Can we cope with the massive production of integrated circuits (ICs) within environmental limits ?

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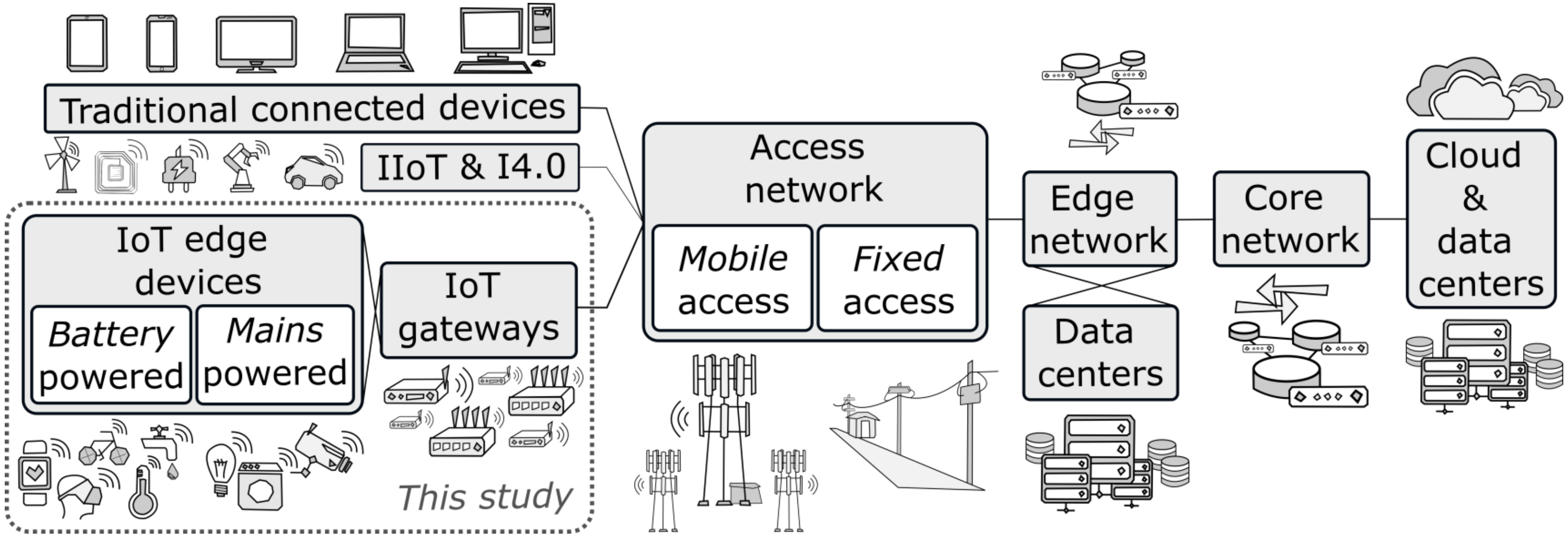
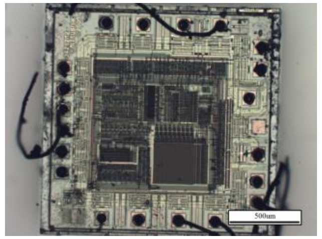
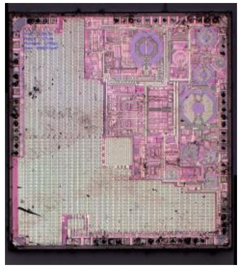
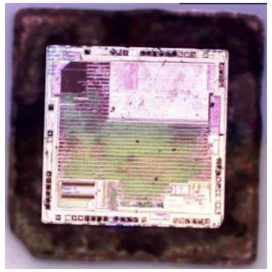
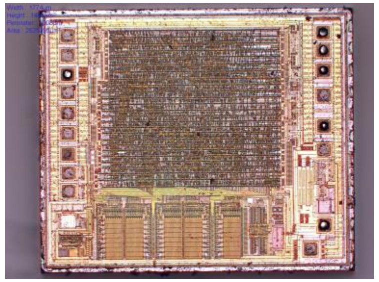
ICs are everywhere…





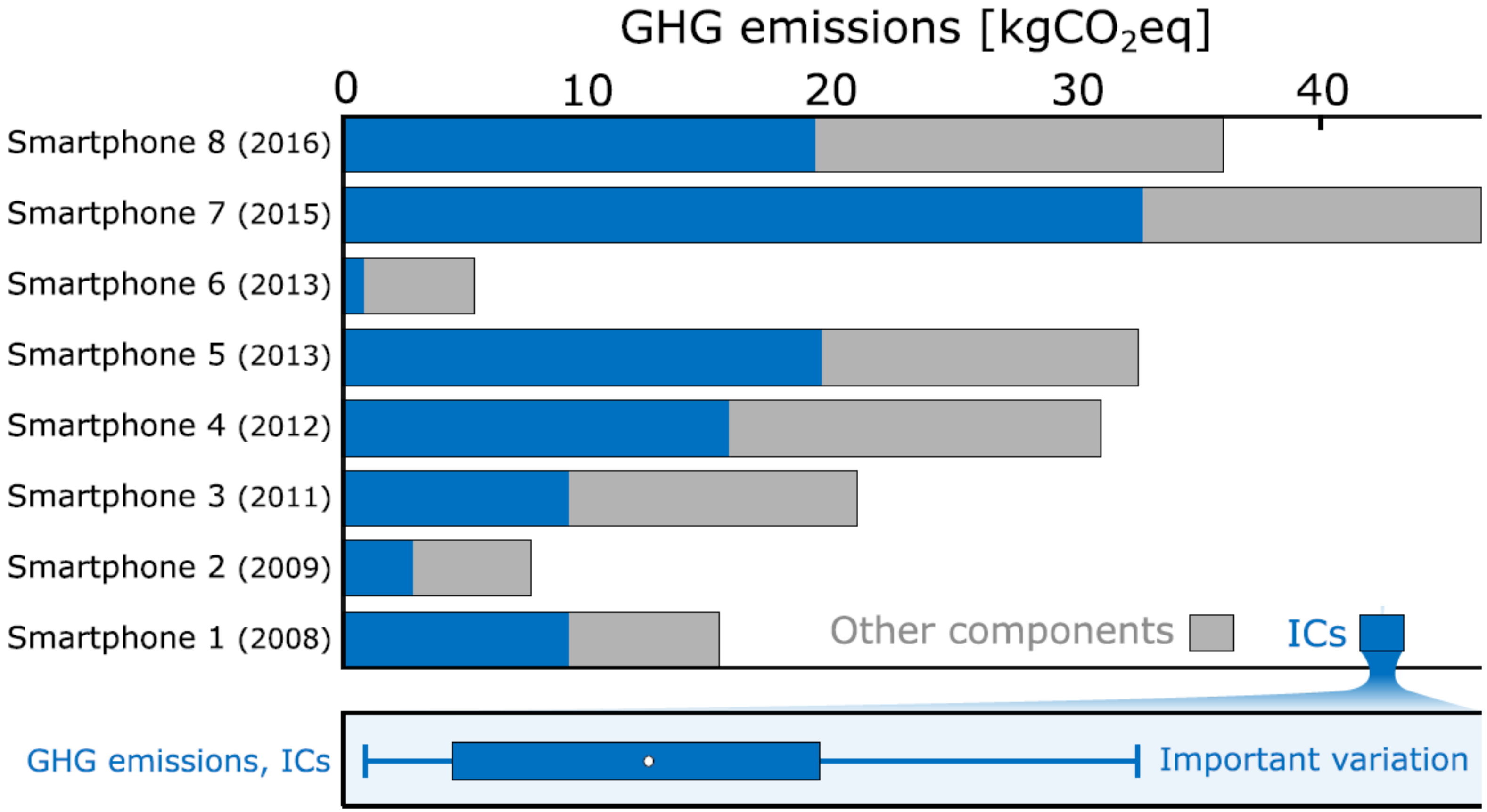






Integrated circuits (ICs) are the **building blocks** of ICTs supporting digital products and services.

ICs require a specific focus



ICs represent a **high share** of the **production impacts** in existing LCA

Source : [Pirson, 2022]

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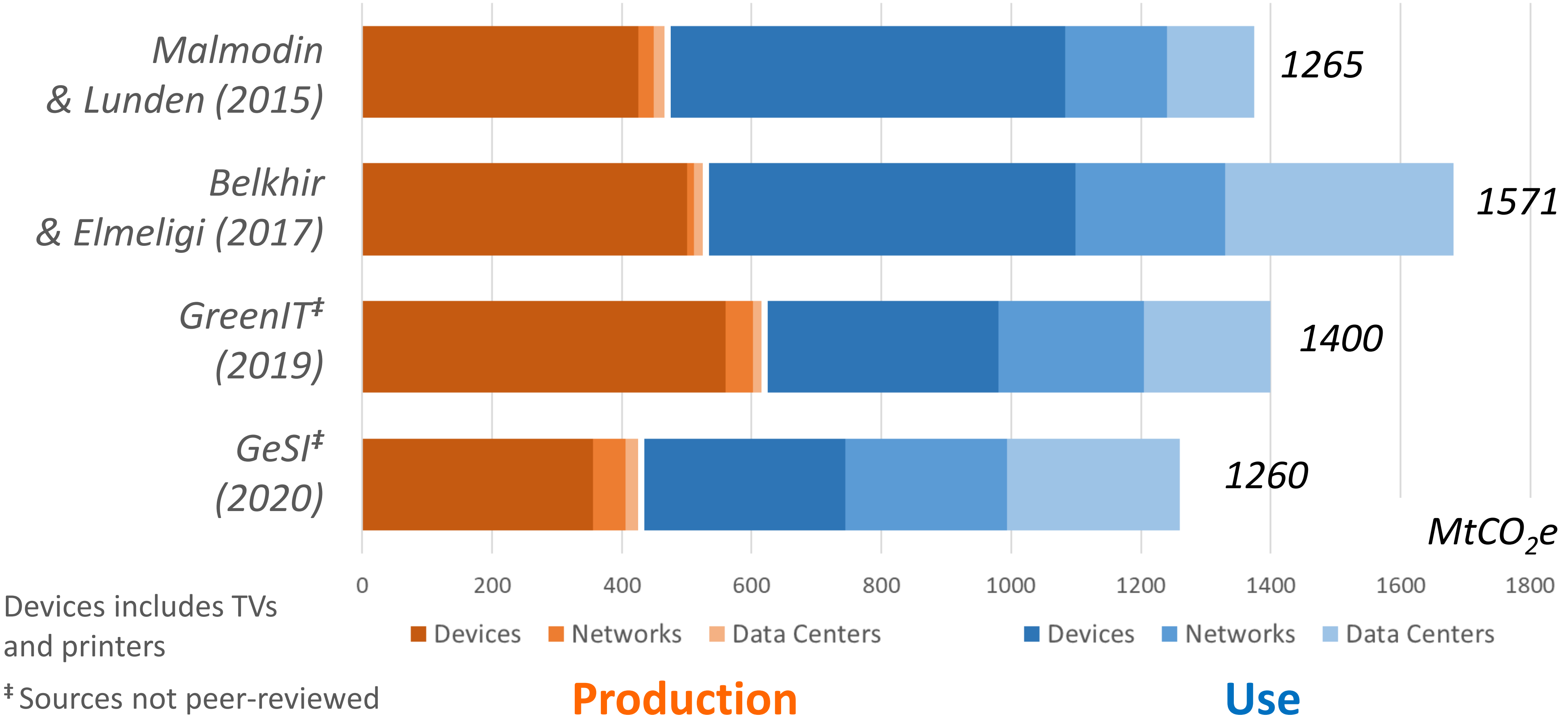
Carbon footprint of ICT



2.1-3.9 %
of global
GHG emissions

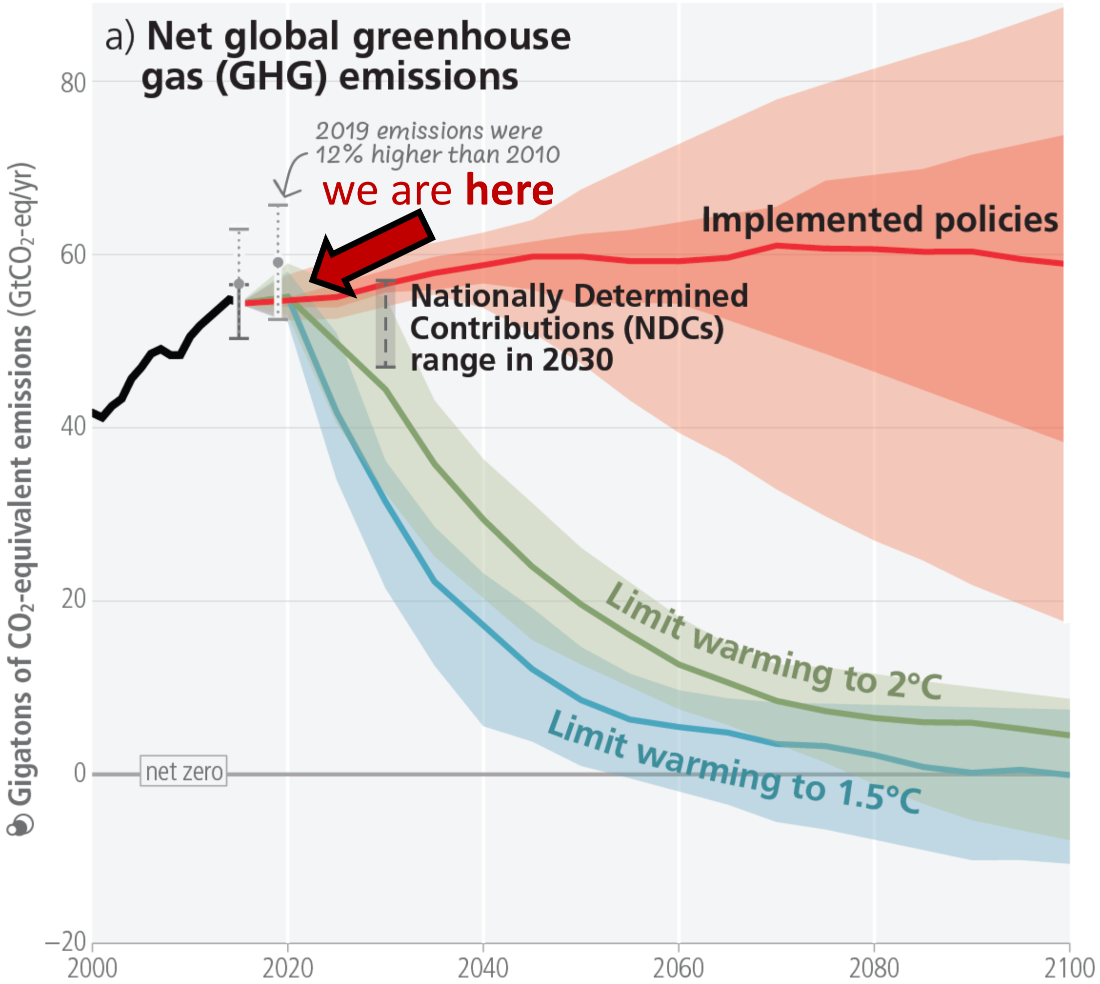
(wrt. 59 $GtCO_2e$
in 2019
[IPCC 2022],
+ accounting
for truncation error
[Freitag, 2021])

Devices includes TVs and printers

‡ Sources not peer-reviewed

Source : [Malmodin, 2018; Belkhir, 2018; GreenIT, 2019, GeSI, 2020]

GHG emissions reduction pathways



Huge challenge:

very few trials to get it right and short period of time (<30 years)

→ today's actions are critical

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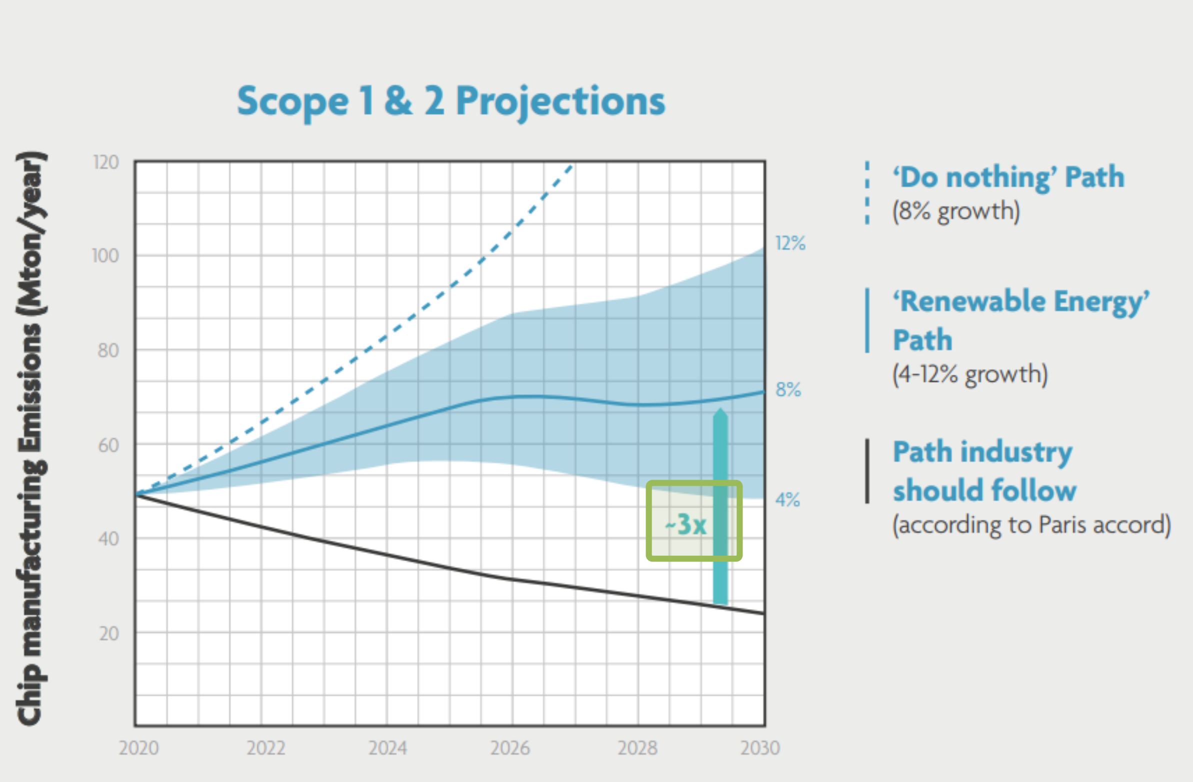
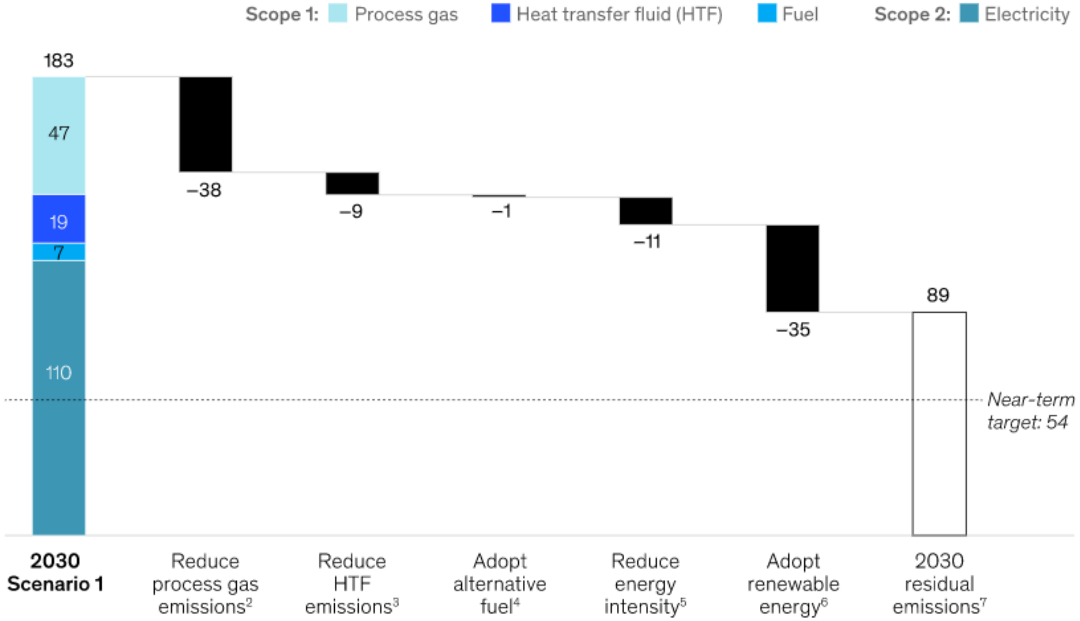
Chip manufacturing and 1.5°C trajectory



Implementing all known decarbonization measures will not get the semiconductor industry on a 1.5°C trajectory by 2030.



[1]Public announcement of 20 key players; assume base year 2020 if not specified. [2]Install gas-abatement system (90% destruction efficiency) on 90% of tools with greenhouse-gas emissions (GHG); replace 80% nitrogen trifluoride (NF3) and 20% tetrafluromethane (CF4) with zero global warming potential (GWP) gas; 20% process gas emission is NF3, 50% is CF4 (average of industry reports). [3]Replace 70% HTF with low GWP alternative; reduce chiller leakage by 30%. [4]Replace 80% fuel supply in EU and US with hydrogen/biomass. [5]Reduce energy consumption per wafer by 10% from 2020 level. [6]Renewable energy adoption: Europe, 56%; US, 46%; Malaysia, 100%; Taiwan, 15%; China 42% (Asia average); Japan, 100%; South Korea, 60%; Singapore, 15%; rest of world, 53% (industry average 2020). [7]The 2030 goal of 54 million tons of CO_2e is based on a cross-sector pathway calculation method offered by Science Based Targets initiative (SBTi): it assumes emissions reduction at a linear annual rate of 4.2% from 2020 base year; the long-term goal, which is based on the International Energy Agency's Net-Zero Emissions scenario, requires energy and industrial-process CO_2 emissions to fall 95% between 2020–50, resulting in emissions of 4.7 million tons CO_2e.
Source: CDP Worldwide reports; expert interviews; SBTi guidelines; SEMI World Fab Forecast; McKinsey wafer capacity model; McKinsey analysis

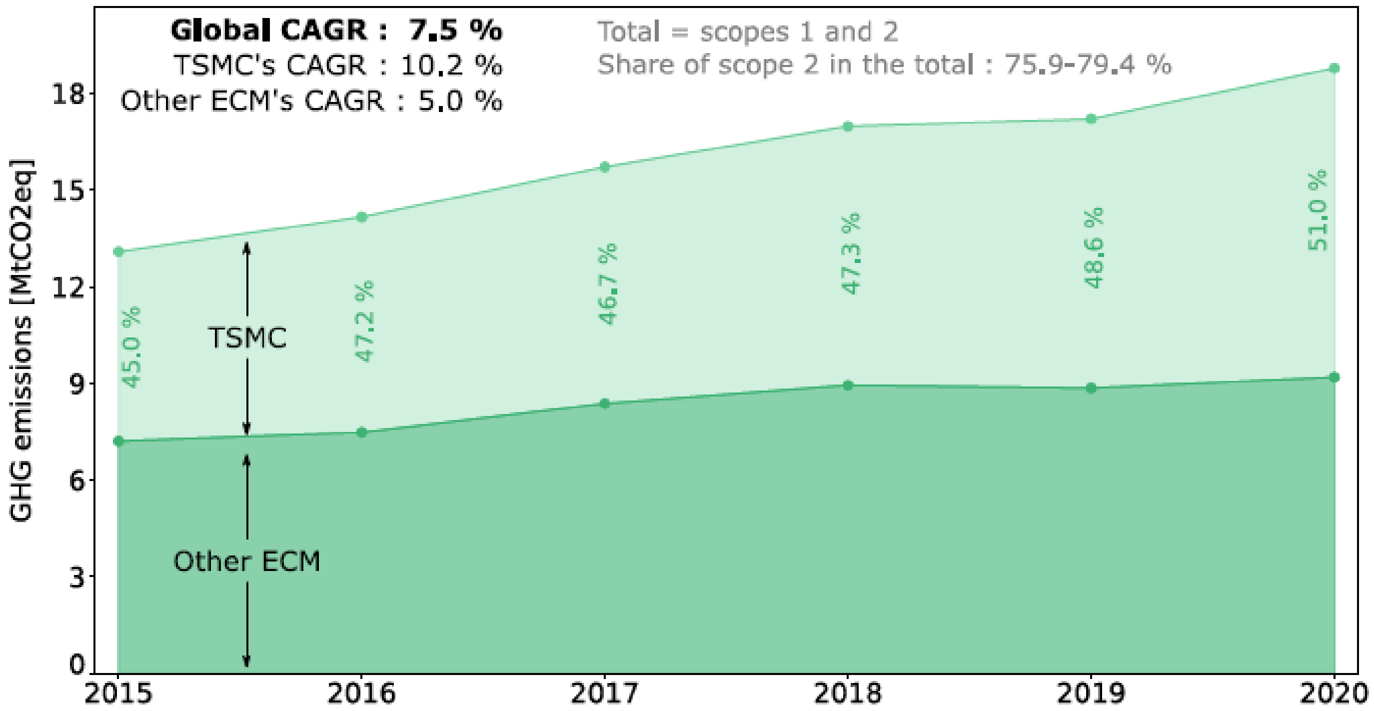
McKinsey & Company

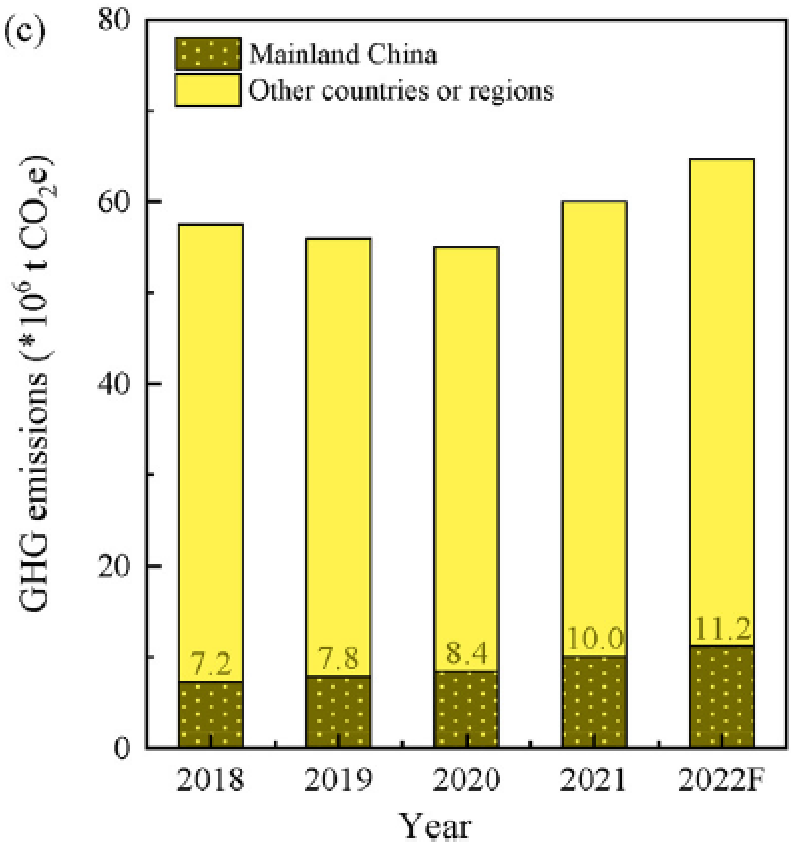
Source : [imec, 2022; McKinsey&Company, 2022]

Funded by the European Union

Insights from the academia …

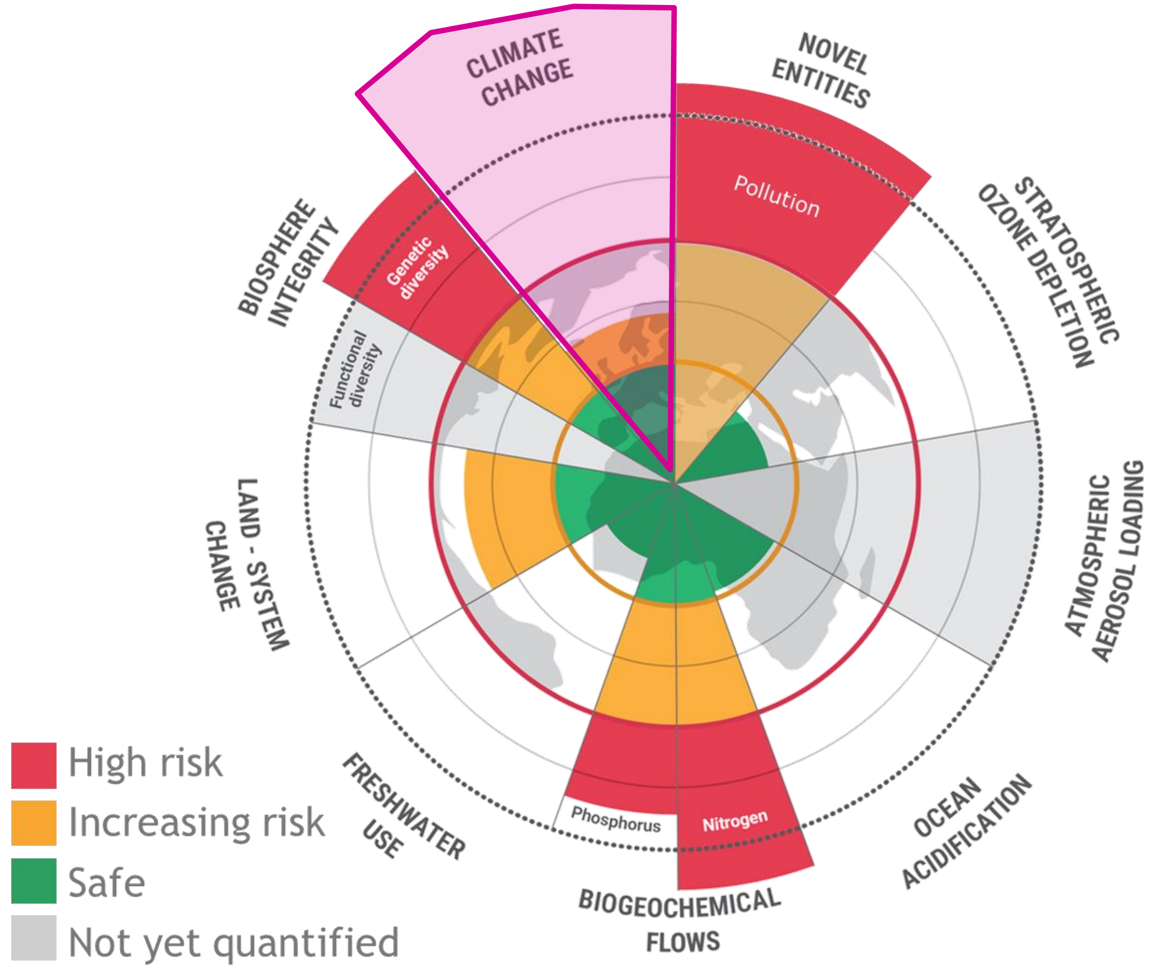
(Sub-set of ECMs in Taiwan)





Source : [Roussilhe, 2022; Wang, 2023]

Planetary boundaries



- Represent a sage operating space for Humanity
- 3 boundaries are FULLY exceeded in the high-risk zone
- 2 boundaries are in the increasing-risk zone: **climate change** and land change (deforestation)

Source : [Steffen, 2015]

Can we **cope** with the **massive production** of integrated circuits (**ICs**) **within environmental limits**?

1. Clear conflicting trends are already identified for GHG emissions (Paris Agreement)
2. The minimization of the environmental impacts per cm^2 will not be sufficient
3. Roadmaps currently fail in defining environmental targets
4. Issue with the choice of environmental efficiency metrics
5. The EU Chips Act adds difficulty for reaching the climate targets at the EU scale

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Outline

- Context
- The Impact of Pursuing Advanced Scaling for Foundries
- The Issue with Environmental Targets in Industrial Roadmaps
- Environmental perspectives for the European Chips Act
- Take-aways
- Suggestions

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Our previous work on …

… the environmental footprint of IC production

TODAY

56 IEEE TRANSACTIONS ON SEMICONDUCTOR MANUFACTURING, VOL. 36, NO. 1, FEBRUARY 2023

The Environmental Footprint of IC Production: Review, Analysis, and Lessons From Historical Trends

Thibault Pirson, Graduate Student Member, IEEE, Thibault P. Delhaye, Alex G. Pip, Grégoire Le Brun, Jean-Pierre Raskin, Fellow, IEEE, and David Bol, Senior Member, IEEE

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The Environmental Footprint of IC Production: Meta-Analysis and Historical Trends

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Embedded Tutorial Paper

Moore's Law and ICT Innovation in the Anthropocene

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From Silicon Shield to Carbon Lock-in? The Environmental Footprint of Electronic Components Manufacturing in Taiwan (2015-2020)

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… the environmental footprint of IoT and 5G

Journal of Cleaner Production 322 (2021) 128966

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Assessing the embodied carbon footprint of IoT edge devices with a bottom-up life-cycle approach

Thibault Pirson *, David Bol
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Technical and Ecological Limits of 2.45-GHz Wireless Power Transfer for Battery-Less Sensors

Marco Gonzalez, Student Member, IEEE, Pengcheng Xu, Member, IEEE, Rémi Dekimpe, Student Member, IEEE, Maxime Schramme, Student Member, IEEE, Ivan Stupia, Member, IEEE, Thibault Pirson, and David Bol, Senior Member, IEEE

Annals of Telecommunications
https://doi.org/10.1007/s12243-022-00932-9

Evaluation and projection of 4G and 5G RAN energy footprints: the case of Belgium for 2020–2025

Louis Golard[1] · Jérôme Louveaux[1] · David Bol[1]

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Modeling the Carbon Footprint of Battery-Powered IoT Sensor Nodes for Environmental-Monitoring Applications

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The Impact of Pursuing Advanced Scaling for Foundries

The environmental footprint of IC production


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The Environmental Footprint of IC Production: Review, Analysis, and Lessons From Historical Trends

Thibault Pirson, *Graduate Student Member, IEEE*, Thibault P. Delhaye, Alex G. Pip, Grégoire Le Brun, Jean-Pierre Raskin, *Fellow, IEEE*, and David Bol, *Senior Member, IEEE*

	Literature review → (Section II-A)	**In-depth analysis** → (Section III)	**Historical trends** (Section IV)
Goals	(1) Identify key sources (2) Identify LCA data	(1) Identify the scope of the sources† (2) Identify variation in LCA data†,*	(1) Put results in a long-term perspective†,* (2) Foster systemic thinking
Methodology (Section II)	(1) Review 4 literature categories$^{\triangleleft}$ (2) Focus on 3 indicators$^{\triangleright}$	(1) Define 10 objective features† (2) Normalize impacts per area*	(1) Define 10 objective features† (2) Normalize impacts per area*
Outputs	(1-2) 27 key sources identified$^{\diamond}$ *(+ 9 historical sources)*	(1) Scope mismatch identified† (2) Environmental impacts per area*	(1) Lack of roadmaps and environmental targets†,* (2) Limits of environmental improvements per area*

† : qualitative ⋆ : quantitative ▷ : energy consumption, carbon footprint and water consumption ◇ : 27 = 5+1+18+3, see Table III for more details
◁ : foundry reports, industry roadmaps, scientific literature, and commercial state-of-the-art LCA databases

TODAY

- ❑ Focus on **3 environmental indicators**: energy, **GWP (this talk)**, water
- ❑ All metrics are **normalized** by silicon area (cm^2)

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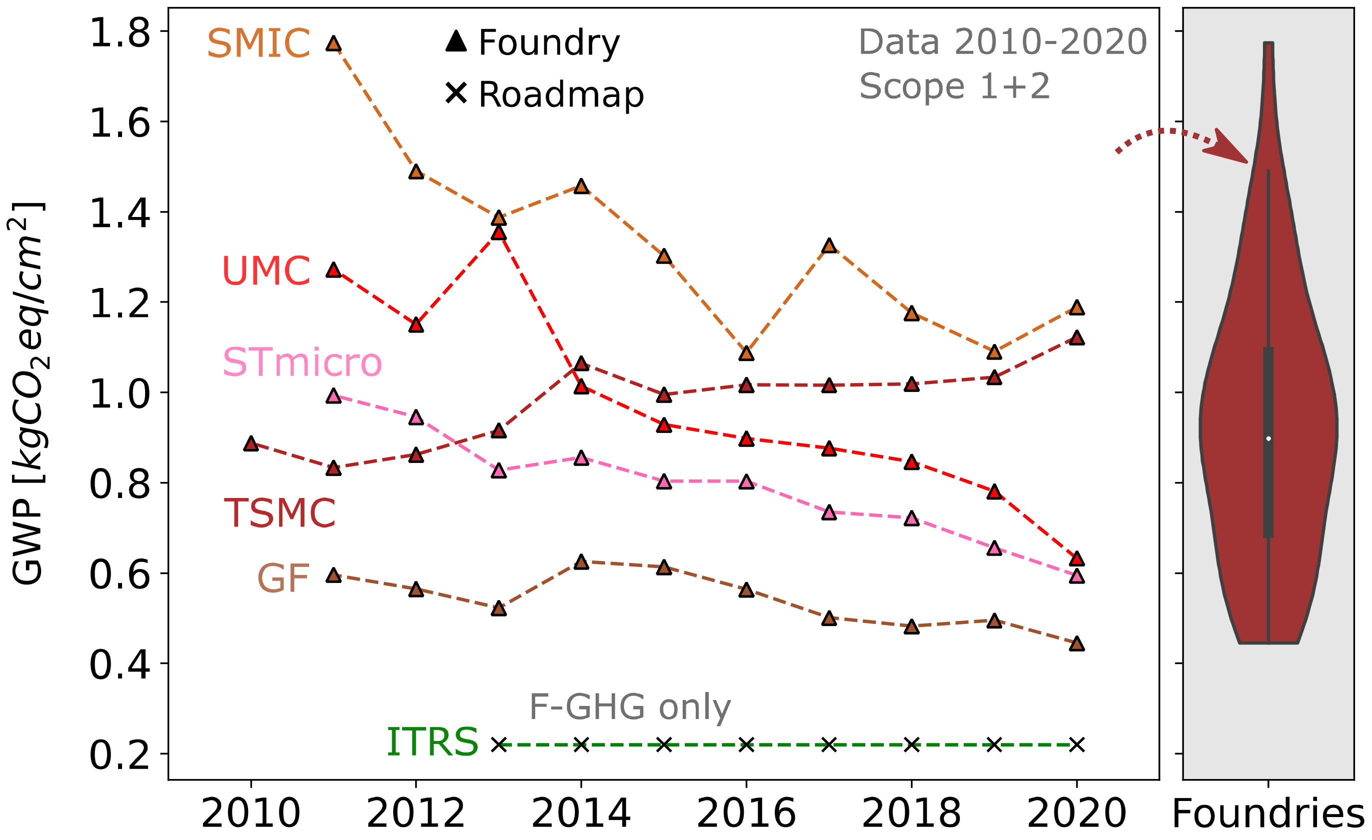
The environmental footprint of IC production

TODAY

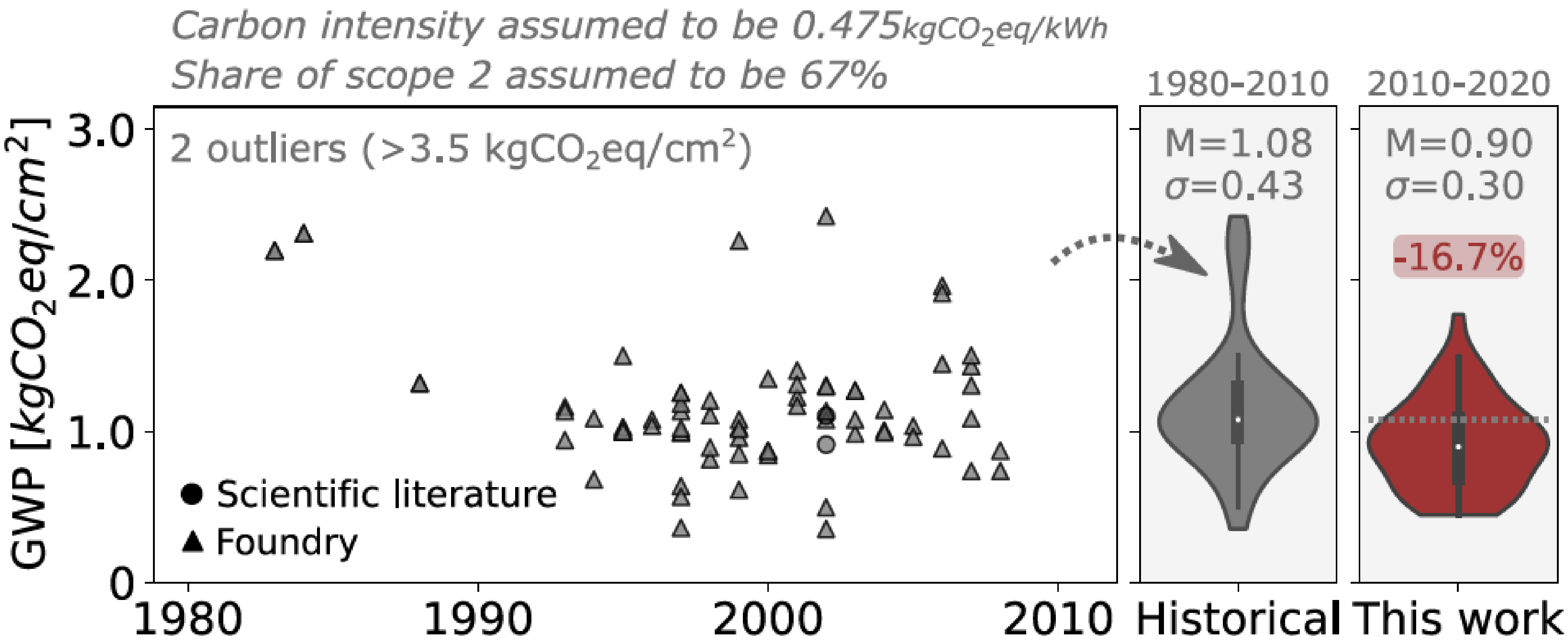
1. Foundry reports (N=5)
2. Industry roadmap (N=1)
3. Scientific literature (N=18)
4. Commercial databases (N=3)

The Impact of Pursuing Advanced Scaling for Foundries



- The impacts per area either (slightly) **decrease** over the period 2010-2020 for most of the foundries, while they **increase for TSMC**
- **This is not due to a lack of effort from the foundry** to pursue efficiency but rather to the introduction of more demanding processes such as extreme ultra-violet (EUV) lithography for scaling purpose

Historical trends



Source : [Pirson, 2022]

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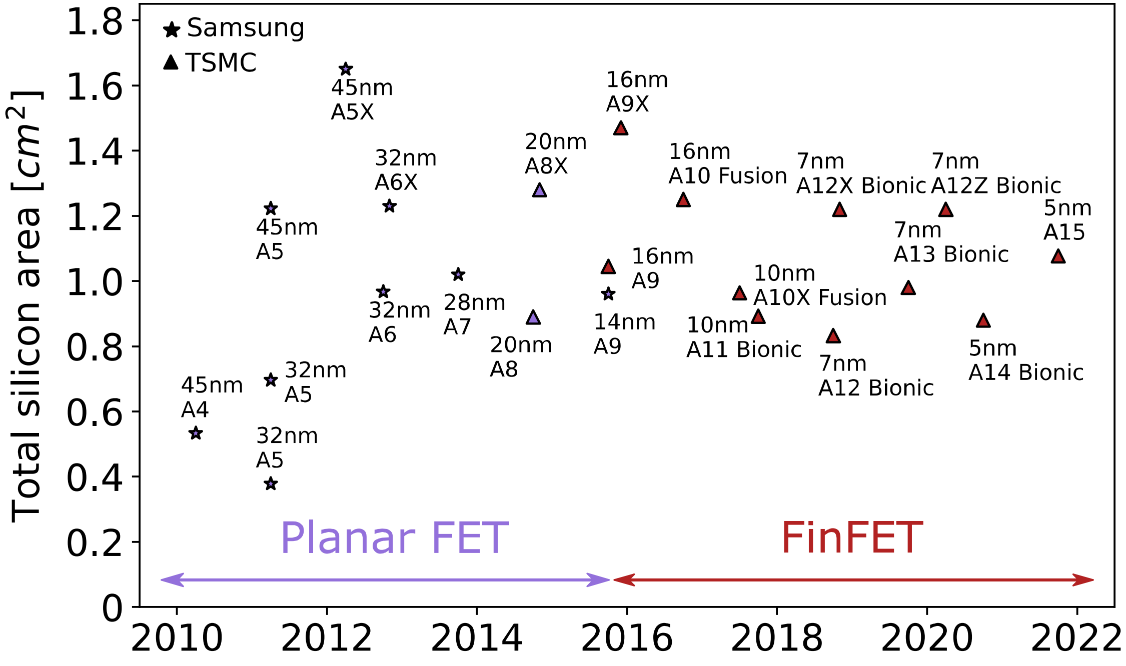
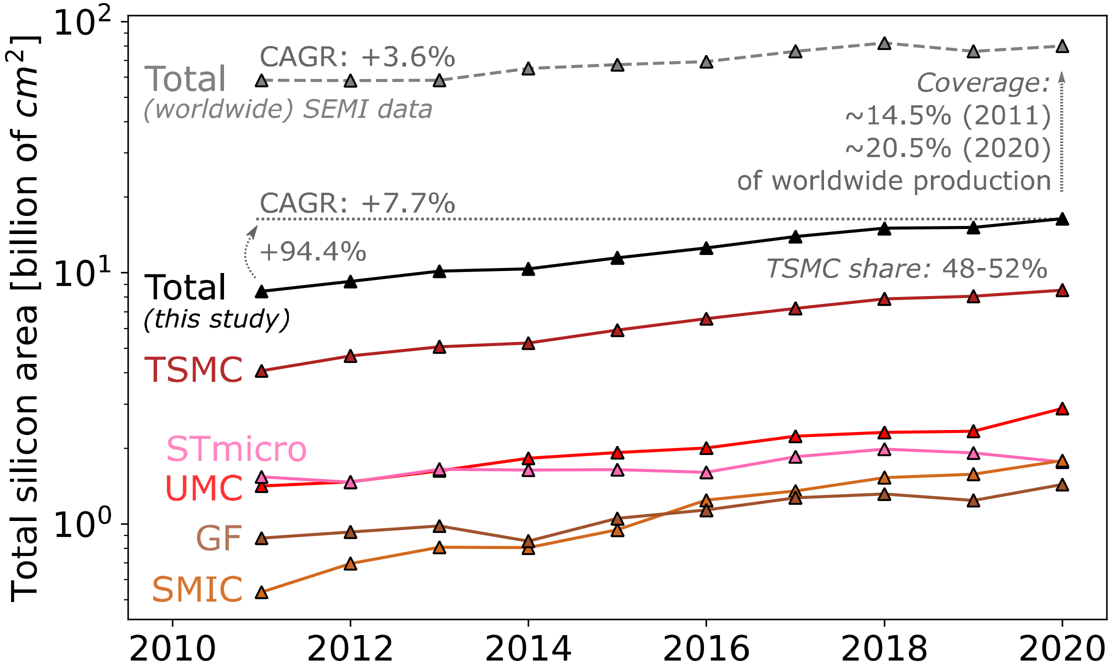
Rebound effect



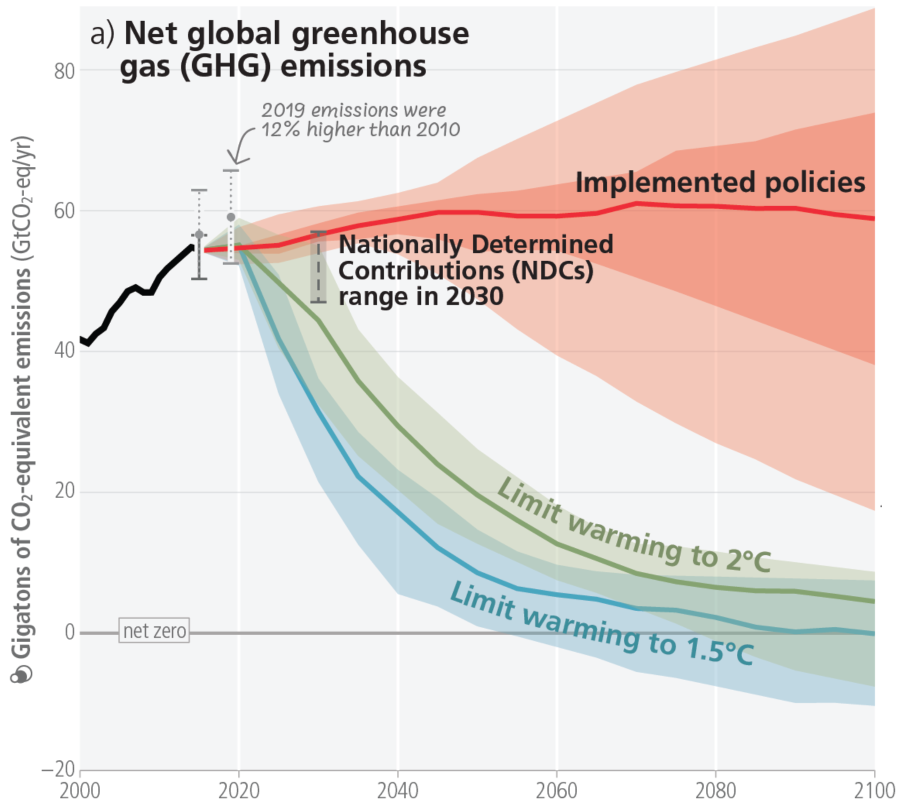


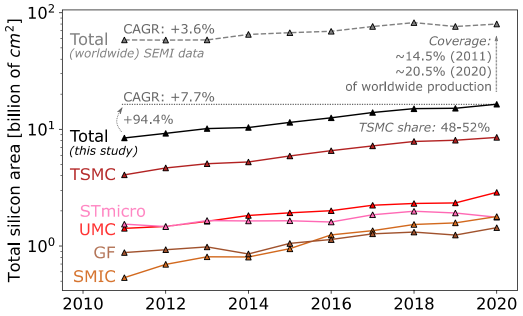
- The average die area is roughly **constant** for Apple's A-processors although technology node shifted from 45 to 5 nm → ever increasing functionality
- The **total** silicon area produced over time keeps **increasing**, faster than the reduction in environmental impacts per area → rebound effect

Funded by the European Union

Source : [Pirson, 2022]

Conflicting trends





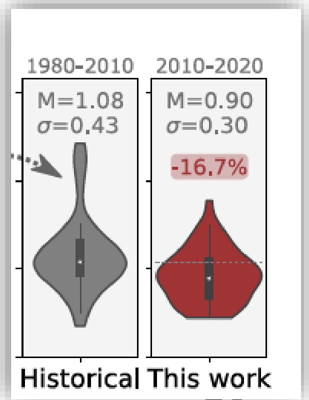
→ **-7.6%/year**

(if started in 2020) to meet the **1.5°C target**

→ The production (cm²) is increasing of about **+3.6%/year**

… This would therefore require a **reduction of the GWP/cm²** close to **11-14%/year** to reach this pathway …

BUT … -16.7% (1980→2020)



About -1%/year … (if 2015-1995=20 years)

Quick summary

- Rebound effect are observed at the hardware level

→ The minimization of the environmental impacts per cm^2 will not be sufficient

→ Clear conflicting trends between massive production of ICs and GHG reduction pathways (Paris Agreement)

The Issue with Environmental Targets in Industrial Roadmaps

Long-term analysis of ITRS roadmaps

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INTERNATIONAL TECHNOLOGY ROADMAP FOR SEMICONDUCTORS
2001 EDITION

ENVIRONMENT, SAFETY, AND HEALTH

INTERNATIONAL TECHNOLOGY ROADMAP FOR SEMICONDUCTORS
2007 EDITION

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Table ESH5 Facilities Technology Requirements

Table ESH5 Facilities Technology Requirements																
Year of Production	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022*	*2023*	*2024*	*2025*	*2026*	*2027*	*2028*
Facilities Design																
Facilities Design **Important**	Meet established goal and metrics					Meet established goal and metrics										
Water																
Total fab* water consumption (liters/cm^2) [1]																
300mm/450mm fabs	7.8	7.8	7.3	7.0	6.4	6.4	5.8	5.5	5.5	5.3	5.0	5.0	5.0	4.6	4.6	4.6
200mm fabs	7.6	7.6	7.0	6.4	5.8	5.8	5.0	4.8	4.8	4.3	4.1	4.1	3.9	3.5	3.5	3.5
Important																
Total UPW consumption (liters/cm^2) [1] **Important**	6.5	6.5	6.5	6.0	6.0	6.0	5.0	5.0	5.0	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Site water recycled/reclaimed** (% of use) **Important**	50%	50%	60%	60%	70%	70%	70%	75%	75%	75%	80%	80%	80%	90%	90%	90%
Energy (electricity, natural gas, etc.)																
Total fab energy usage (kWh/cm^2)																
Non EUV	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6
EUV			1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Important																
Waste																
Hazardous waste (g per cm^2) [1] **Important**		8			7.5		7.2	7.2	7.2	7.2	6.5	6.5	6.5	6	6	6
Air Emissions																
Volatile Organic Compounds (VOCs) (g per cm^2) [1] **Important**		0.06			0.055		0.05	0.05	0.05	0.05	0.045	0.045	0.045	0.045	0.045	0.045
Fluorinated greenhouse gases, fluorinated heat transfer fluids, and nitrous oxide **Critical**	Normalized emission rate (NER) to be 0.22 kg CO_2 equivalent/cm^2 by 2020 -- as agreed to by the World Semiconductor Council (WSC).			Normalized emission rate (NER) to be 0.22 kg CO_2 equivalent/cm^2 by 2020 -- as agreed to by the World Semiconductor Council (WSC).					Normalized emission rate (NER) <0.22 kg CO_2 equivalent/cm^2							

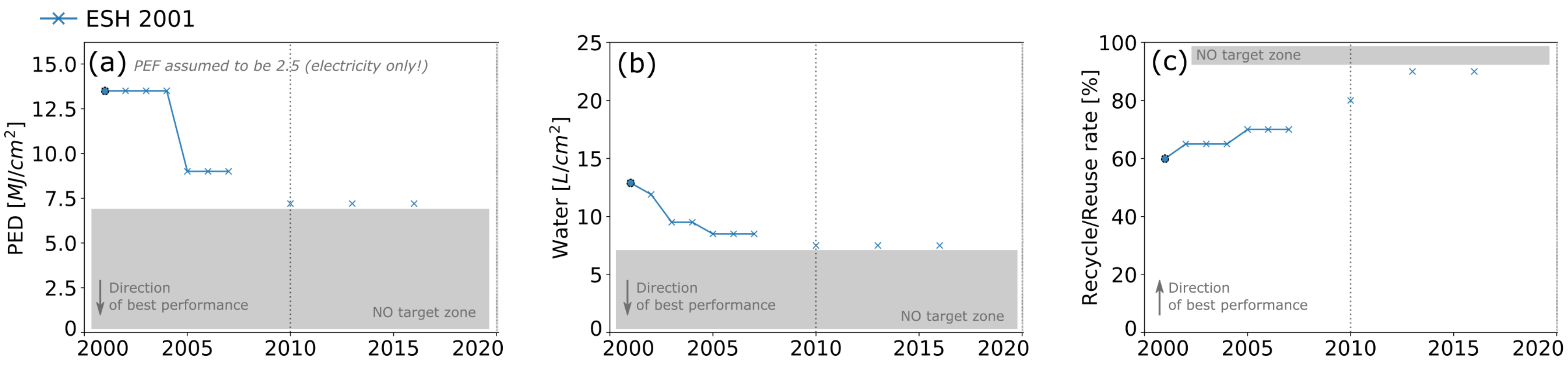
Manufacturable solutions exist, and are being optimized
Manufacturable solutions are known
Interim solutions are known
Manufacturable solutions are NOT known

Notes for Table ESH5:
**Fab = manufacturing space + support systems*
***Recycle = Re-use after treatment*
***Reuse = Use in secondary application (without treatment)*
***Reclaim = Extracting a useful component from waste*
[1] cm2 per wafer out

IMPORTANT:

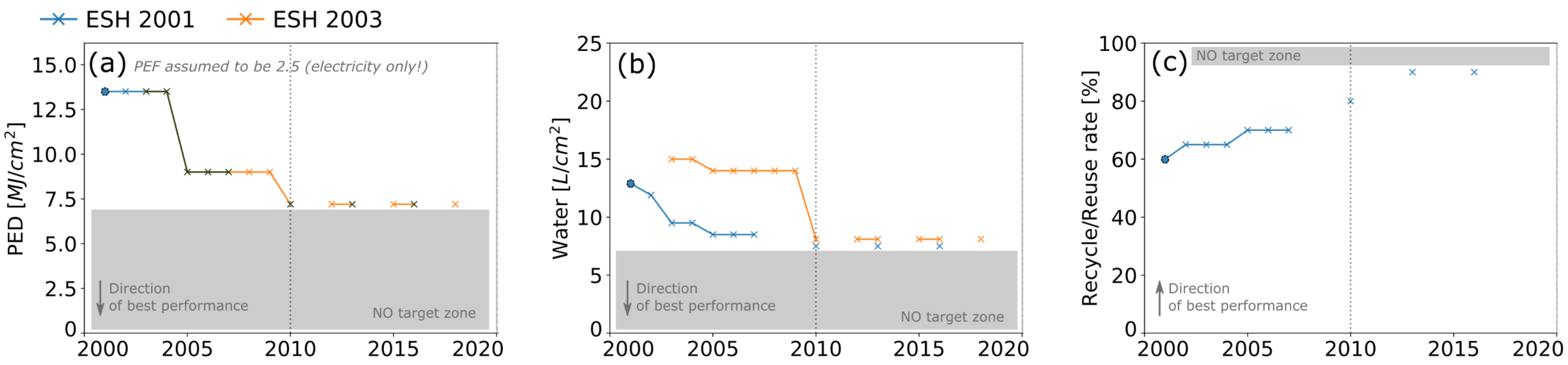
1. No target for GHG emissions/cm^2 (only for F-GHG)
2. No quantitative data after 2015

Long-term analysis of ITRS roadmaps

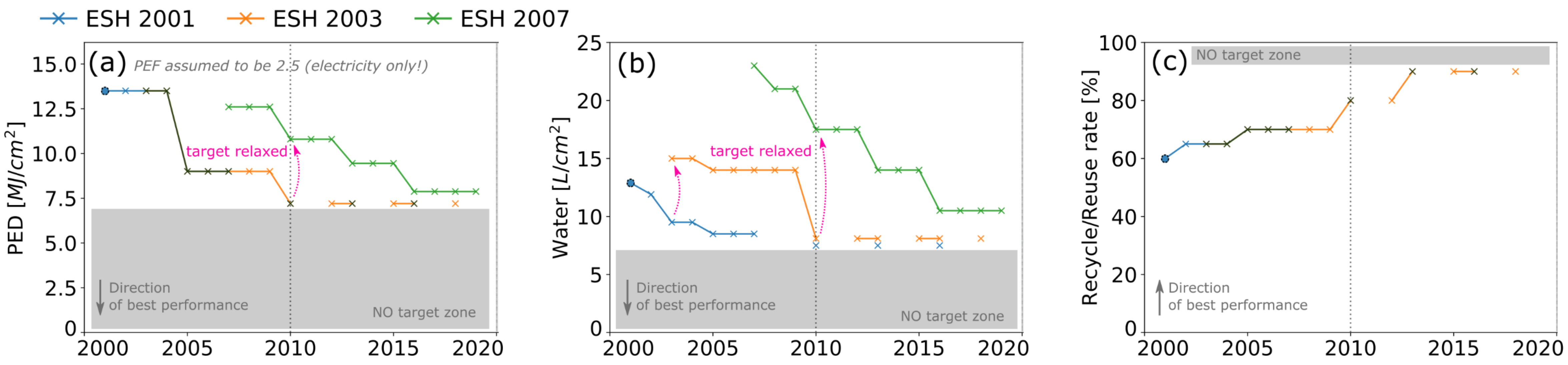


Source : [Pirson, 2022]

Long-term analysis of ITRS roadmaps

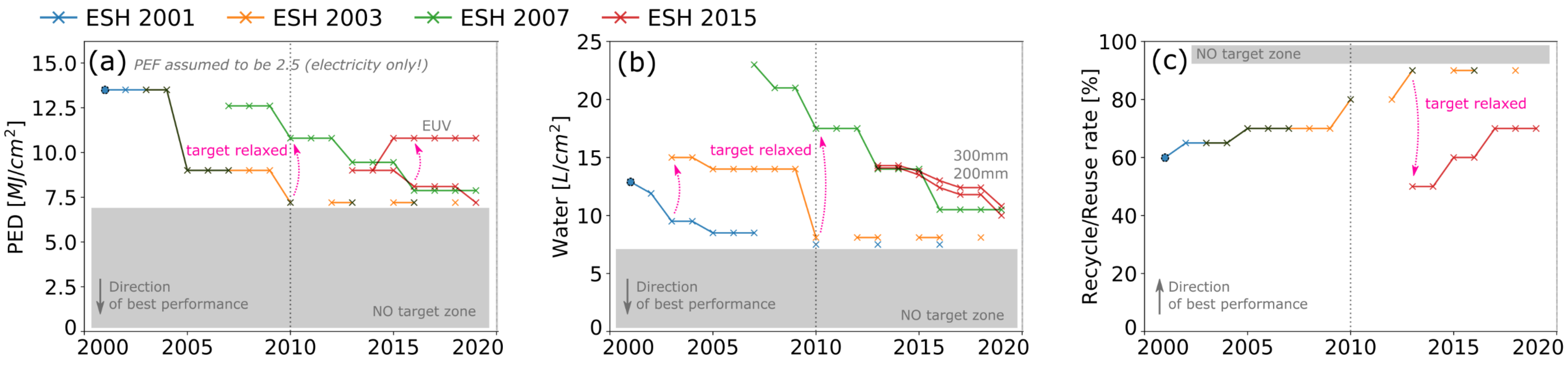


Long-term analysis of ITRS roadmaps



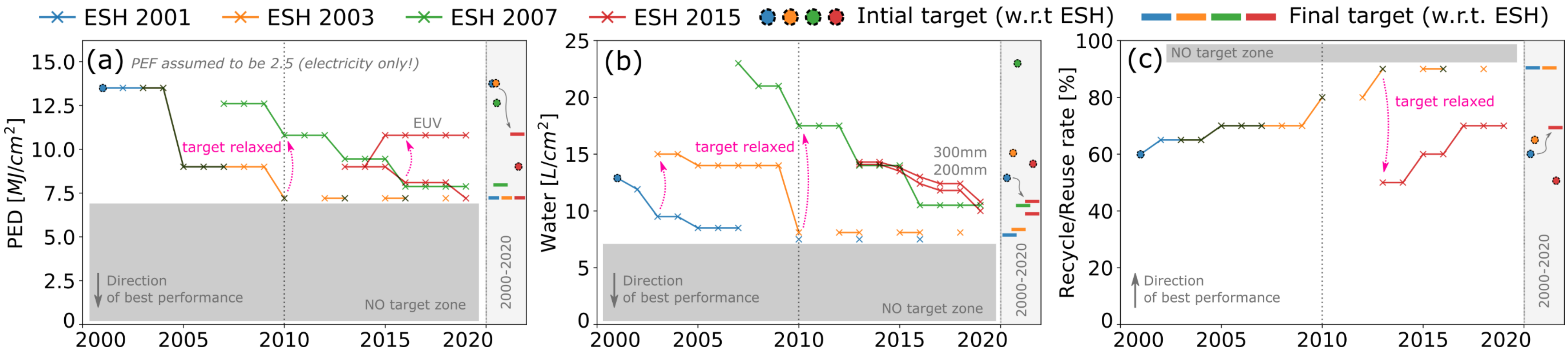
Source : [Pirson, 2022]

Long-term analysis of ITRS roadmaps



Source : [Pirson, 2022]

Long-term analysis of ITRS roadmaps



Environmental targets are at best reaching the targets from the ESH 2001 roadmap

(in the meantime, more transistors are fitted on a given square cm.

Yet, the total area produced keeps on increasing)

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Need for a fundamental reset

IEEE Advancing Technology for Humanity

IRDS
INTERNATIONAL ROADMAP FOR DEVICES AND SYSTEMS™

INTERNATIONAL ROADMAP FOR DEVICES AND SYSTEMS™

2022 EDITION

EXECUTIVE SUMMARY

THE IRDS™ IS DEVISED AND INTENDED FOR TECHNOLOGY ASSESSMENT ONLY AND IS WITHOUT REGARD TO ANY COMMERCIAL CONSIDERATIONS PERTAINING TO INDIVIDUAL PRODUCTS OR EQUIPMENT.

40 Roadmap Process and Structure

The IRDS International Focus Team on More than Moore, as listed in the acknowledgments section has generated the content of this chapter. Extensive use has been made of the NEREID NanoElectronics Roadmap for Europe.[4]

2.2.12. ENVIRONMENT, SAFETY, HEALTH AND SUSTAINABILITY (ESH/S)

The Environmental, Safety, Health, and Sustainability (ESH/S) chapter was not updated for 2021 IRDS given the many changes that have occurred within the industry and externally, which require a fundamental reset in how ESH/S emerging challenges are addressed from a technology roadmap perspective. However, a white paper will be published in the 2022 IRDS as a result of re-energizing the IFT effort. To effectively define critical issues and gaps, a broader approach to comprehend the overarching risks, upstream from the supply chain, within the semiconductor manufacturers and downstream to key customers in microelectronics will require a systems integration approach to ensure strong linkage and alignment with key stakeholders.

2021 & 2022 IRDS executive summary:

*"the ESH chapter has not been updated for 2021 IRDS given the many changes that have occurred within the industry and externally, **which require a fundamental reset** in how ESH/S emerging challenges are addressed from a technology roadmap perspective."*

Quick summary

- Systematic relaxation of the environmental targets (a-posteriori)
- Lack a standardization across the ITRS/IRDS roadmaps

→ Roadmaps currently fail in defining environmental targets as manufacturing processes become more and more complex for advanced technologies.

Environmental perspectives for the European Chips Act

The European Chips Act

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Resilience (geopolitics)

Green growth

Green deal

A European Green Deal

Striving to be the first climate-neutral continent

- "No net emissions of greenhouse gases by 2050,
- economic growth decoupled from resource use,
- no person and no place left behind."

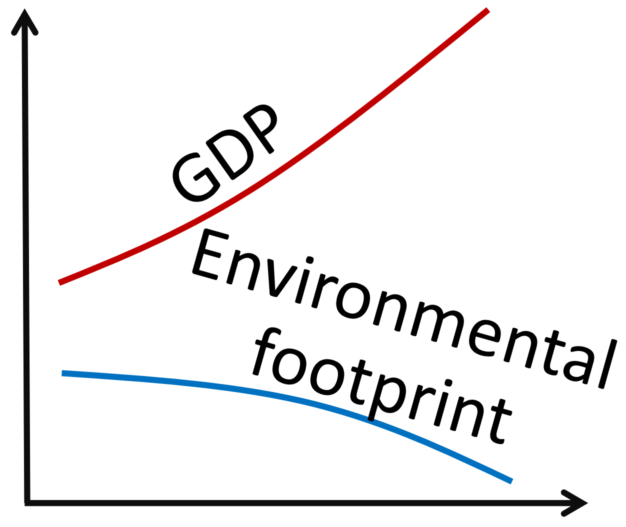
Green growth

The first climate-neutral continent	At least 55% less	3 billion
by 2050	net greenhouse gas emissions by 2030, compared to 1990 levels	additional trees to be planted in the EU by 2030

Local … not global

Is “green growth” possible?

- Green growth = the absolute decoupling of GDP growth from the ecological footprint

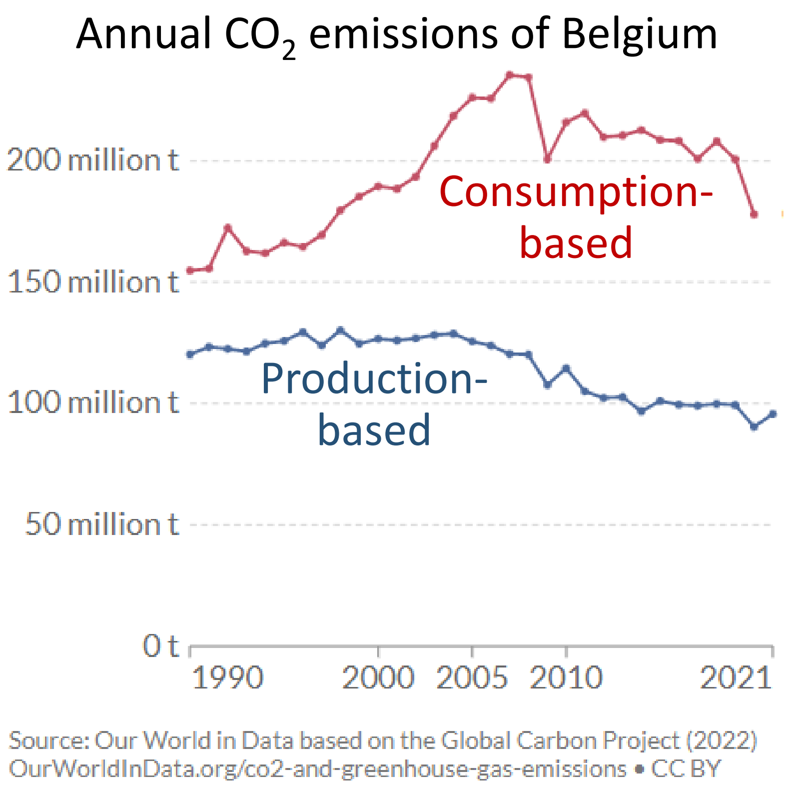


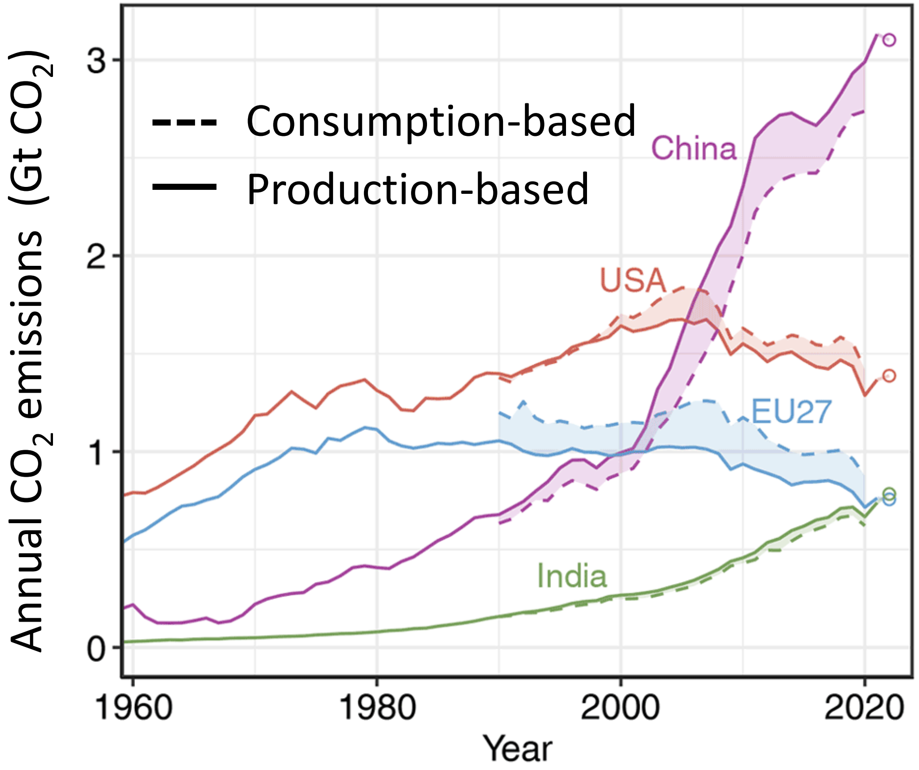
- Can only be studied at the global world scale because of *[Parrique, 2019]*:
  - rebound effects,
  - problem & cost shifting issues.

- **Absolute decoupling has never been observed so far at global scale** *[Jackson, 2009][Parrique, 2019][Hyckel and Kallis, 2020]*

- **Betting on green growth for carbon neutrality is a risky strategy**

Cost shifting issue





Source : [Friedlingstein, 2022]

Citizen protest

Water resources: 800 people demonstrate in front of STMicroelectronics in Isère

4/1/2023, 2:08:54 PM

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Environmental concerns …

Europe Technology
Policy Committee

COMMENTS OF THE
ACM EUROPE TECHNOLOGY POLICY COMMITTEE
ON THE PROPOSAL FOR A REGULATION ESTABLISHING A
FRAMEWORK OF MEASURES FOR STRENGTHENING
EUROPE'S SEMICONDUCTOR ECOSYSTEM

9 May 2022

Capsule Conclusion

Europe TPC supports the Commission's intention to promote European digital sovereignty, but also see its Proposal for a Regulation Establishing a Framework of Measures for Strengthening Europe's Semiconductor Ecosystem as an important opportunity to improve the sustainability of semiconductor technologies and applications. With this goal in mind, we raise a number of environmental considerations that would need to be accounted for, noting that at present the Chips Act fails to address the substantial probability that it will produce "rebound" effects potentially significant enough to wholly negate efficiency savings or even induce net energy and emissions increases (aka "backfire"). The Framework should thus be amended to expressly identify, quantify, and mitigate such impacts, with a view to aligning semiconductor innovation with the technological and environmental objectives of the Green Deal.

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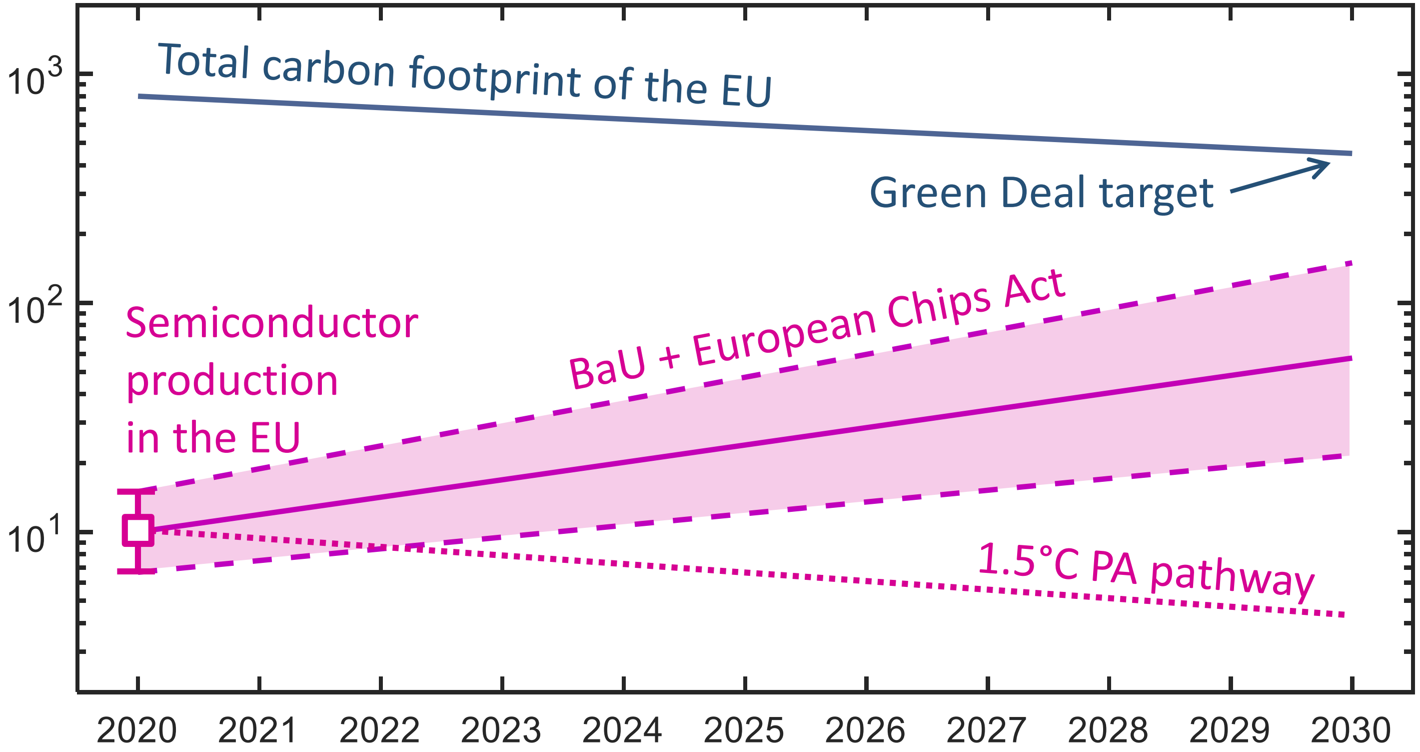
Prospective GHG emissions for EU chips



<u>Assumptions:</u>

- In 2020: 10% of 100 $MtCO_2e$ (SEMI data) with 1.5× uncertainty
- Global market: CAGR +8% +/-4%
- Complexity: CAGR +5% +/-2%
- Fixed abatement schemes
- Carbon intensity of electricity mix: CAGR -2%/year
- Chip production: 5-33% of the total EU carbon budget !

Prospective GHG emissions for EU chips

- The European Chips Act targets the supply chain sovereignty (increase resilience) …

- … at the cost of 3-10× higher GHG emissions for the EU semiconductor fabrication sector (BaU scenario targeting 20% market share in 2030)

→ **At the EU scale: one more difficulty for reaching the climate targets**

Let's focus on the world scale …

Substitution	Accumulation
Replacing existing products	Deploying new products
EU Chips Act = opportunity for climate (depends on electricity mix)	EU Chips Act = threat for climate

What would be the additional chip production capacity fostered by the European Chips Act for ?

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Current initiatives (megafabs only)

Company	Location	Market	Tech. node
Intel	Magdeburg, DE	?	7-5nm
TSMC	Dresden, DE	?	28/22nm ?
ST & GF	Crolles, FR	Automotive & 6G	22-18nm
European Chips Act plan		Automotive, 6G, Quantum, AI	12/10nm + 3/2nm ?

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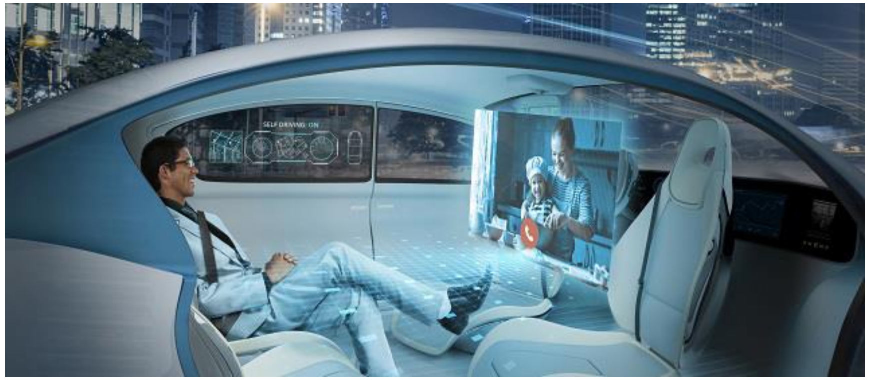
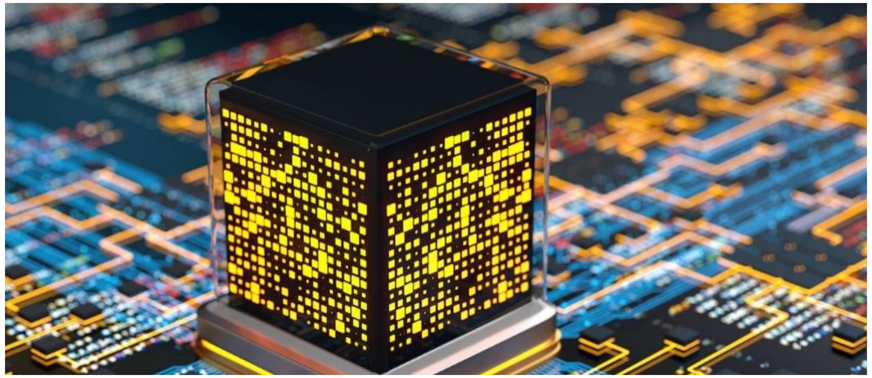
Substitution or accumulation ?


Quick summary

- **At the world scale**, two options:
  - opportunity: replacement of carbon-intensive capacity somewhere else in the world (substitution)
  - threat: additional capacity for new markets (accumulation)
- **At the EU scale**, one more difficulty for reaching the climate targets

Take-aways

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Can we **cope** with the **massive production** of integrated circuits (**ICs**) **within environmental limits**?

1. Clear conflicting trends are already identified for GHG emissions (Paris Agreement)
2. The minimization of the environmental impacts per cm^2 will not be sufficient
3. Roadmaps currently fail in defining environmental targets
4. Issue with the choice of environmental efficiency metrics
5. The EU Chips Act adds difficulty for reaching the climate targets at the EU scale

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Suggestions

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Suggestions

- Develop a clear and transparent methodology for reporting environmental targets → *insights and suggestions provided in [Pirson, 2022] and [Roussilhe, 2022]*
- Foster coherency between CSR reports and ITRS roadmaps terminology
- Evolution of relative efficiency metrics through time should be (better) monitored and reported
- Carbon tuneling should be (systematically) avoided (already partially the case is ESH ITRS reports)
- Include explicit environmental regulations in te Chips Act, together with in-depth reporting of environmental indicators
- Investigate the potential of low-throughput resilient and economically viable production lines in Europe → *important change in current semiconductor business models*
- Using backcasting instead of forecasting for designing roadmaps for European IC manufacturing → *focusing on absolute cumulative GHG emissions rather than relative environmental efficiency improvements*

Suggestions

- Levers for aligning the sector emissions on climate targets:
  - ✓ *savings in other sectors (caution: requires proper science-based evaluation including negative enabling effects*
    + political guidance to arbitrate the targets between sectors),
  - ✓ efficiency #1: sourcing low-carbon electricity
    (location matters, beware of preemption mechanism !),
  - ✓ efficiency #2: lower energy intensity of the fabs + GHG abatement,
  - ✓ efficiency #3 + sobriety #1: reduce die size,
  - ✓ sobriety #2: planned degrowth of production volumes through:
    longer service lifetime, circular economy and sober innovation!
    → deep changes for the semiconductor industry business models

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WORKSHOP - Sustainable Electronics & International Cooperation On Semiconductors

www.icos-semiconductors.eu

www.enmieux.be

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UNION EUROPEENNE
Wallonie
LE FONDS EUROPÉEN DE DÉVELOPPEMENT RÉGIONAL
ET LA WALLONIE INVESTISSENT DANS VOTRE AVENIR

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