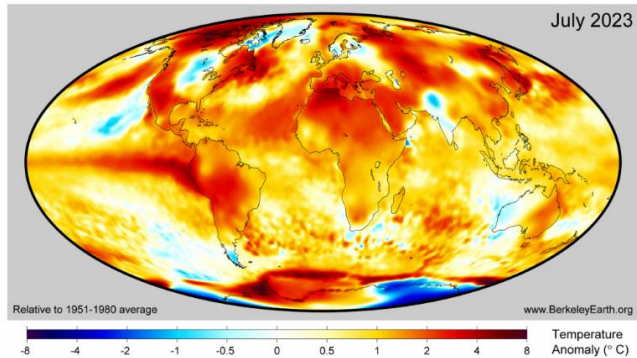
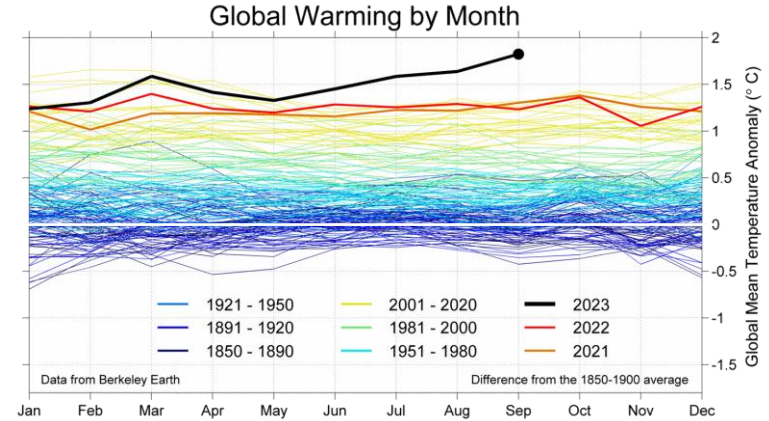
Where do we stand?
(The place)

2023 – A year of new climate records

July 2023: highest average surface temperature; September 2023: highest deviation measured

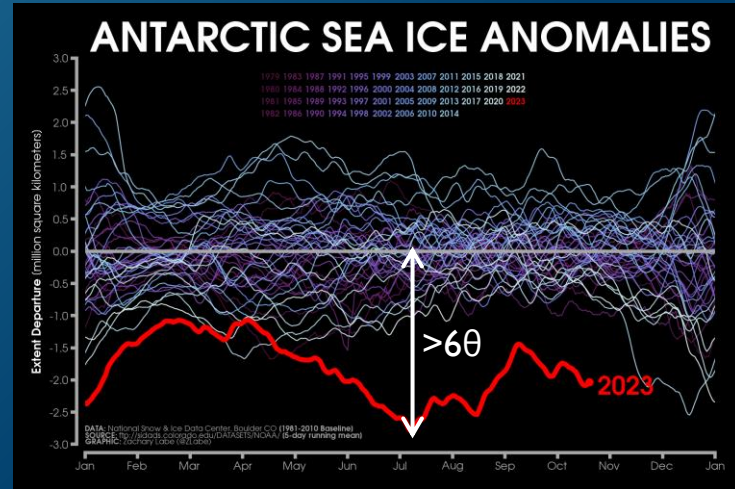
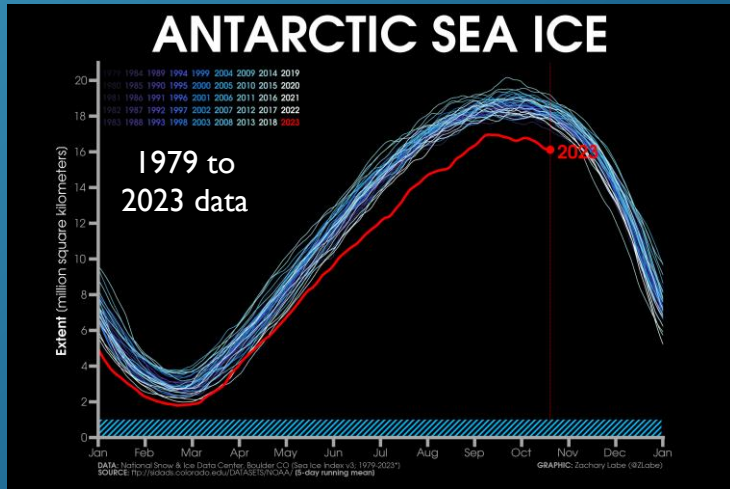


1850-1900
baseline



<https://berkeleyearth.org/september-2023-temperature-update/>
<https://earthobservatory.nasa.gov/world-of-change/global-temperatures>

Antarctic sea ice anomaly in 2023



Missing ice
the size of
Greenland

60 event:

- 1 chance in 500M to be caused by random fluctuations
- Platinum standard for “non-natural” cause
- This type of event may create chain reaction and system tipping

<https://zacklabe.com/antarctic-sea-ice-extentconcentration/>

<https://www.climate.gov/news-features/event-tracker/antarctic-sea-ice-reaches-early-winter-record-low-june-2023>

https://nsidc.org/data/seai_index

CO₂ emissions from semiconductor industry in perspective

~ 50 billion tons



World-wide

Source: <https://www.ipcc.ch/report/ar6/syr/figures/figure-2-1>
(Excluding land use, land-use change and forestry)

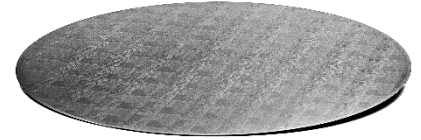
~ 1.2 billion tons



ICT Industry

Source: Freitag, C. Et al. 2021.
<http://arxiv.org/abs/2102.02622>

~ 175 million tons



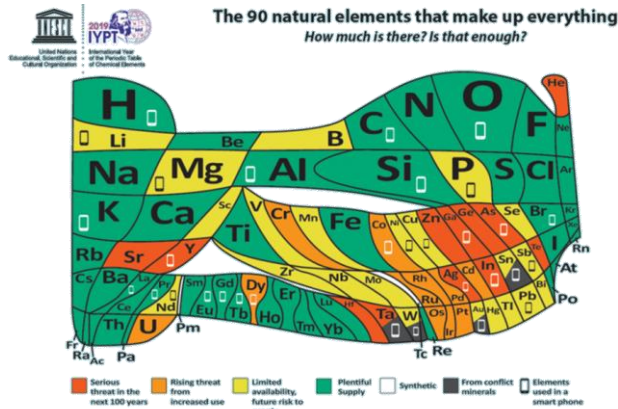
Semiconductor
manufacturing

Includes Scope 1, scope 2 and scope 3 consumables and services. For industry in 2021.

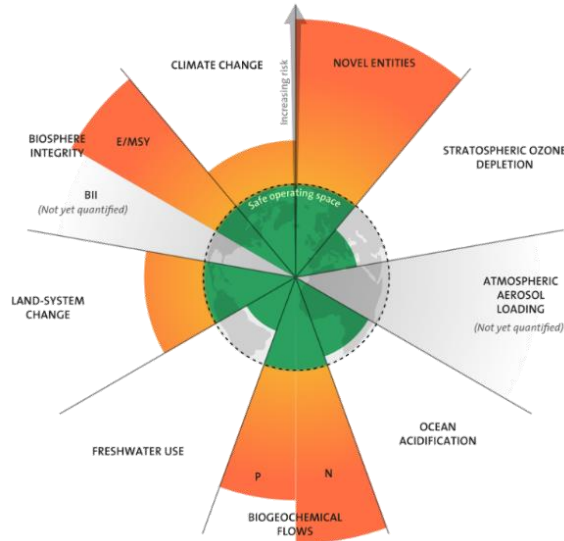
Source: SEMI SCC Whitepaper on Transparency, Ambition, and Collaboration - 2023

Other areas of concern

Stress points beyond climate change



Resource depletion and geopolitical tensions on material sourcing



Other planetary boundaries



Toxic substances

Credits:

- Azote for Stockholm Resilience Centre, based on analysis in Persson et al 2022 and Steffen et al 2015.
- <https://www.euchems.eu/newsletters/euchems-periodic-table-element-scarcity-in-the-spotlight/>
- Health and Environment Alliance | [How PFAS chemicals affect women, pregnancy and human development: Health actors call for urgent action to phase them out \(env-health.org\)](https://www.env-health.org/)



Towards netzero (The characters)

Semiconductor & tech companies accelerating on sustainability

A selection of press releases

News - 28 August, 2023

ASM first in semiconductor industry to have net-zero target verified by SBTi

Almere, The Netherlands
August 28, 2023

[Press releases | ASM](#)



Advanced materials for sustainable electronics

April 21, 2023 [Press release Air Liquide](#)



Transparency, Ambition, and Collaboration:

Advancing the Climate Agenda of the Semiconductor Value Chain

[SCC White Paper](#)



Apple unveils its first carbon neutral products

The new Apple Watch lineup marks major progress toward ambitious Apple 2030 climate goal



[Product Environmental Report](#)



January 31, 2023

[Press Release Amazon](#)



Amazon Sets a New Record for Most Renewable Energy Purchased by a Single Company

TSMC Accelerates Renewable Energy Adoption and Moves RE100 Target Forward to 2040

Issued by: TSMC
Issued on: 2023/09/15



[Press release TSMC](#)

 [TSMC Accelerates Renewable Energy Adoption and Moves RE100 Target Forward to 2040](#)

Do not discount embodied carbon

- **Operational emissions** are the sum of all GHG emissions required to operate the product during its lifetime
- Product performance is key in reducing use phase emissions & costs
- **Embodied emissions** are the sum of all GHG emissions required to bring any given product to market
- Given the **complexity of quantifying** embodied carbon, it may be **ignored** during design phase

Why Embodied Carbon is a poor Architecture Design metric, and Operational Carbon remains an important Problem

by Andrew A. Chien on Jul 24, 2023 | Tags: Accelerators, amd, apple, Cloud computing, Datacenters, embodied carbon, intel, nvidia, operational carbon, qualcomm, Sustainability, tsmc

[Link to Sigarch blogpost 1](#)

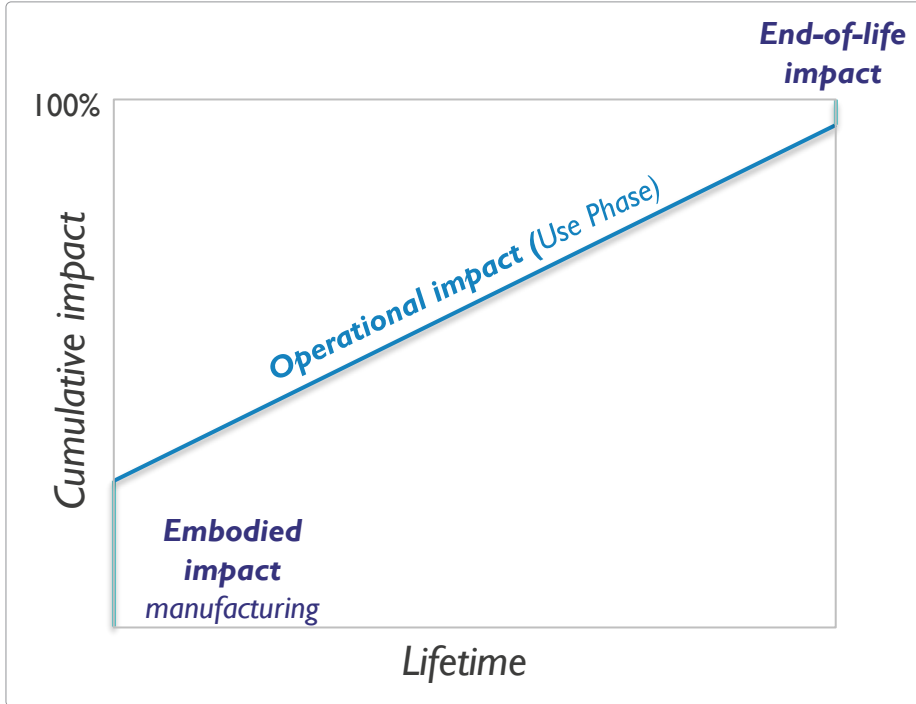
[Link to Sigarch blogpost 2](#)



ACM SIGARCH

Embodied vs. operational impact

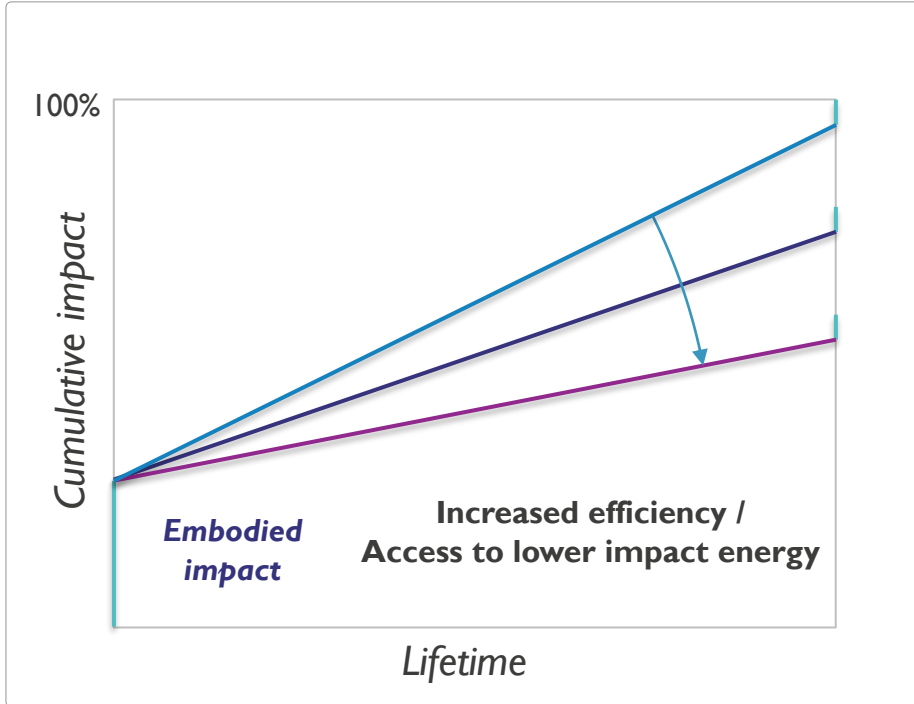
Or the importance of systemic thinking



- A product (e.g. *IC chip*) or a system (e.g. *datacenter*) accumulates impact (e.g. $\text{kgCO}_{2,\text{eq}}$) during its lifetime

Embodied vs. operational impact

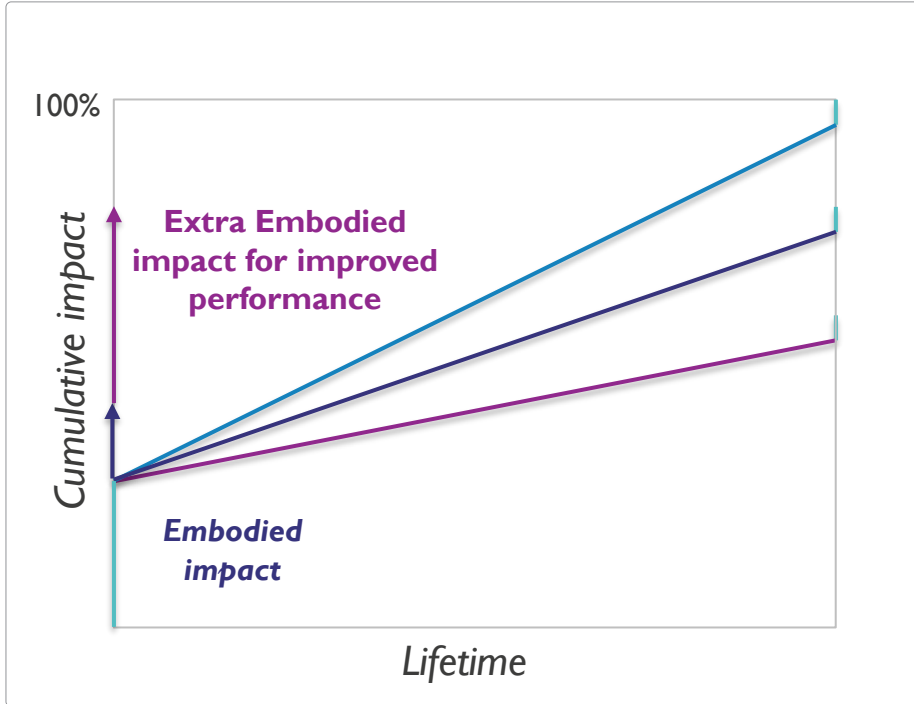
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Embodied vs. operational impact

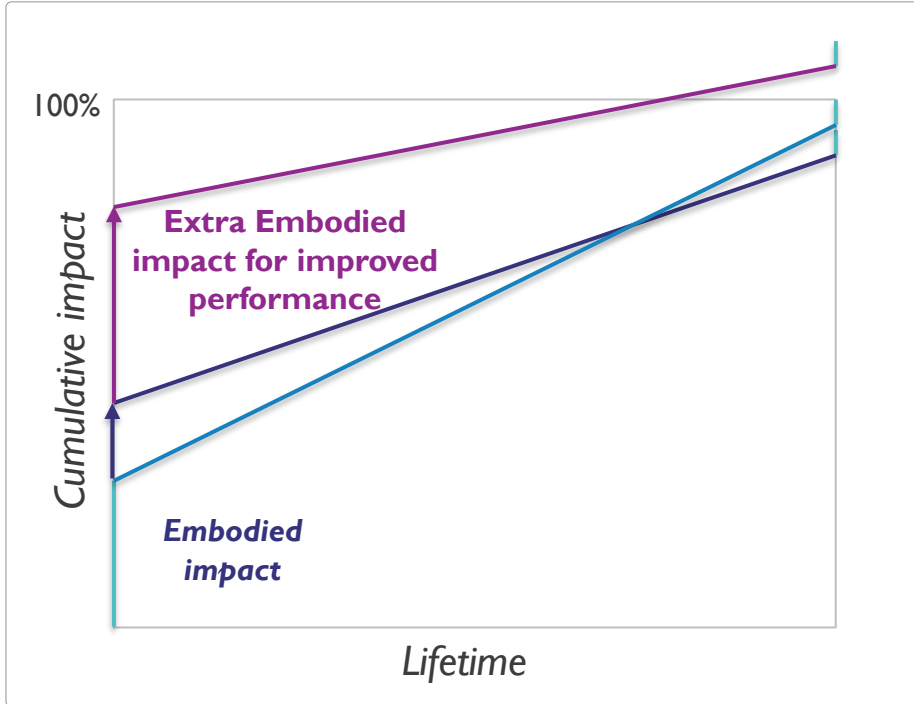
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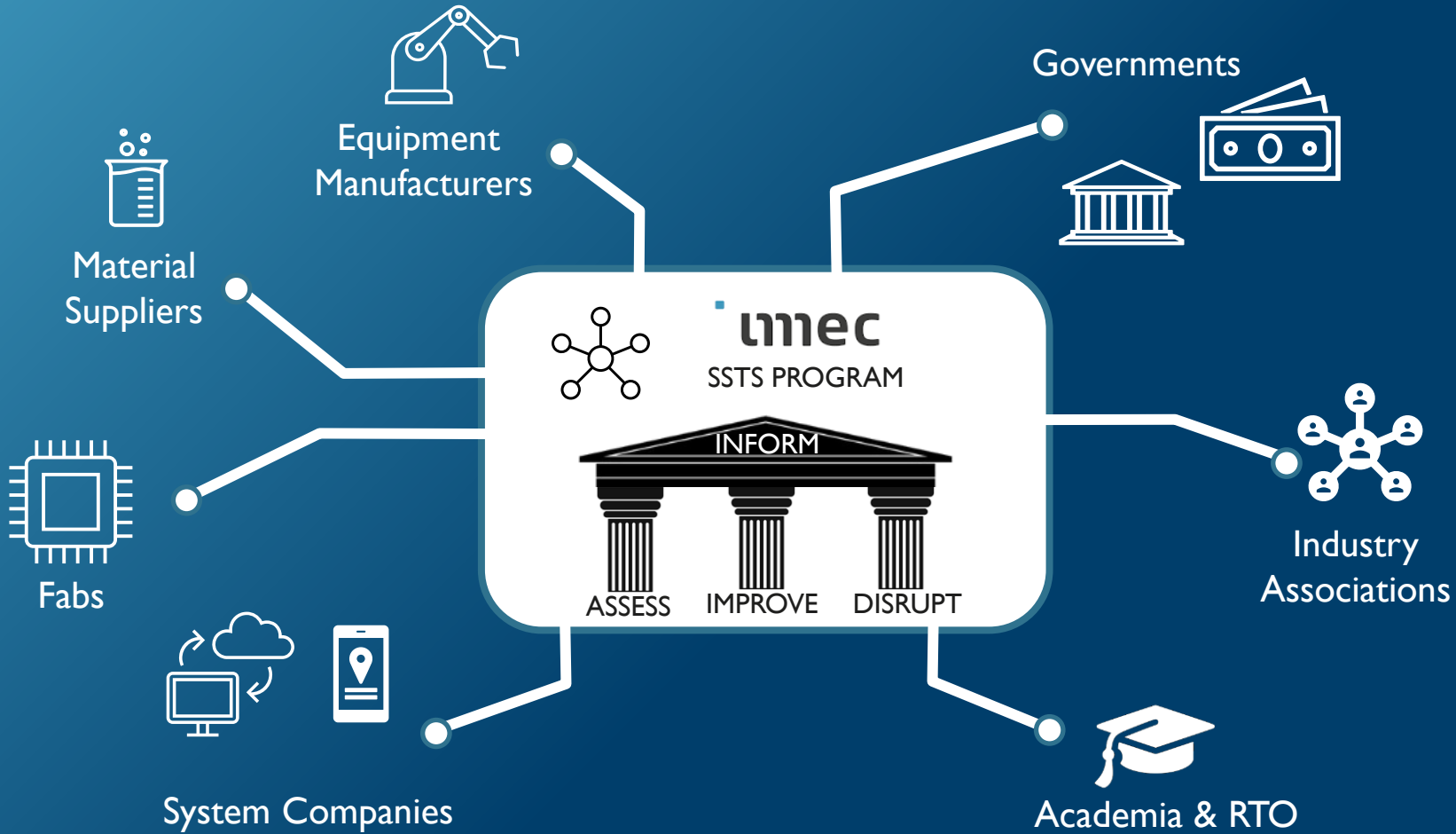
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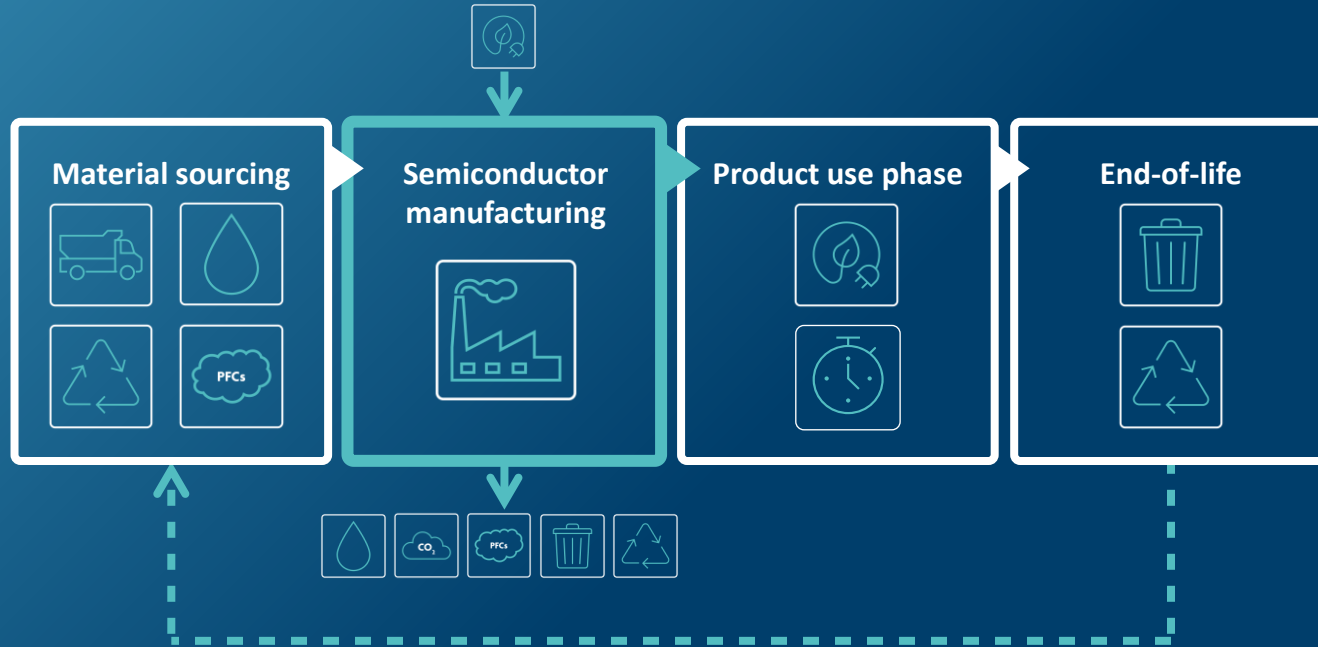


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- **AVOID SHIFTING BURDENS**
 - Pursue a holistic, life cycle approach



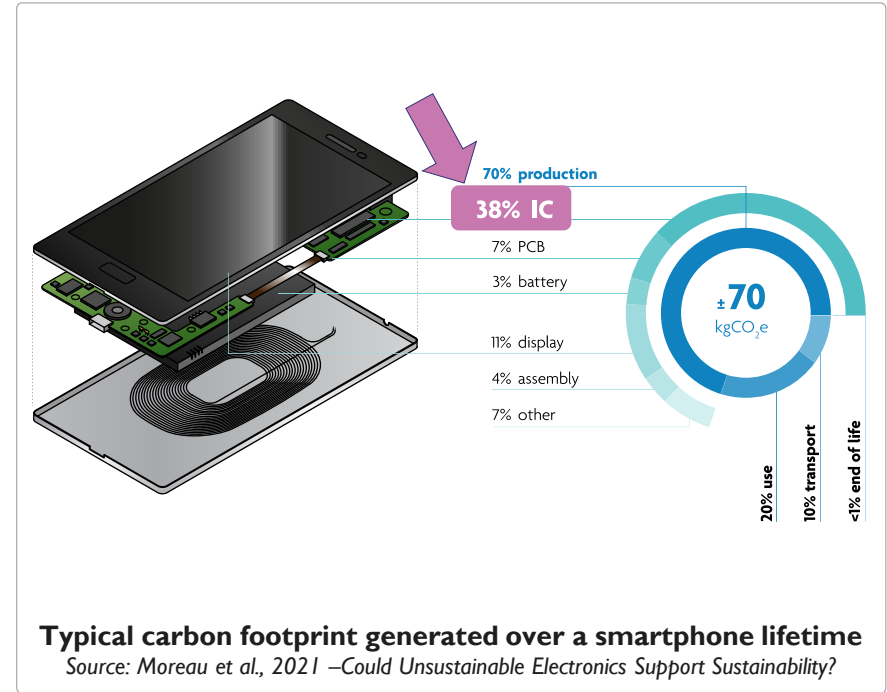
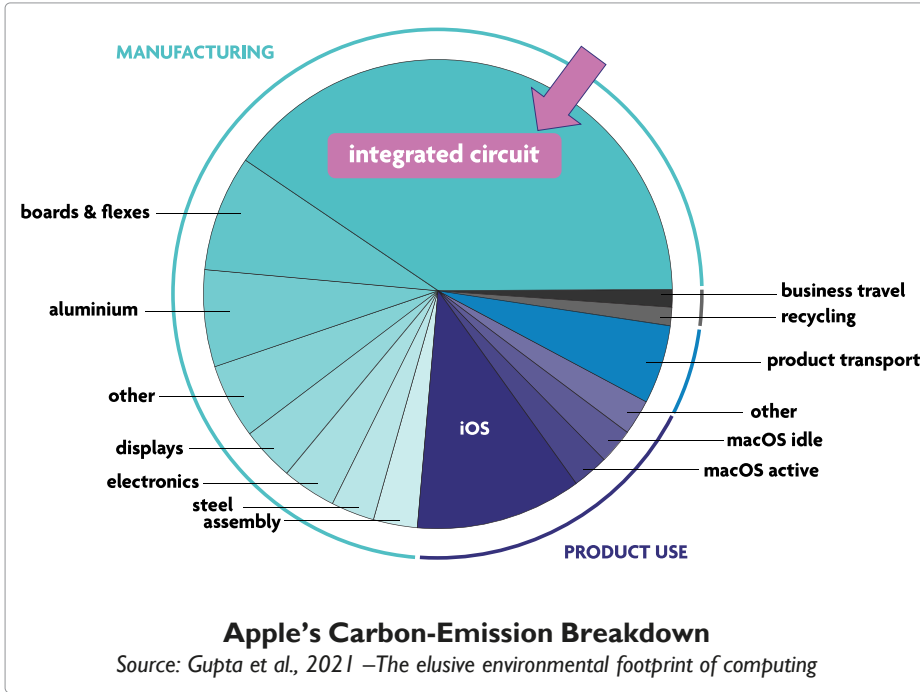
Putting the E in PPAC-E

Virtual fab model



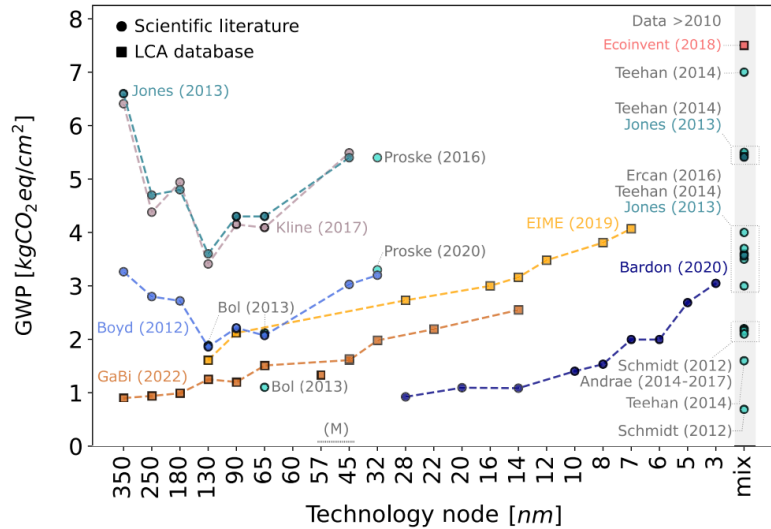
The climate impact of consumer electronics manufacturing

Life Cycle Assessment (LCA)



IC chip manufacturing accounts for the largest share of the climate impact, dominating the product use phase

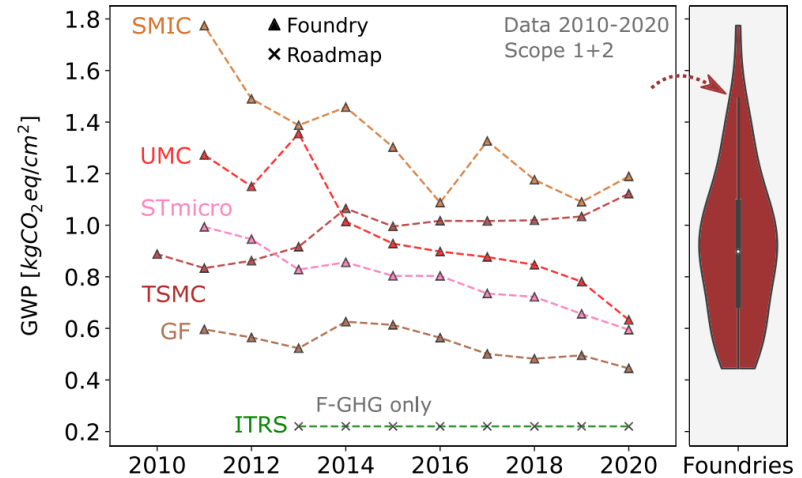
Current LCA situation: varied and outdated



Literature and LCA database data:

- Variable scope
- Variable sources (primary vs. secondary)
- Variable approaches (e.g. bottom-up vs top-down)
- Data gaps require “creative” plugging methods

Source: Pirson et al., 2023 – The Environmental Footprint of IC Production: Review, Analysis, and Lessons From Historical Trends



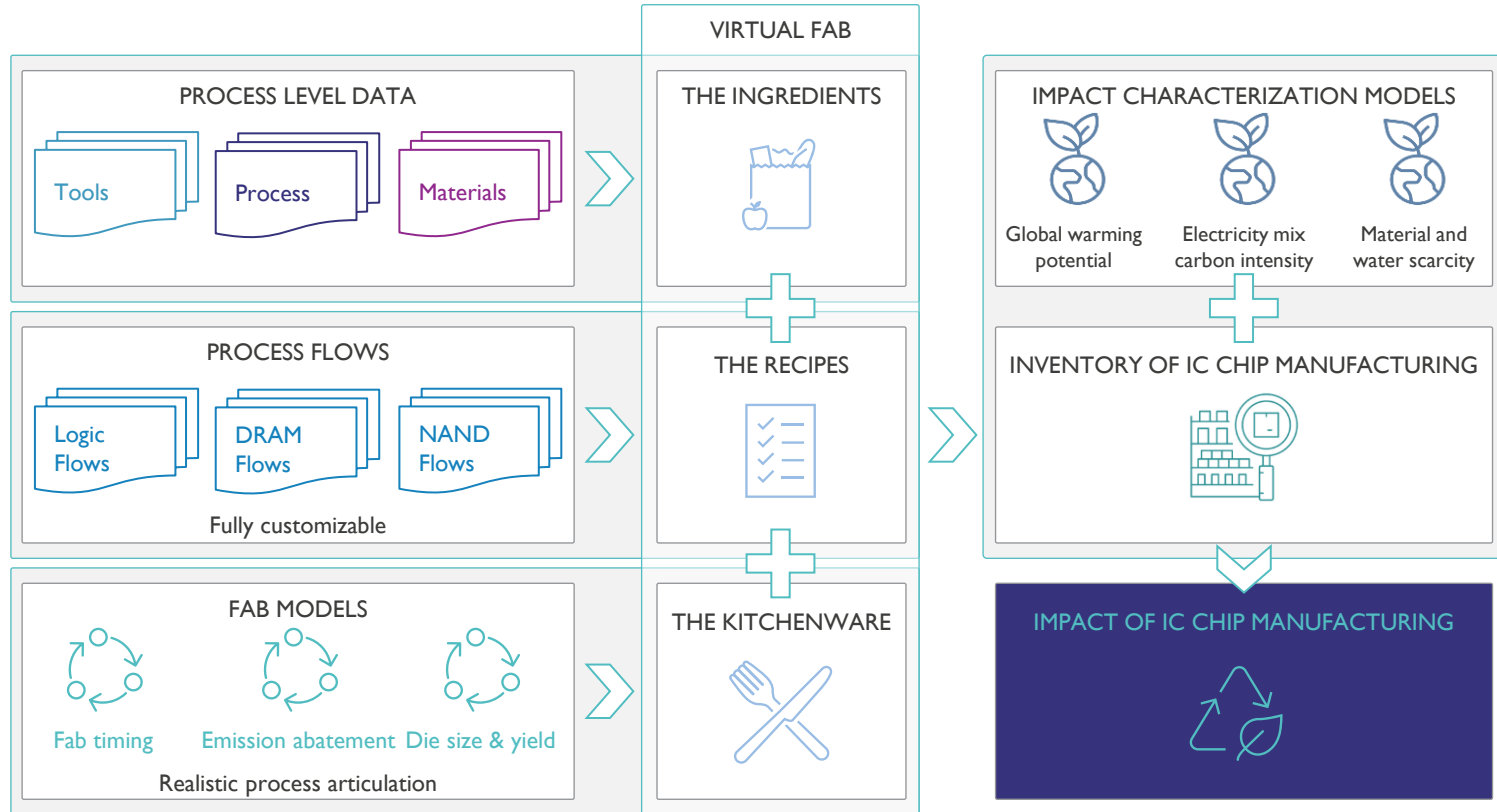
Industry data from public corporate social responsibility report:

- Top-down, primary sourced data
- Aggregated over entire company operation, not “per chip” or “per-node”
- Limited scope
- Non-transparent methodology

GWP: Global Warming Potential

imec.netzero – a bottom-up virtual fab model

Quantify the footprint of a chip



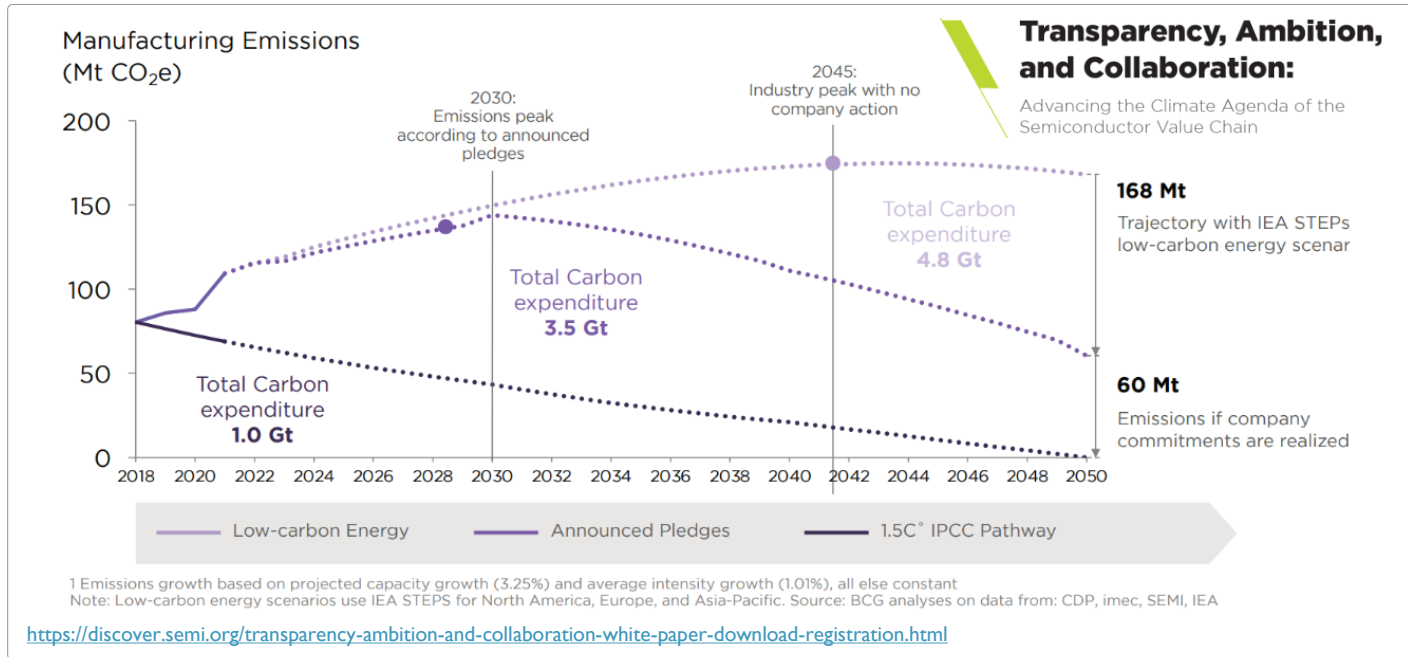
The background is a dark blue field filled with a complex, isometric pattern of light blue and white geometric shapes, primarily cubes and rectangular prisms, creating a sense of depth and architectural structure. A single, glowing blue wireframe cube is positioned in the upper center, appearing to float or be highlighted above the main pattern.

Levers towards netzero (The action)

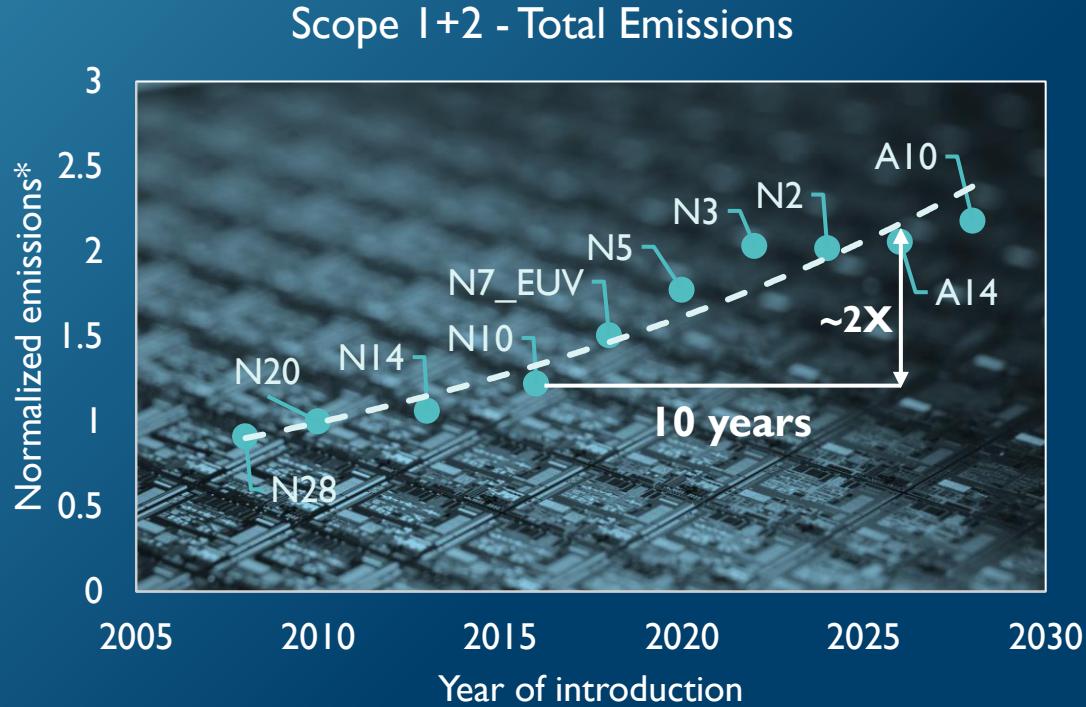
Where are we heading?

Scope 1 and 2 of the IC industry

- Accounting for industry growth → significant **increase** in emissions are expected
- Accounting for announced pledges → significant **gap remains**



Evolution towards future logic nodes: growth without action



**imec.netzero v2.0.1: emissions estimate of imec process nodes representative of foundry nodes. 0.454 kgCO₂eq/kWh assumption for electricity*

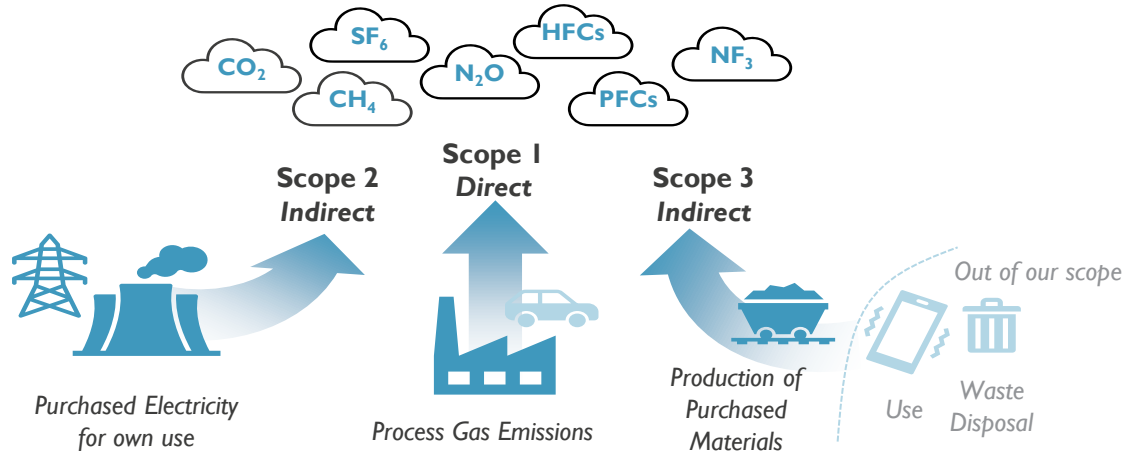
Photo by [Laura Ockel](#) on [Unsplash](#)

Levers towards netzero IC manufacturing

Per GHG protocol scopes from the fab perspective

Act on the three scopes to reduce:

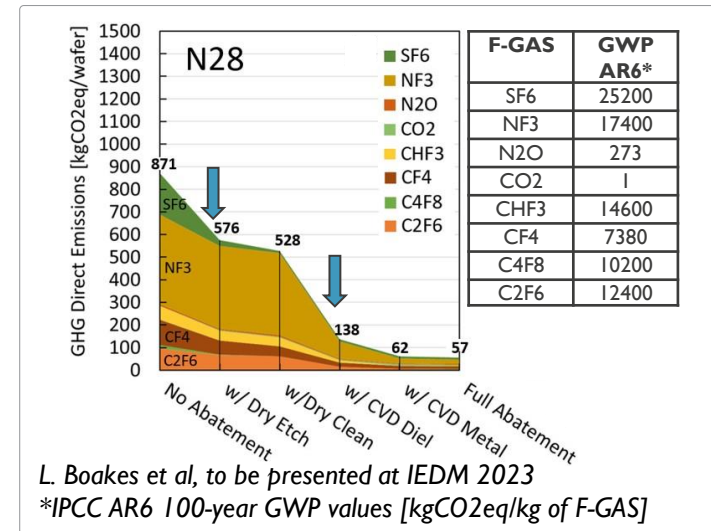
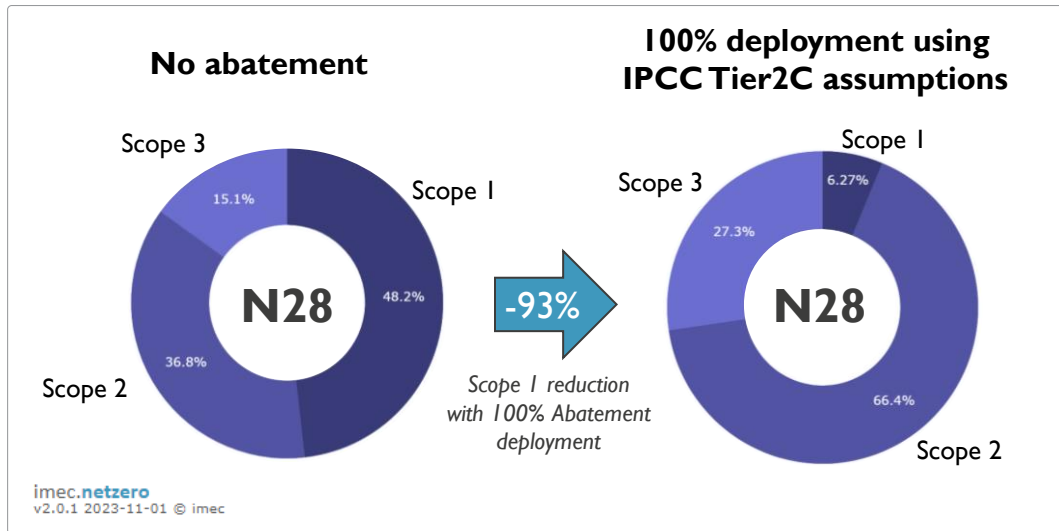
1. direct emissions through abatement and replacement
2. electrical energy impact with improved efficiency and clean energy
3. upstream material impact by leveraging the supply chain to reduce *their* scopes 1 to 3...



Scope I: reduction with efficient abatement

Levers towards netzero IC manufacturing

- F-GHG has very significant impact due to their high GWP
 - Pursue lower GWP process gases
 - **Apply abatement: deploy optimize and maintain**



Scope I: measurements

Levers towards netzero IC manufacturing

- Gap between atmospheric measurements and estimated emissions is large
- NF_3 levels in the atmosphere increase at a 12% yearly rate.
 - Since NF_3 is almost only used by the Semi industry this is very concerning
- Model **assumptions*** and/or **reporting** must be improved

*Destruction efficiency, utilization efficiency

Fluorinated greenhouse gas and net-zero emissions from the electronics industry: the proof is in the pudding

Sébastien Raoux

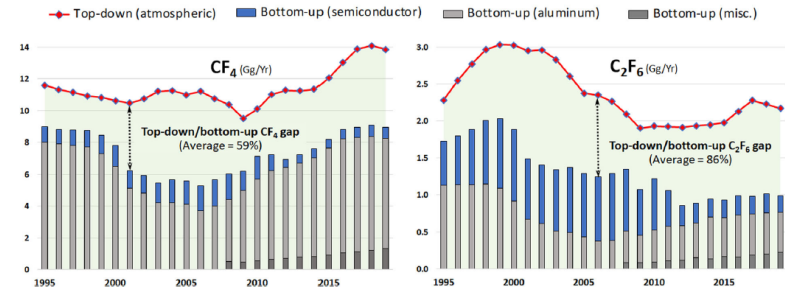
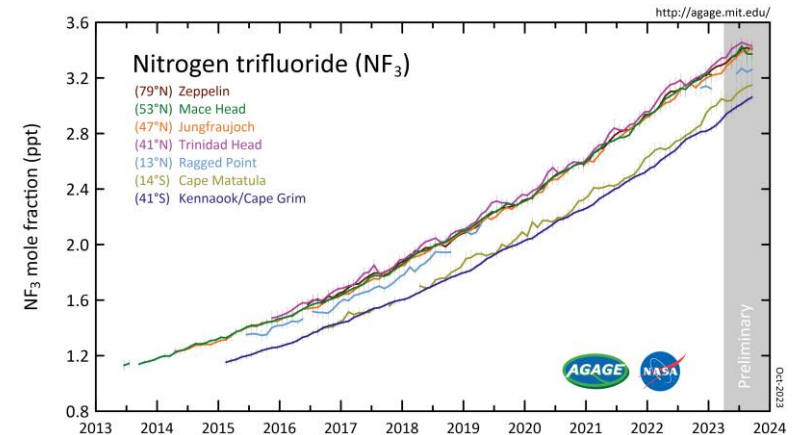


Figure 2. Global top-down and bottom-up emissions of CF_4 and C_2F_6 between 1995 and 2019. Compiled and reproduced with permission from Kim et al. [13,14] and Trudinger et al. [15].

<https://www.tandfonline.com/doi/full/10.1080/17583004.2023.2179941>

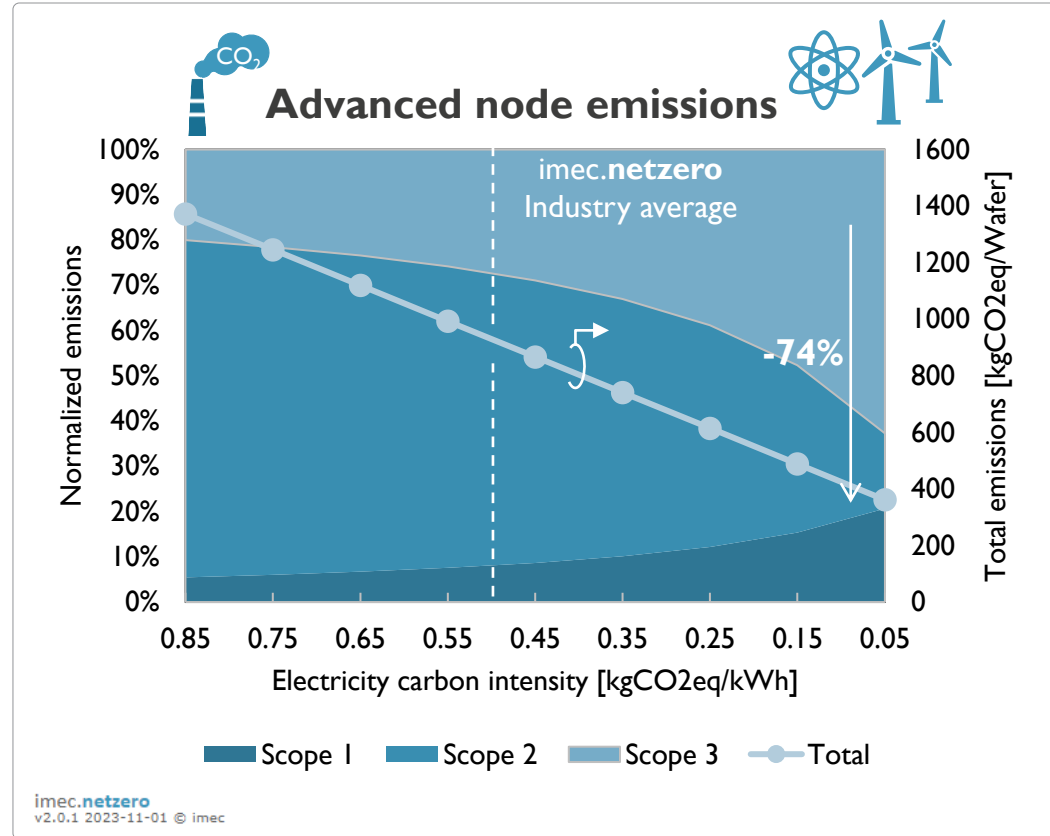


<https://agage.mit.edu/data/agage-data>

Scope 2: efficiency and cleaner energy are significant

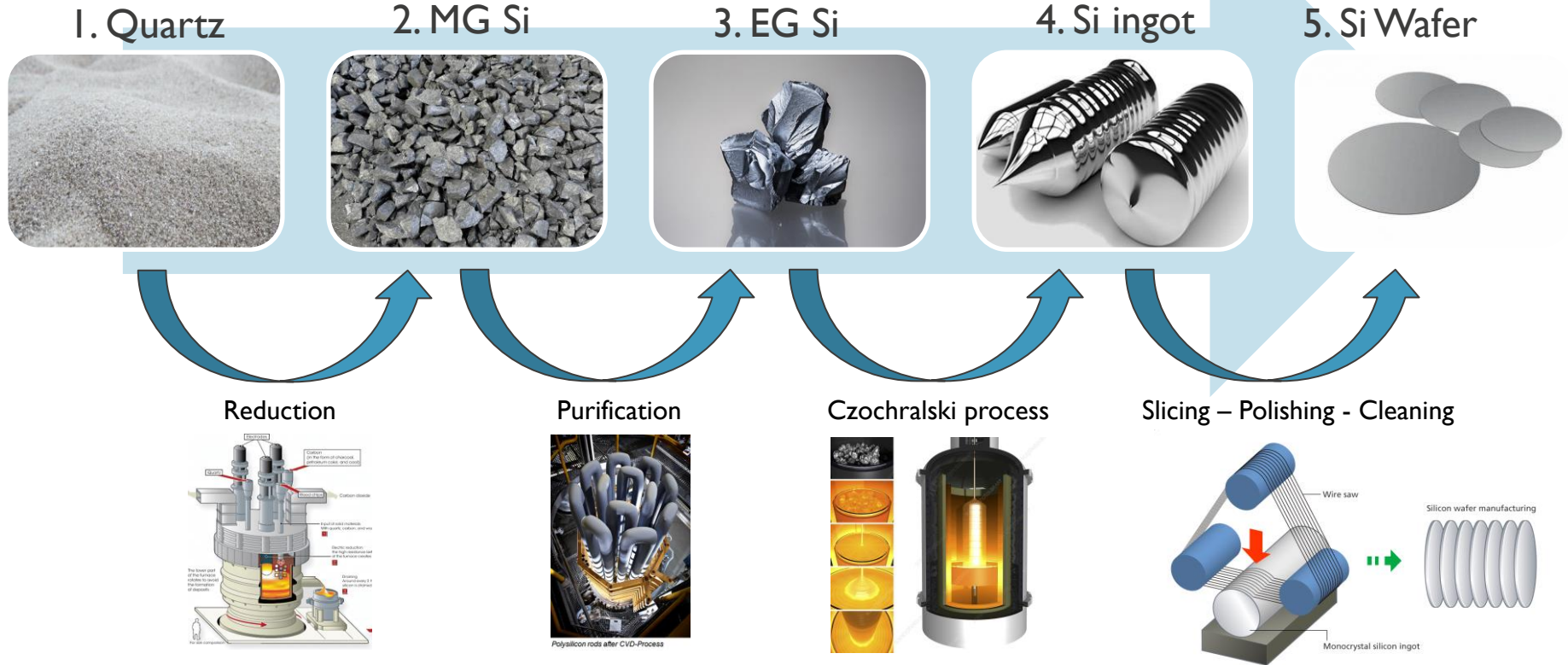
Lever towards netzero IC mfg

- Moving from a coal-based to low-carbon energy
 - Decreases total emissions by 74%
Scope 2 importance is reduced from 75% to 17%
- Improved **efficiency** and abundant **low carbon** energy is essential



Scope 3: upstream material emissions – very complicated

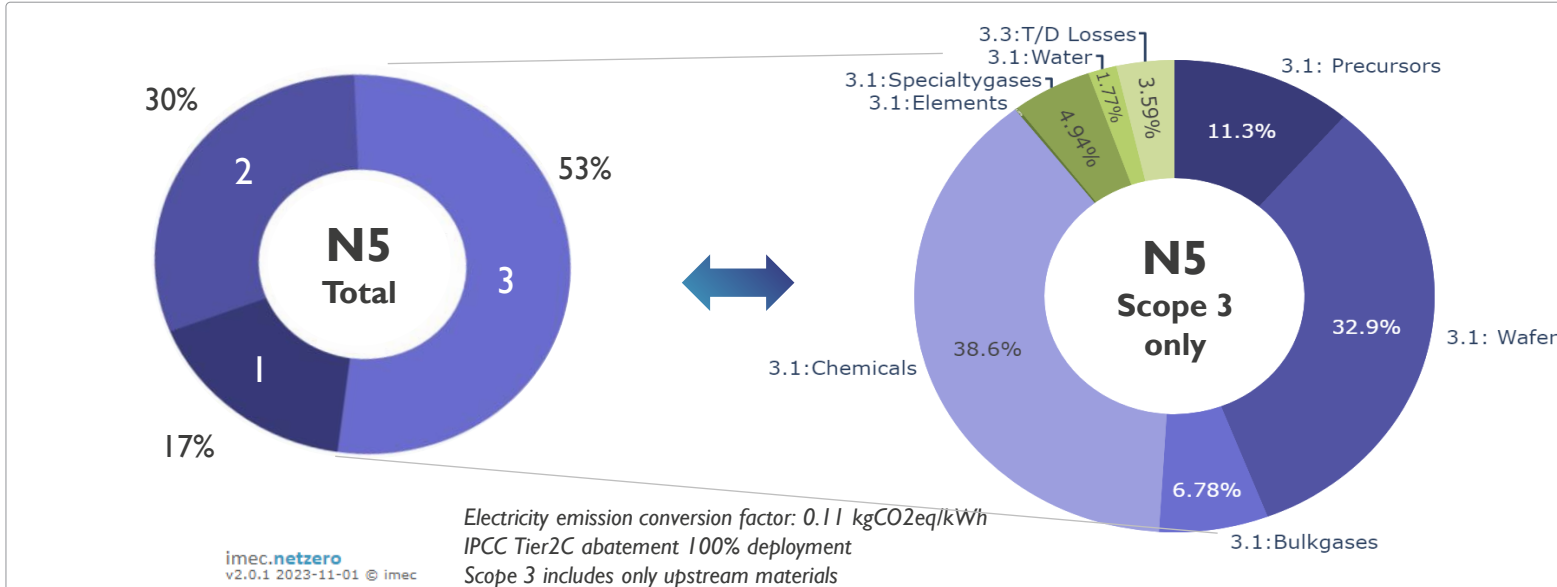
Full supply chain must be involved



Scope 3: our current estimates, but they will grow

Full supply chain must be involved

- Scope 3 dominates when electricity of the fab* is low-carbon (upstream materials)
 - Underestimated - material emission conversion factors** are mostly not semiconductor grade
- **Collaboration towards lower impact materials is crucial**



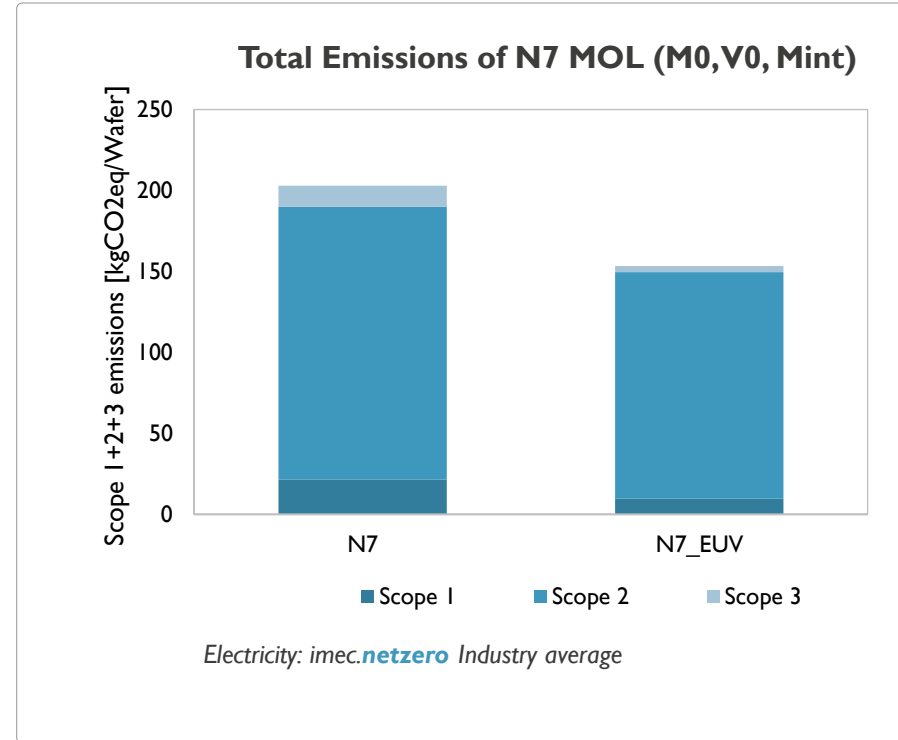
* Emissions from material production is assumed constant when the fab change its electricity

** Emission conversion factors are from Ecoinvent 3.9.1, Ashby 2022 (elements)

Example: process decision informed by environmental impact

Example of EUV introduction in MOL in N7

- Middle of the line (MOL) process change for N7
 - 193i SADP M0 + 193i LELELE V0
→ EUV LE for M0 and V0
 - 3x fewer mask layers; 2.4x fewer process steps
- **Total MOL reduction in emissions: -24%**
 - Scope 1 (fewer etch and deposition steps): -71%
 - Scope 2 (fewer steps, more energy for EUV): -17%
 - Scope 3 (less materials): -54%
- Holistic and outside-of-box thinking is crucial; Innovation guided by PPAC-E



Another example in ITF Europe 2023.

“High NA EUV introduction – a sustainable choice?”, Carlo Luijten

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Conclusions (The lessons)

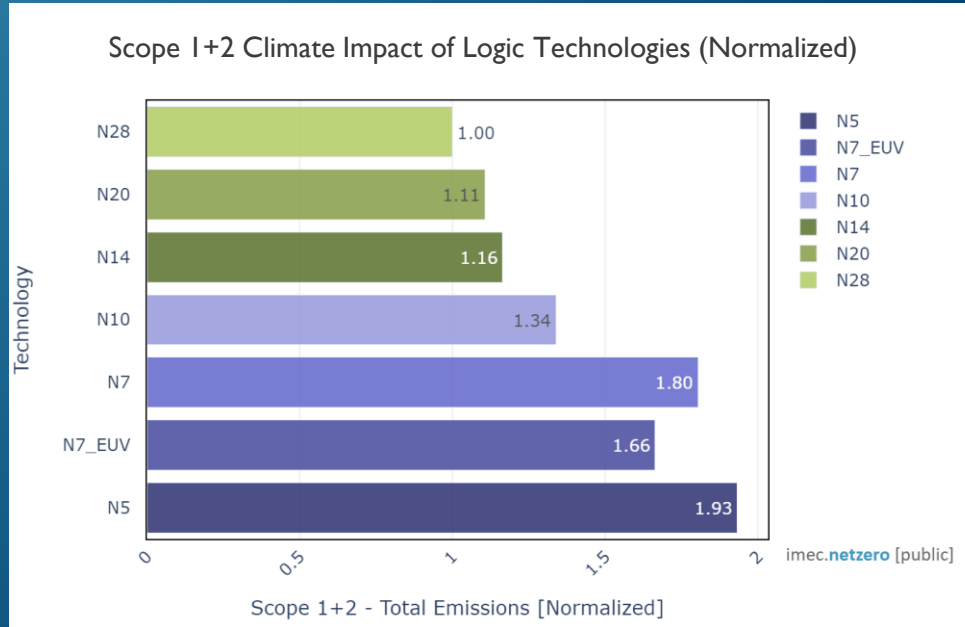
Conclusion

Towards netzero for the IC industry

- The climate situation is dire; the ICT industry has:
 - A significant and growing impact and responsibility to act
 - This impact will increase due to more fabs and higher complexity
- There are many opportunities for improvement:
 - Abatement, low GWP gases, process innovation, clean energy and materials etc.
- The future of the IC industry is bright - **let's make it greener as well**
- Join the journey **towards netzero**



Public version of imec.netzero



Go to <https://netzero.imec-int.com> and sign-up for imec.netzero



Acknowledging Lars-Åke Ragnarsson, Cédric Rolin, the SSTS team and the SSTS partners for their support in this work