SEMICON® EUROPA FORWARD AS ONE

The Environmental Footprint of Si Chip Manufacturing

Cédric Rolin, Program Manager
Sustainable Semiconductor Technologies & Systems (SSTS)
Imec

Cedric.Rolin@imec.be

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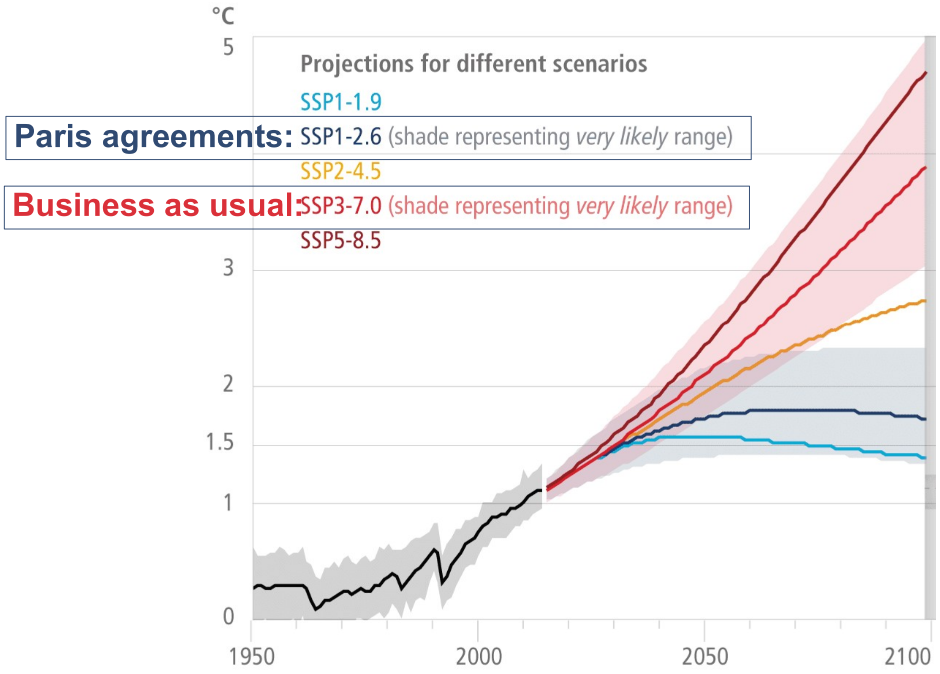
Smart and Green Manufacturing Summit
November 17, 2022

semi™

Risks for increasing levels of global warming

Global surface temperature change



Paris agreements:

Business as usual:

Source: *Climate Change 2022: Impacts, Adaptation and Vulnerability, IPCC Sixth Assessment Report, Feb. 2022.* https://www.ipcc.ch/report/ar6/wg2/

Risks for increasing levels of global warming

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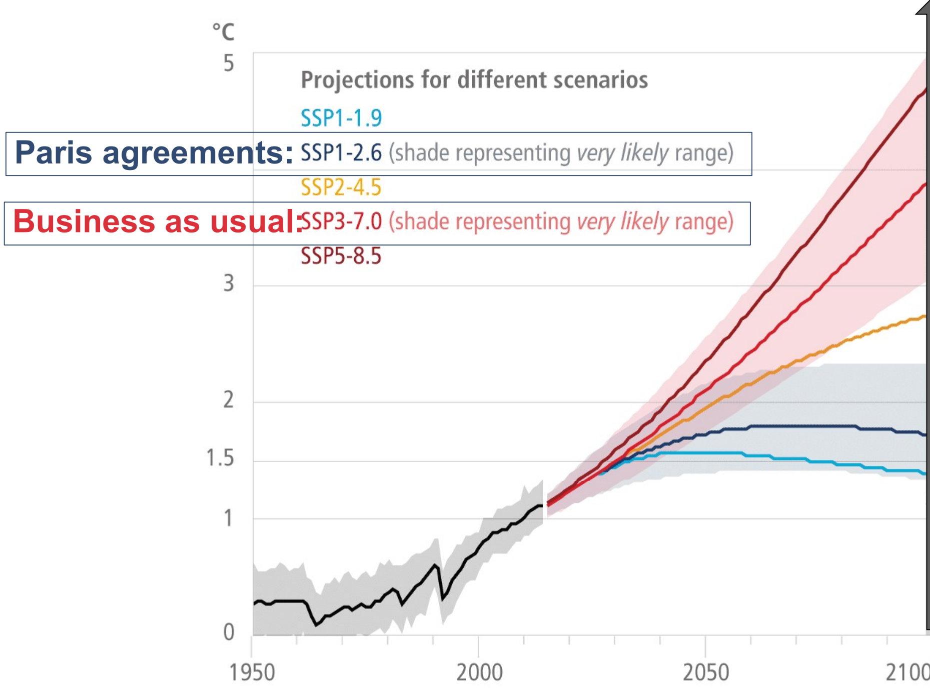
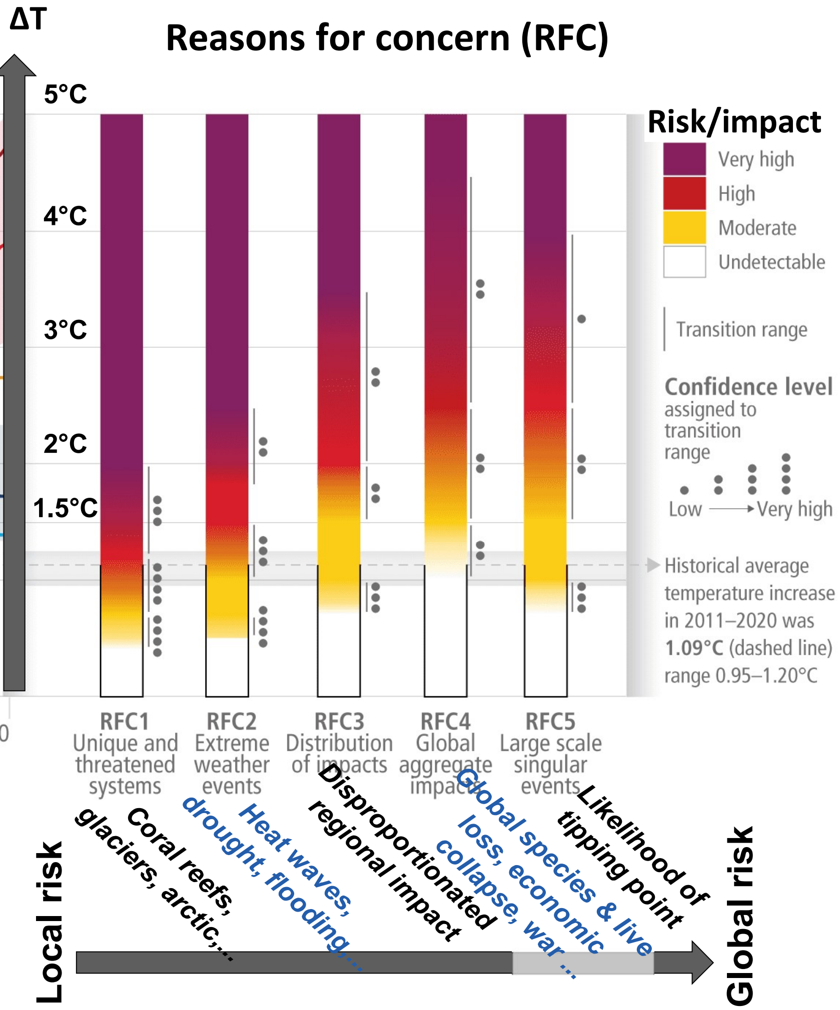


Reasons for concern (RFC)



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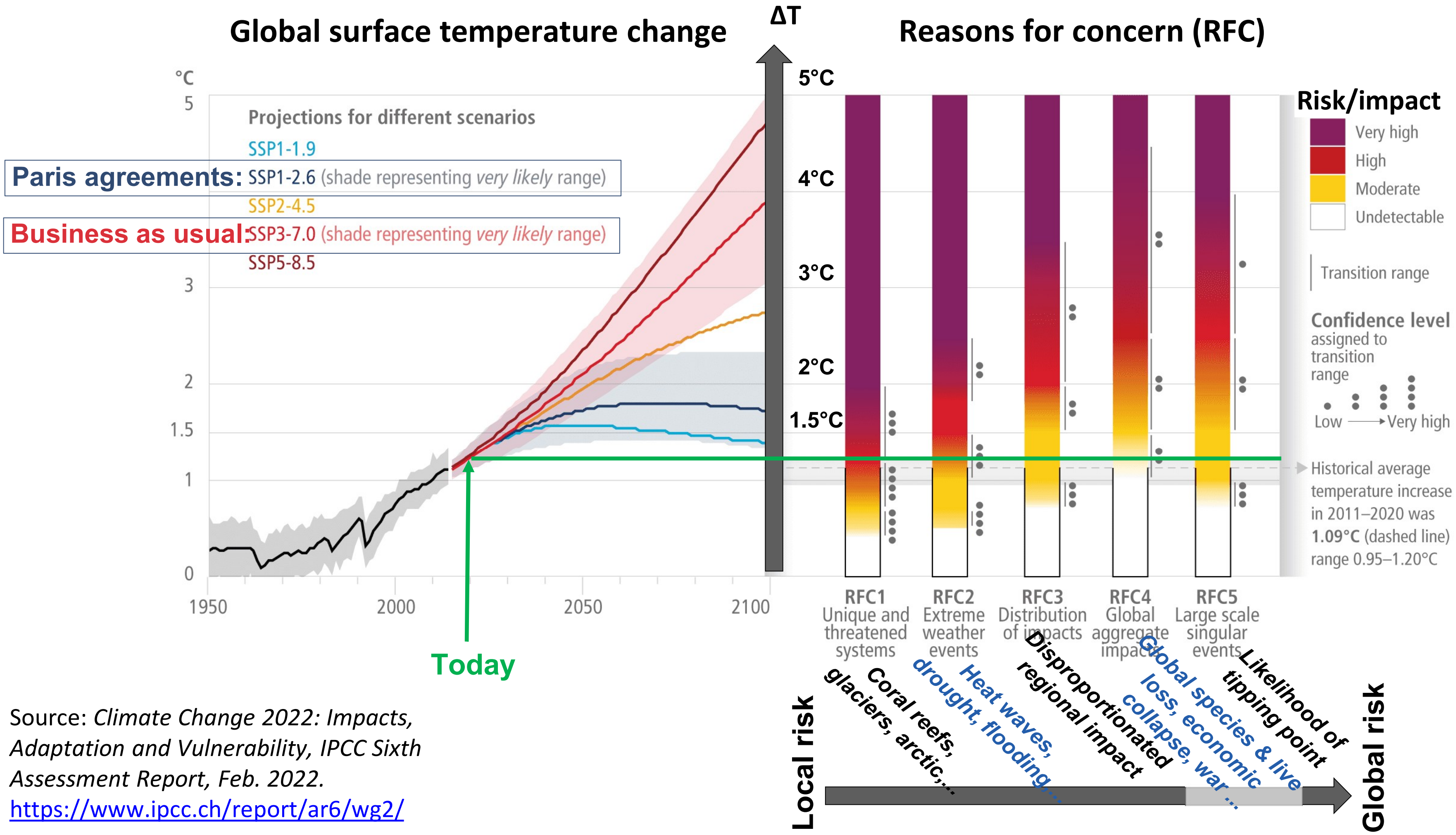

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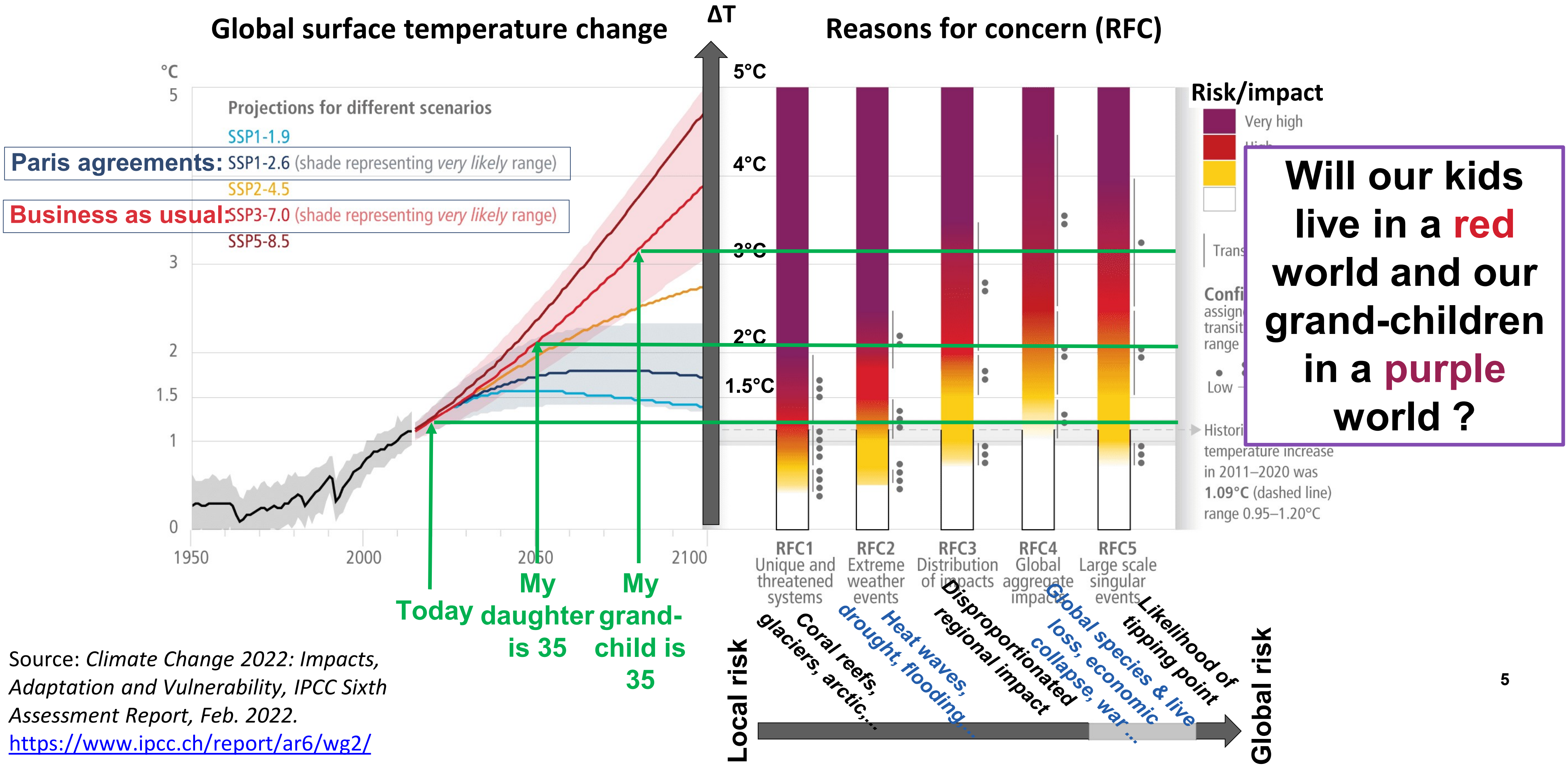
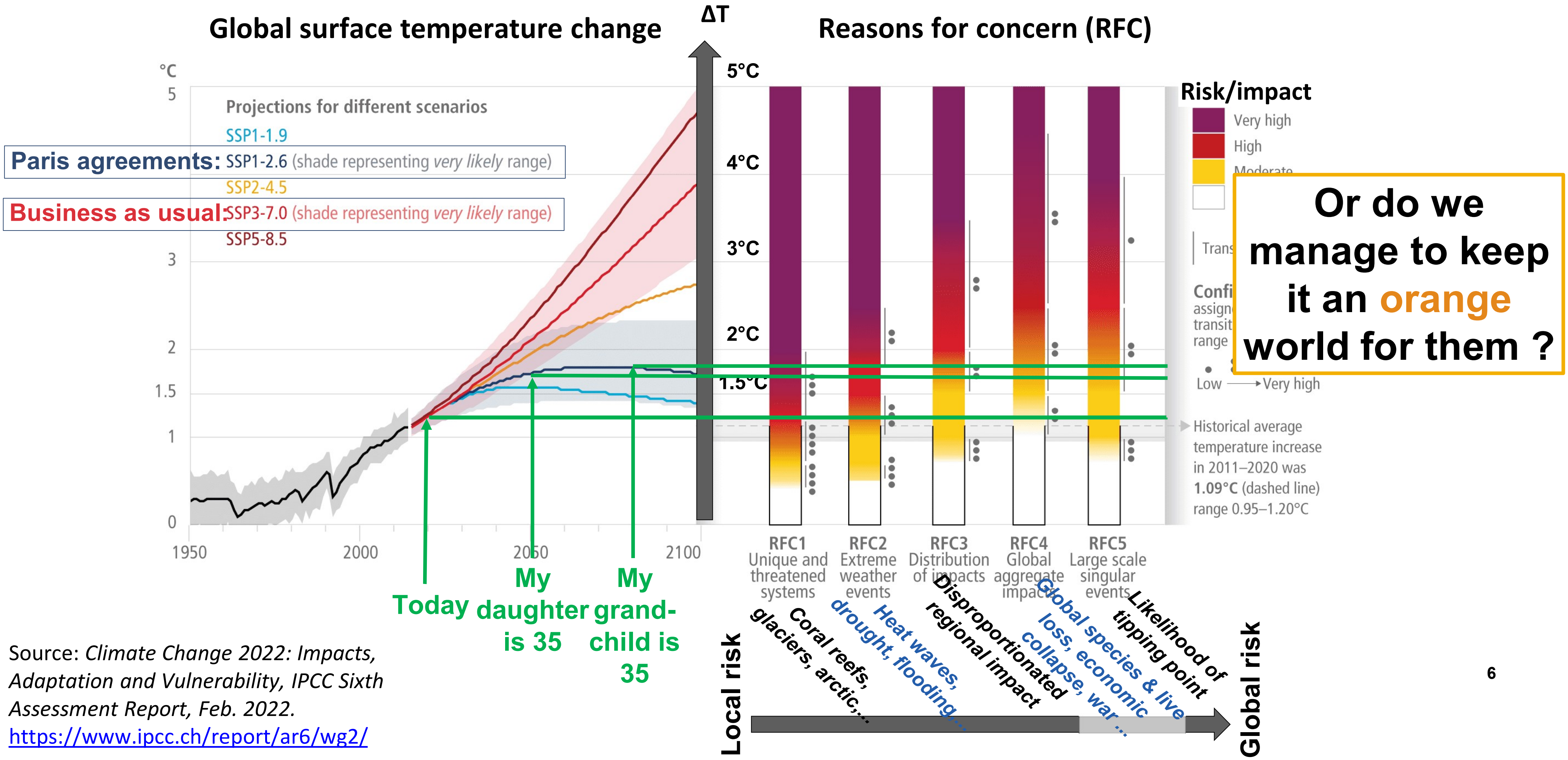
Risks for increasing levels of global warming



Will our kids live in a red world and our grand-children in a purple world ?

Source: *Climate Change 2022: Impacts, Adaptation and Vulnerability, IPCC Sixth Assessment Report, Feb. 2022.*
https://www.ipcc.ch/report/ar6/wg2/

Risks for increasing levels of global warming

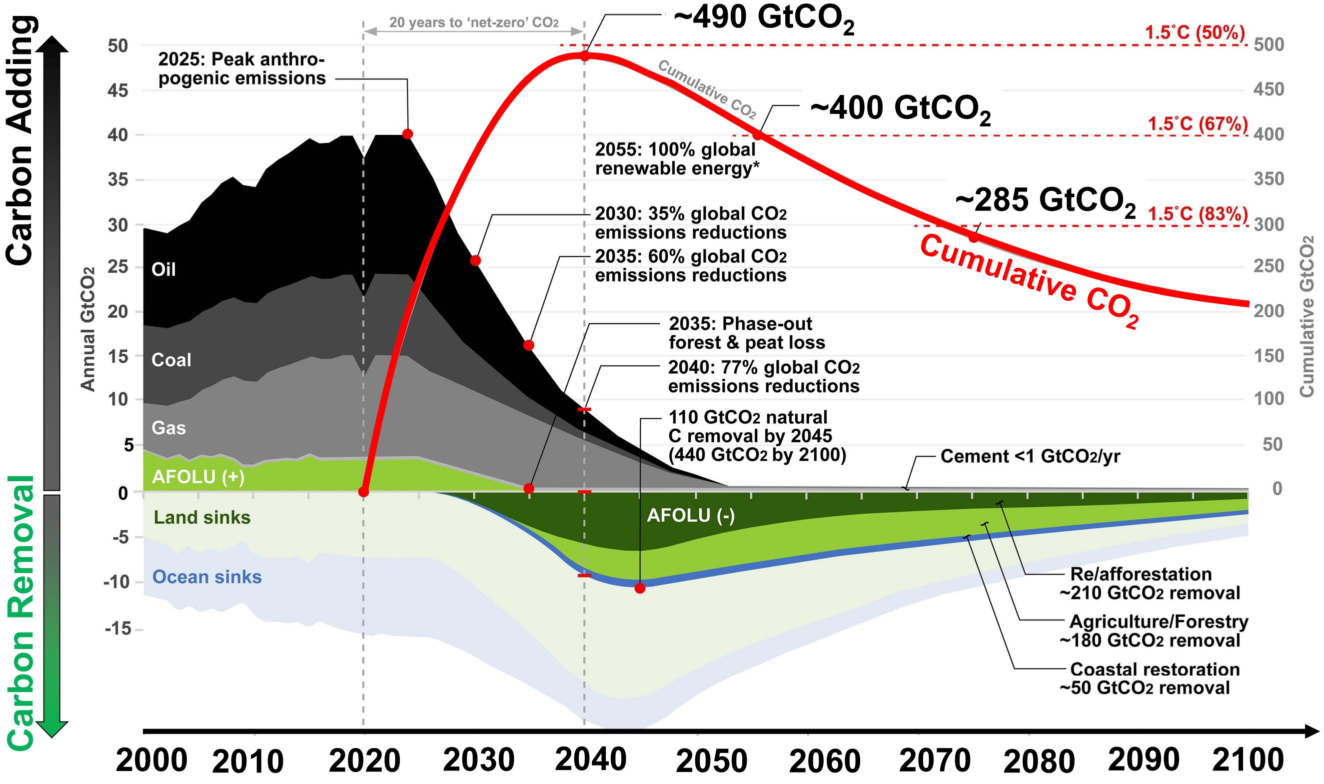


Or do we manage to keep it an orange world for them ?

Source: *Climate Change 2022: Impacts, Adaptation and Vulnerability, IPCC Sixth Assessment Report, Feb. 2022.*
https://www.ipcc.ch/report/ar6/wg2/

What it takes to keep global warming under control

OE Reference Model: 1.5°C Scenario (2025 peak)



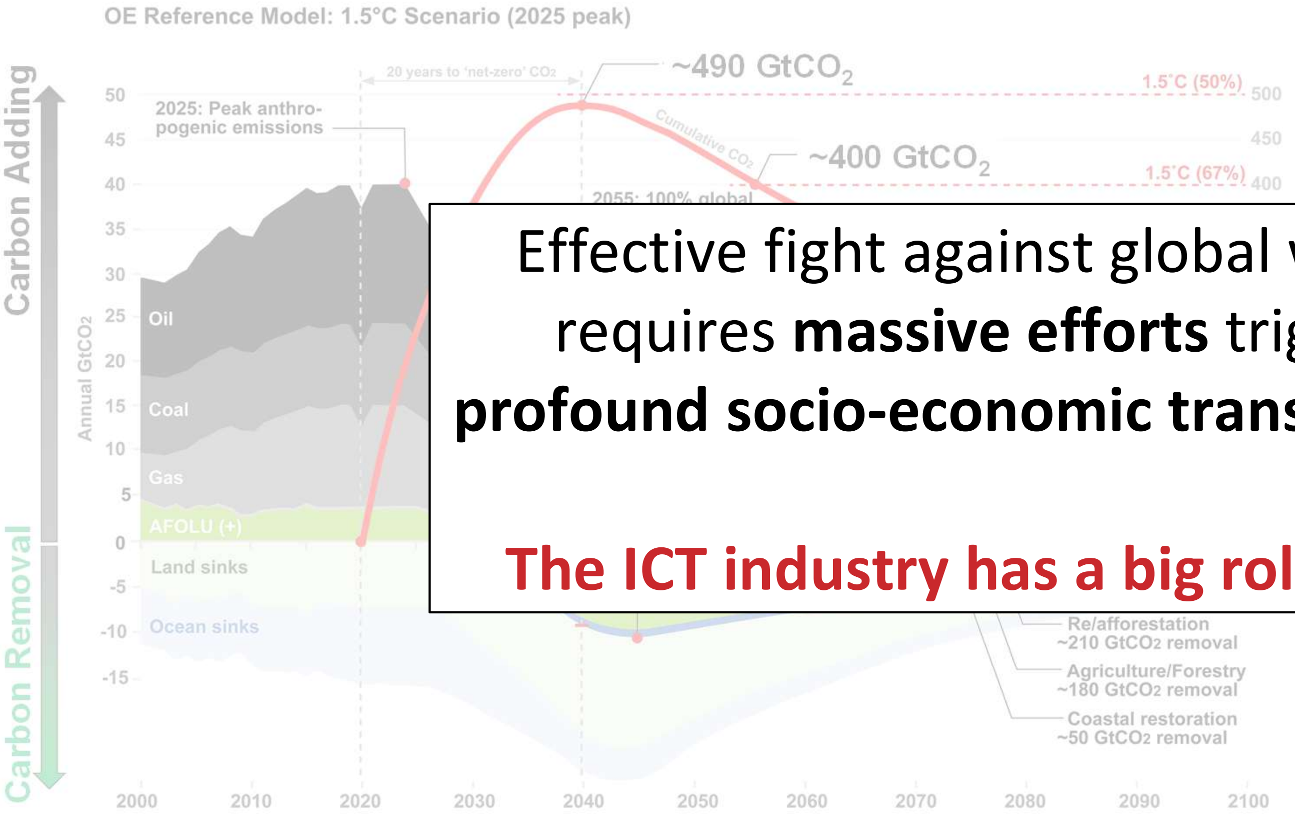
Achieve within 30 years:

- **Phase out fossil fuels =>** decarbonation of human activities, including industry
- 100% **renewable energy**
- 50% of lands and oceans protected and connected*
- Zero net emissions through regenerative agriculture

Source: https://www.oneearth.org/below-1-5-c-a-breakthrough-roadmap-to-solve-the-climate-crisis/
Climate model based on “Achieving the Paris Climate Agreement Goals”, Springer 2019
AFOLU = Agriculture, Forestry & Other Land Use

*https://www.half-earthproject.org

What it takes to keep global warming under control



Effective fight against global warming requires **massive efforts** triggering **profound socio-economic transformation**

The ICT industry has a big role to play

This scenario requires to achieve within 30 years:

t fossil fuels =>

ation of human

including industry

ewable energy

nds and oceans

protected and connected*

- Zero net emissions through regenerative agriculture

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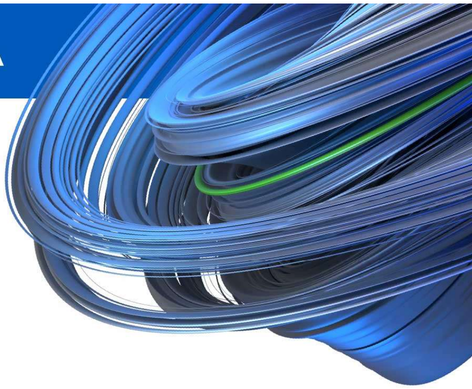


The emissions of ICT industry in perspective

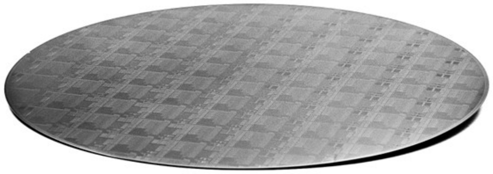
~ 36 $GtCO_{2eq}$/ year

World-wide

~ 1.2 $GtCO_{2eq}$/ year

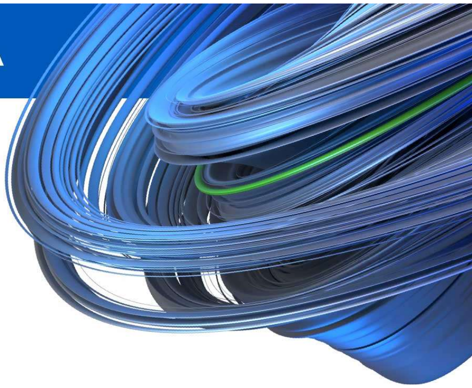
ICT Industry

~ 100 $MtCO_{2eq}$/ year



Semiconductor manufacturing

Sources: IEA Global Energy Review 2021, SEMI



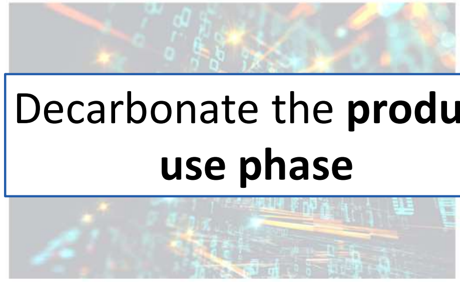
The role of ICT industry in harnessing climate change

~ 36 $GtCO_{2eq}$/ year

Innovate products that help society and other industries along its transformative path: **Enablement vs. Rebound***

World-wide

~ 1.2 $GtCO_{2eq}$/ year



Decarbonate the **product use phase**

ICT Industry

~ 100 $MtCO_{2eq}$/ year

Reduce the environmental footprint of **product manufacturing**

Semiconductor manufacturing

*See: Freitag et al., Patterns, 2021.
Bol et al. IEEE Proceedings -Design, Automation and Test in Europe, 2021.
L. Hilty and B. Aebischer, in ICT innovations for Sustainability. Springer, 2015.
SMARTer2030 - ICT solutions for 21st Century Challenges, GeSi, 2015.

The ICT industry is setting ambitious objectives

ICT industry to reduce greenhouse gas emissions by 45 per cent by 2030

ITU, GeSI, GSMA & SBTi set science-based pathway in line with Paris Agreement

ICT for Sustainable Development

Geneva, 27 February 2020

[Press Release (itu.int)]

PROGRESS TOWARDS NET ZERO

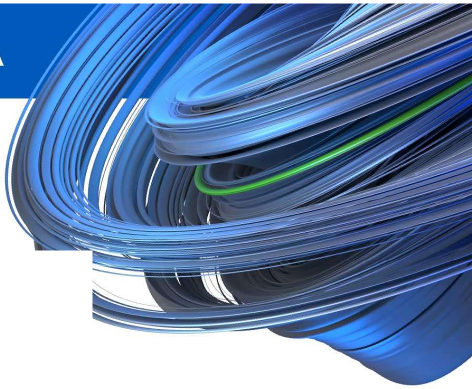
In recent years, big tech companies have been prominently leading the way on voluntary net zero ambition and progress; in many cases, goals are years ahead of the targets laid out by the IPCC.

https://netzeroclimate.org/sectors/tech/

semi | Semiconductor Climate Consortium

SEMI ANNOUNCES SEMICONDUCTOR CLIMATE CONSORTIUM FOUNDING MEMBERS

[SEMI Press release]



imec’s climate ambition

Help the semiconductor industry achieving its objectives

Innovate products that help society and other industries along its transformative path

Decarbonate the **product use phase**

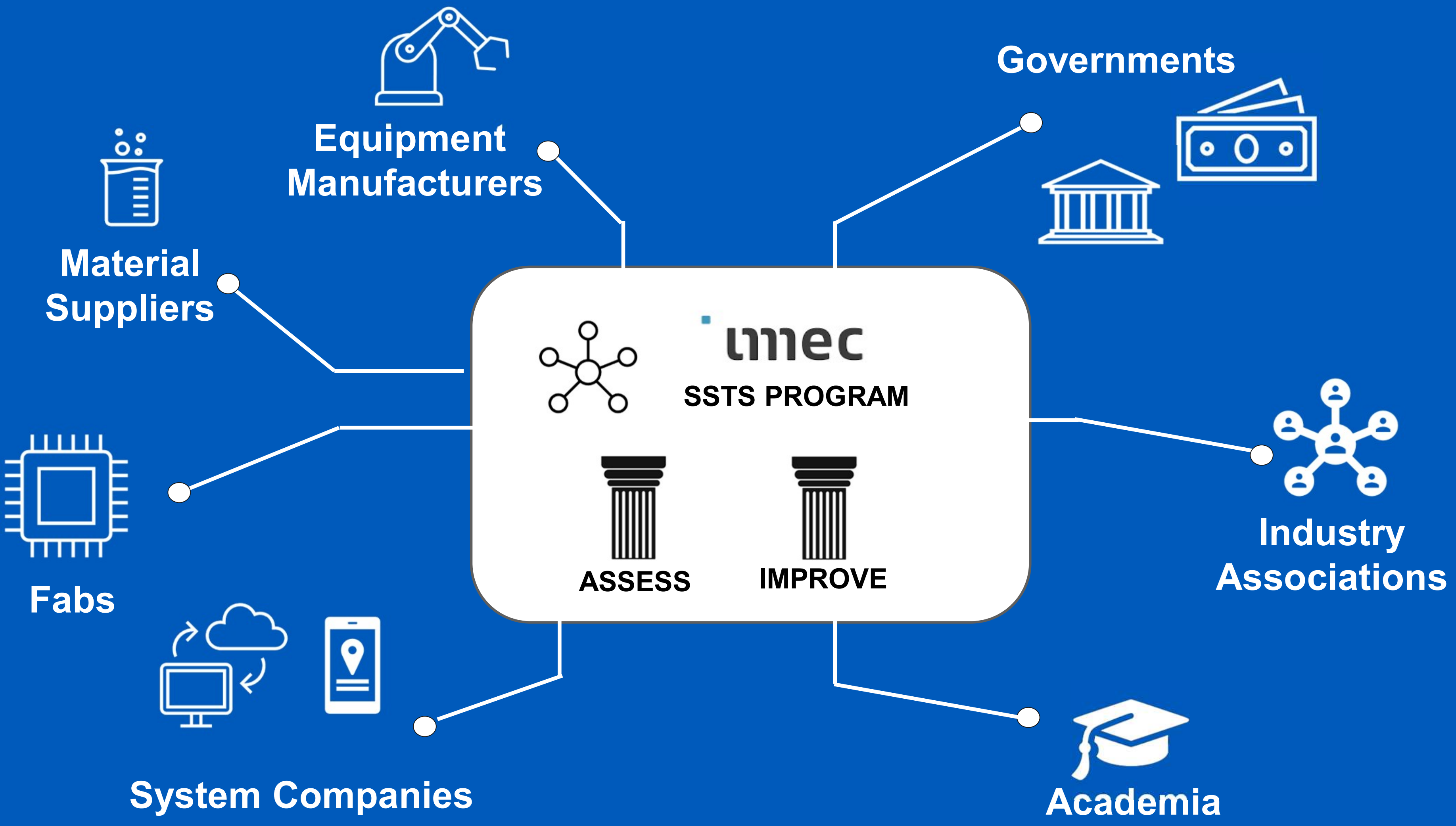
Reduce the environmental footprint of **product manufacturing**

imec programs

Performance Power Area & Cost (PPAC) driven innovation

Environmental driven innovation
without sacrificing PPAC

SSTS Program



imec

SSTS PROGRAM

ASSESS

IMPROVE

Equipment Manufacturers

Governments

Material Suppliers

Industry Associations

Fabs

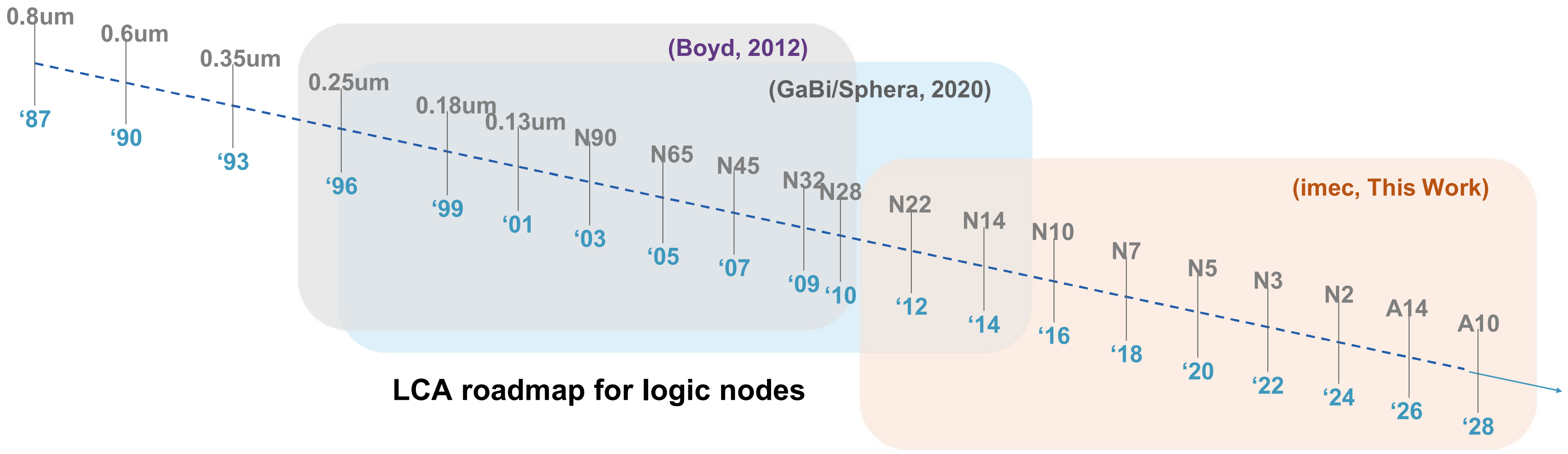
System Companies

Academia

SSTS Assess objective

Quantify the **environmental footprint of making IC chips** in a High-Volume Manufacturing (HVM) semiconductor Fab

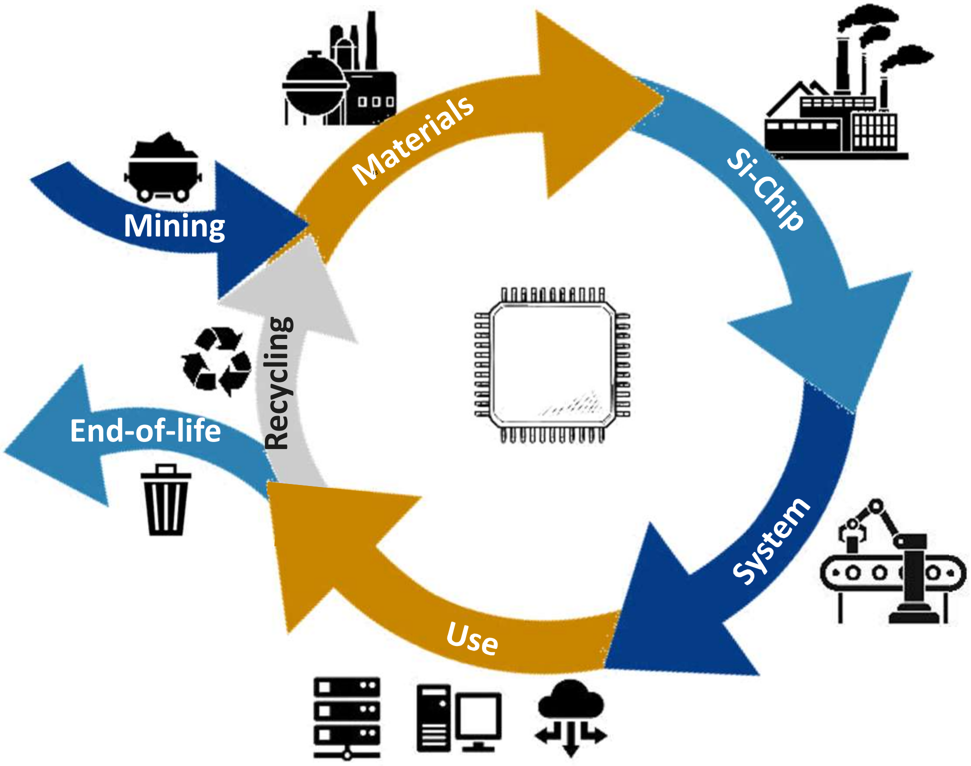
- Fill a **gap in life-cycle assessment** of the latest and future techs
- Identify **high impact problems** to focus Improve efforts
- Project the **future impact of IC chip manufacturing** and guide decision makers



LCA roadmap for logic nodes

The Life-Cycle of a Si-chip

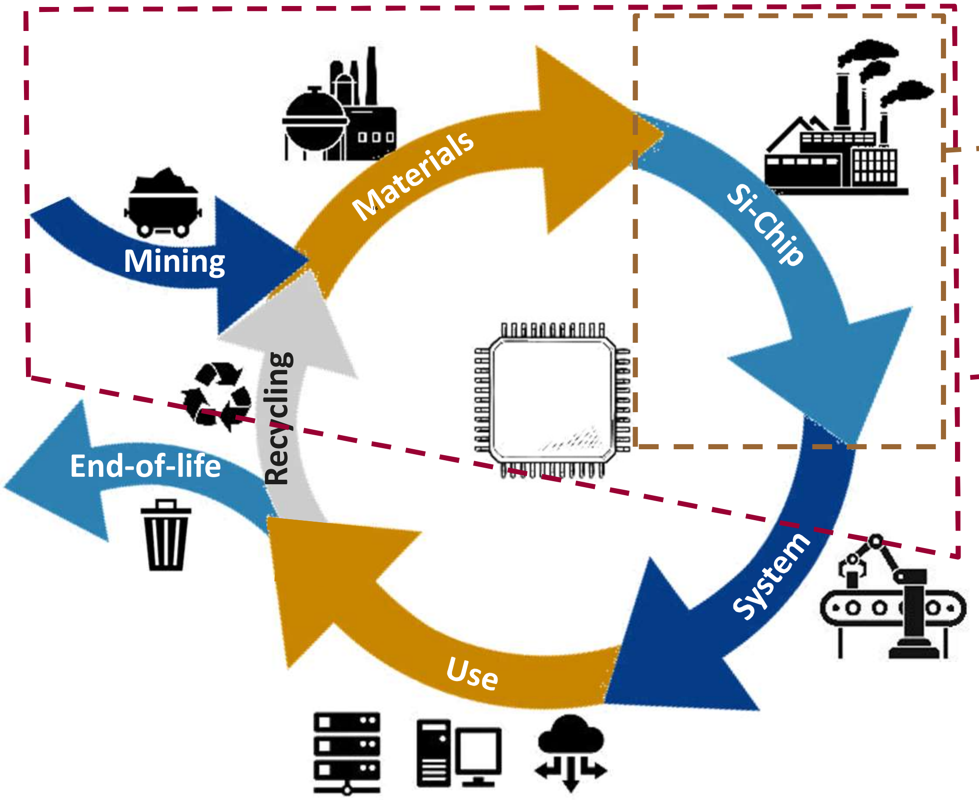
Goal and scope of SSTS Assess



- **Product system**
  - Si chips from a generic 300mm HVM Fab:
    - Logic and Memory applications
    - Multiple (future) technology nodes
- **Functional Unit**
  - For Manufacturing industry: “*per Wafer*”, “per Mask Layer”
  - For IC Chip users: “*per functional die*”, “*per functional cm²*”
- **Impact categories**
  - *Climate Change*
  - *Secondary Energy use (Electricity)*
  - *Water usage*
  - *Mineral usage and depletion potential*

The Life-Cycle of a Si-chip

Goal and scope of imec.netzero

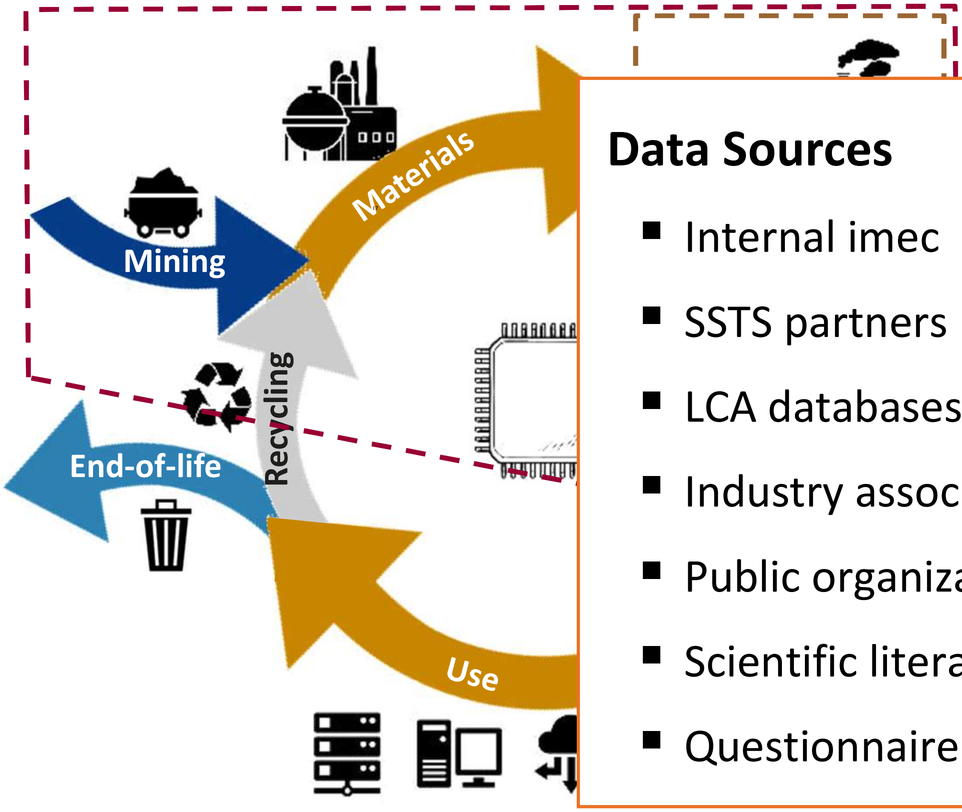


- **System boundaries** – Two sets :
  - Gate-to-Gate semiconductor Fab.
    - Mainly PRIMARY data
    - Flow includes: **Process Equipment**, **Utilities** and **Infrastructure** operation
  - Cradle-to-Gate Si-chip manufacturing.
    - Adding SECONDARY data
  - **Recycling** considered at Fab level

- **Not included in present analysis**
  - Equipment fabrication
  - Infrastructure construction

The Life-Cycle of a Si-chip

Goal and scope of imec.netzero



Data Sources

- Internal imec
- SSTS partners
- LCA databases
- Industry associations: SEMI, ...
- Public organizations: IPCC, IEA, ...
- Scientific literature
- Questionnaire to supply chain

- **System boundaries** – Two sets :

e semiconductor Fab.

MARY data

des: **Process Equipment**, **Utilities**

tructure operation

te Si-chip manufacturing.

CONDARY data

nsidered at Fab level

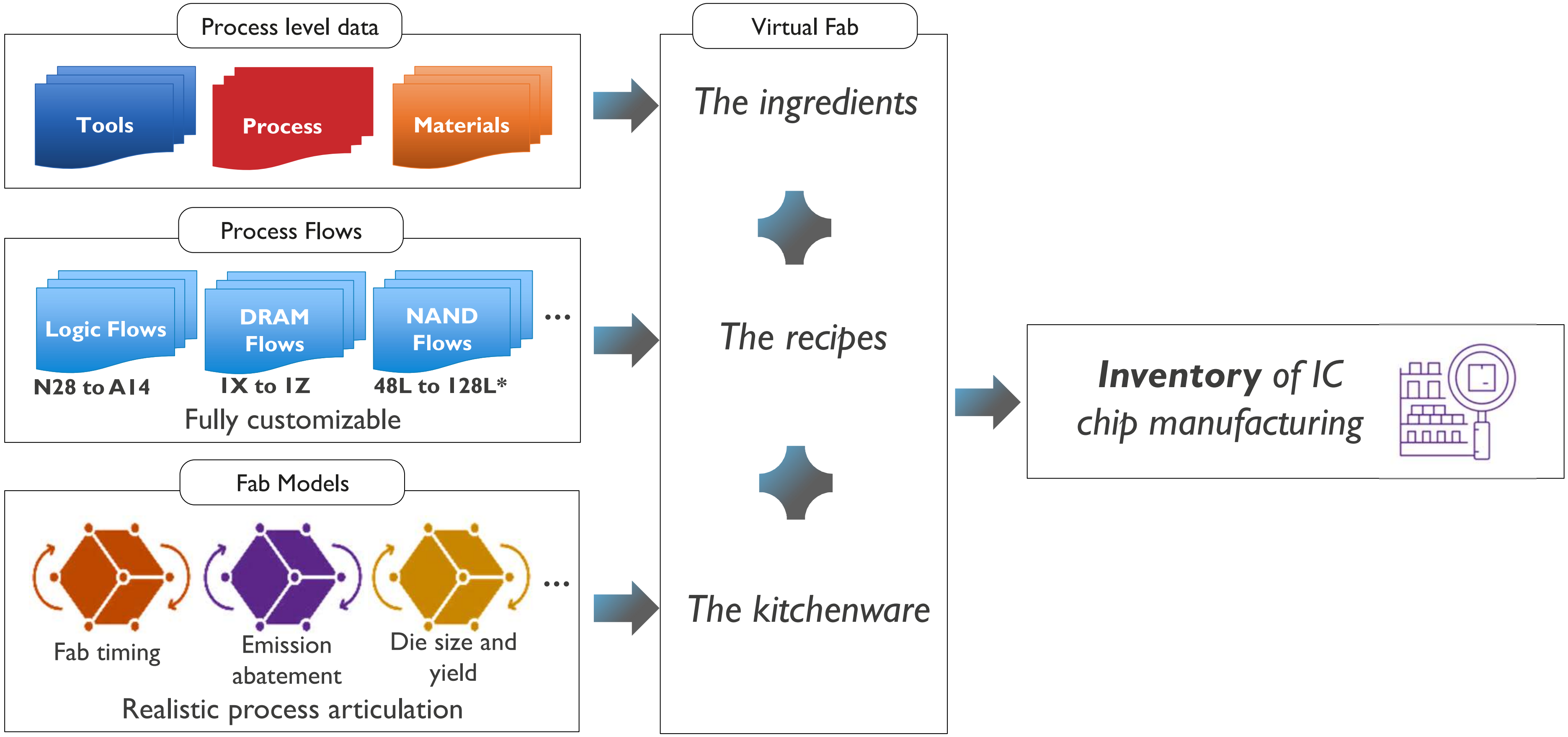
in present analysis

abrication

e construction

Gate-to-gate HVM Fab Life-Cycle Assessment

Bottom-up model implementation



Process level data

Tools

Process

Materials

Process Flows

Logic Flows

N28 to A14

DRAM Flows

1X to 1Z

NAND Flows

48L to 128L*

…

Fully customizable

Fab Models

Fab timing

Emission abatement

Die size and yield

…

Realistic process articulation

Virtual Fab

The ingredients

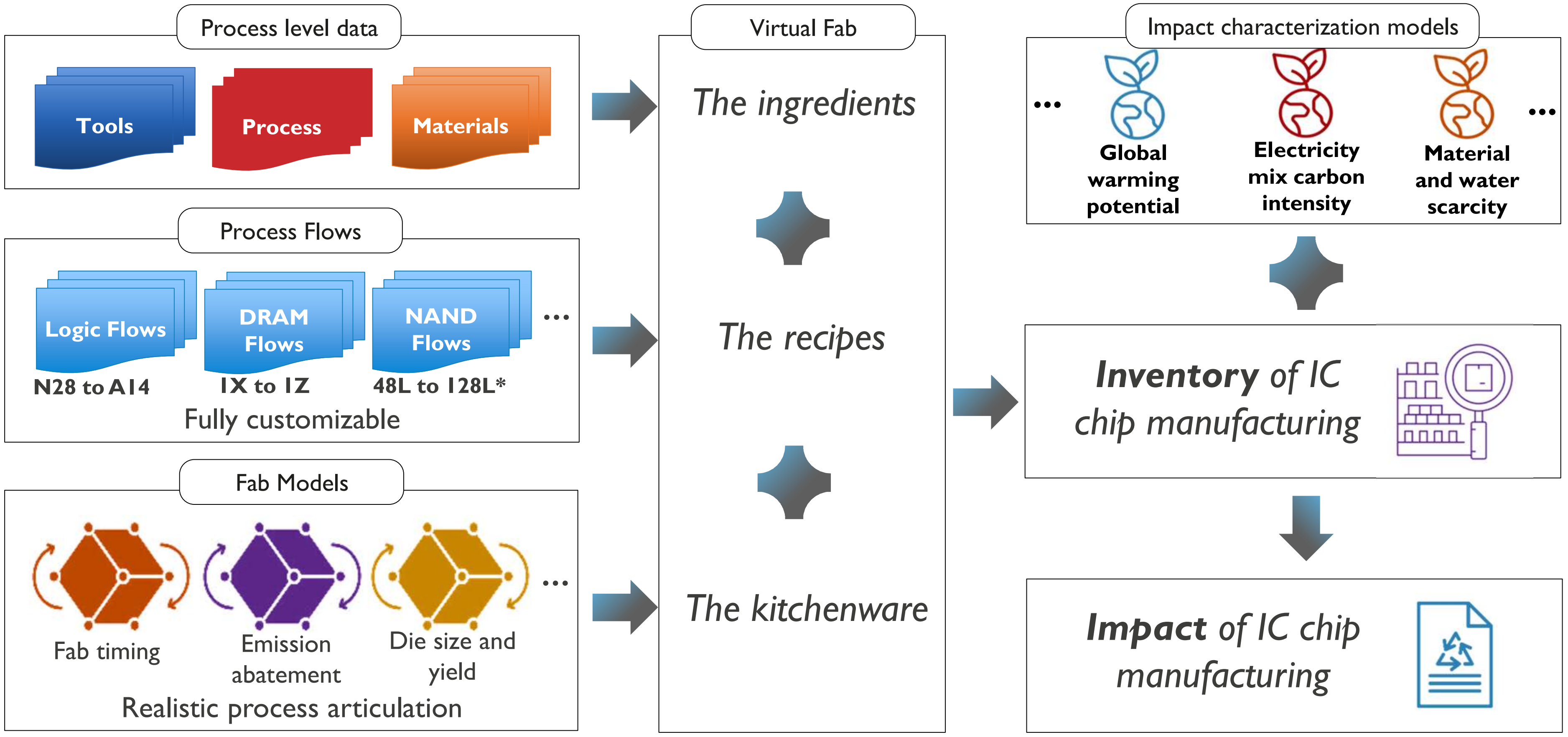
The recipes

The kitchenware

***Inventory** of IC chip manufacturing*

Gate-to-gate HVM Fab Life-Cycle Assessment

Bottom-up model implementation



Process level data

Tools

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N28 to A14

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48L to 128L*

Fully customizable

Fab Models

Fab timing

Emission abatement

Die size and yield

…

Realistic process articulation

Virtual Fab

The ingredients

The recipes

The kitchenware

Impact characterization models

…

Global warming potential

Electricity mix carbon intensity

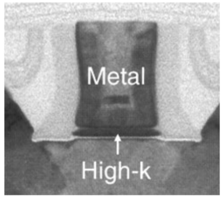
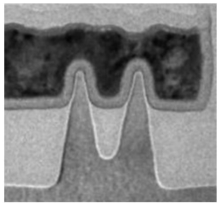
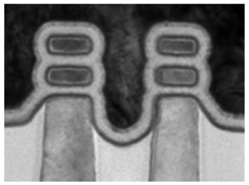
Material and water scarcity

…

***Inventory** of IC chip manufacturing*

***Impact** of IC chip manufacturing*

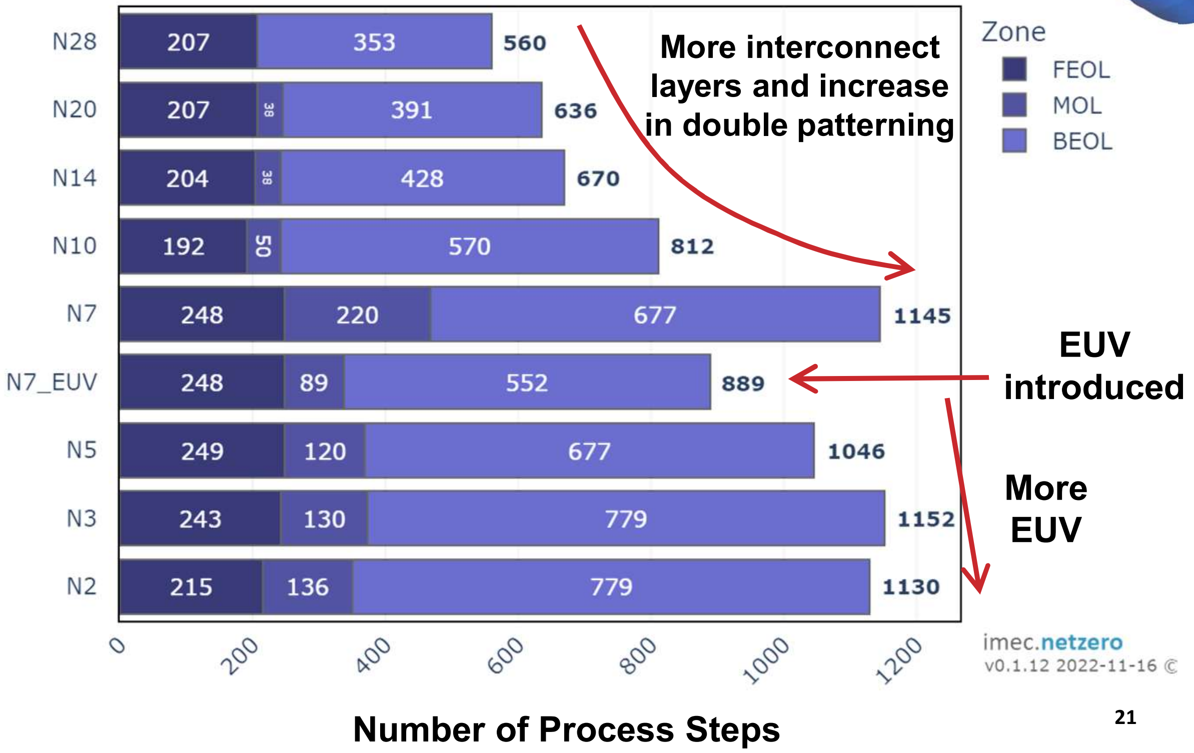
Studied Logic CMOS technologies and nodes

Technology Node	**N28**	**N20**	**N14**	**N10**	**N7**	**N5**	**N3**	**N2**	**A14**
Metal Pitch [nm]	**90**	**64**	**64**	**48**	**40**	**28**	**22**	**21**	**18**
Device structure	 **Planar**		 **FinFETs**					 **Nanosheets**	
Standard cells # tracks	**9T**	**9T**	**9T**	**7.5T**	**6.5T**	**6T**	**6T**	**5T**	**5T**
Scaling boosters					**Self Aligned Gate Contact**		**Metal Gate Cut**	**Backside power delivery**	
Lithography	**Immersion (ArFi)**								**EUV**

Nodes based on imec process flow are generic but representative of foundry nodes.

Complexity Increase of a Mobile SoC

- Increase in Complexity node to node where BEOL interconnects dominate
- Introduction of **EUV slows down the increase in complexity**:
  - Less multi-patterning DUV immersion steps
  - Less deposition, Dry-Etch, Wet-Clean, Metrology steps

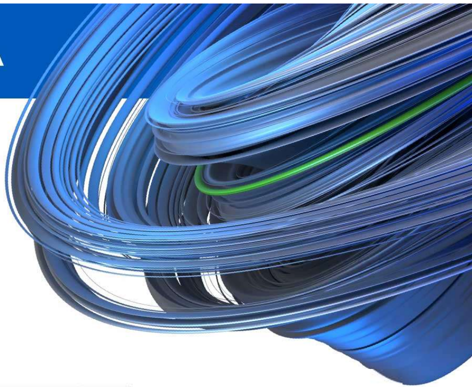


More interconnect layers and increase in double patterning

EUV introduced

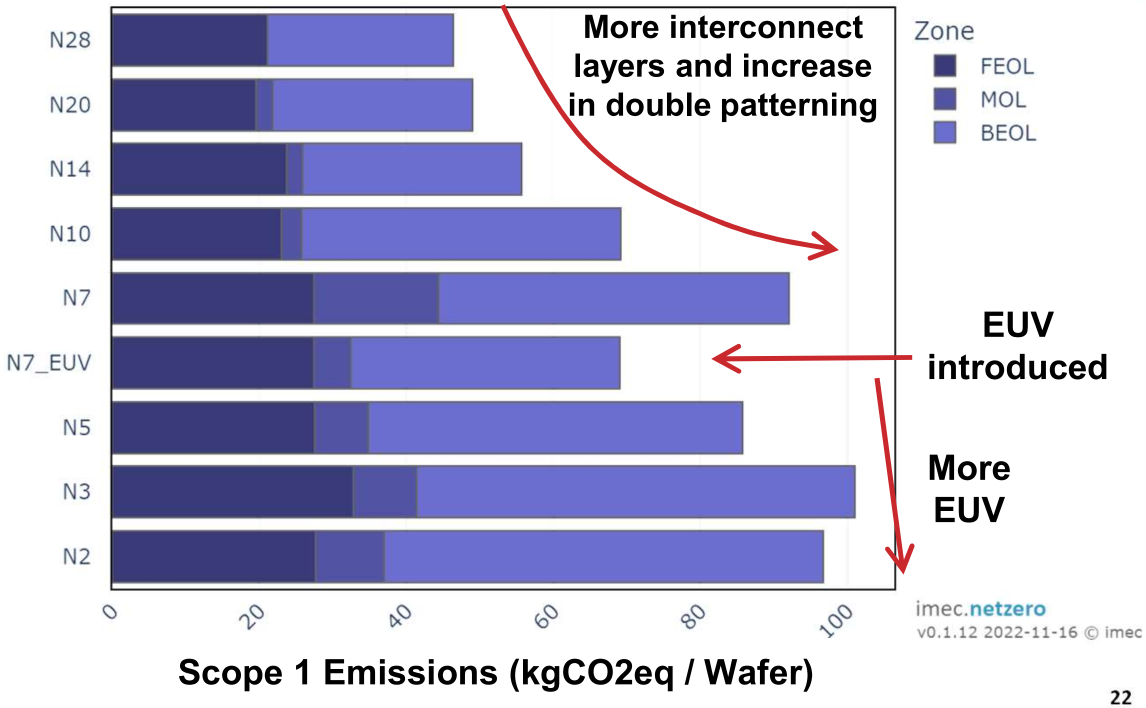
More EUV

imec.netzero v0.1.12 2022-11-16 ©



Direct Emissions (Scope 1)

- Process gases are potent Greenhouse gases => **Deposition and Etch** contribute strongly to direct emissions
- Multi patterning use many repeats of deposition and etch ⇔ **By reducing complexity, EUV keeps direct emissions under check**



More interconnect layers and increase in double patterning

EUV introduced

More EUV

Scope 1 Emissions (kgCO2eq / Wafer)

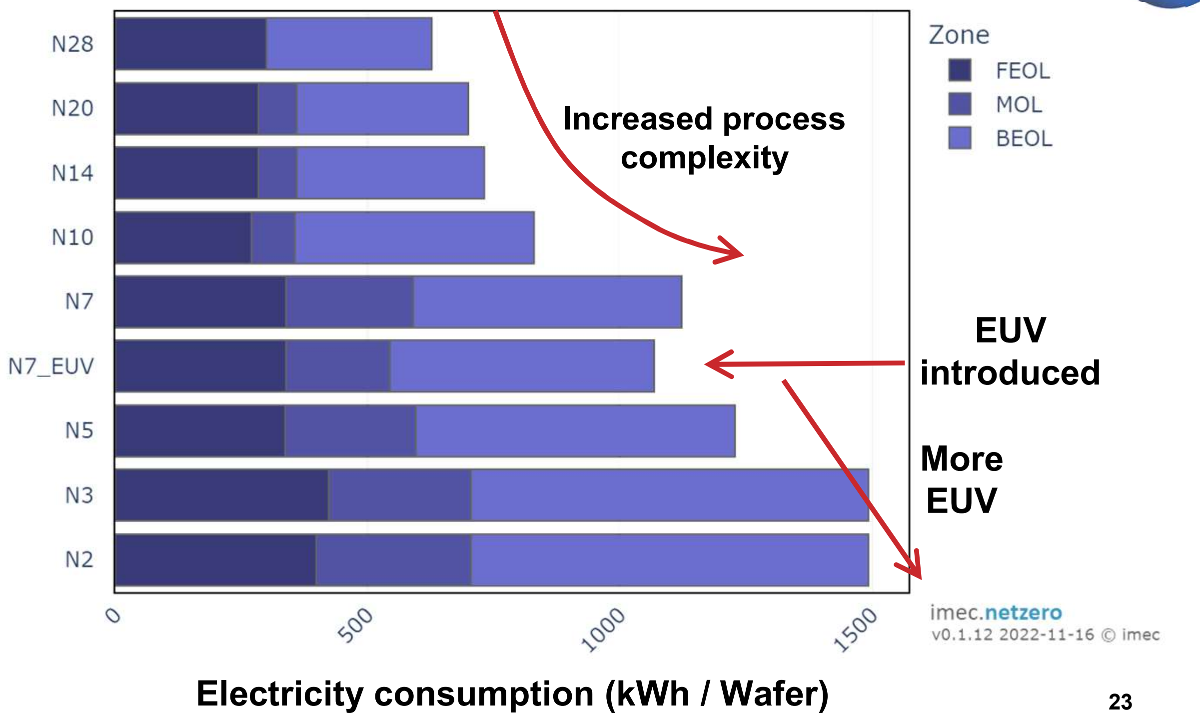
Tier 2C Abatement (2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories) and GHG global warming potential (IPCC AR6).

Electricity consumption

- Increase in process complexity directly leads to increased electricity consumption
- Introduction of EUV leads to:
  - ○ **Reduce in process complexity**
  - ○ **Increased electricity consumption** of the litho process area

These two effect counteract each other leading to a continued increase.

Utility electricity consumption modelled using SEMI S23 standard.



Increased process complexity

EUV introduced

More EUV

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Total Emissions are on the rise

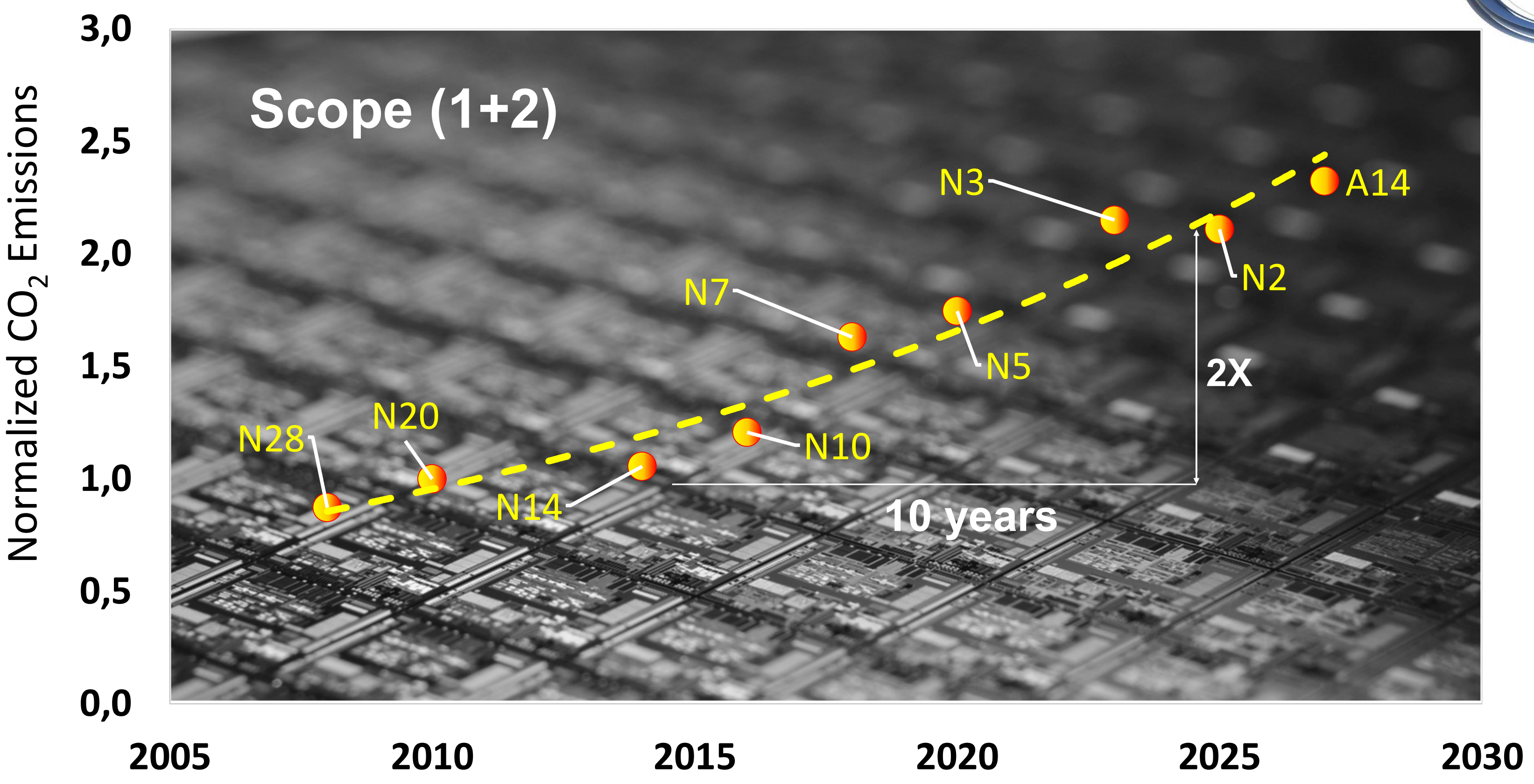
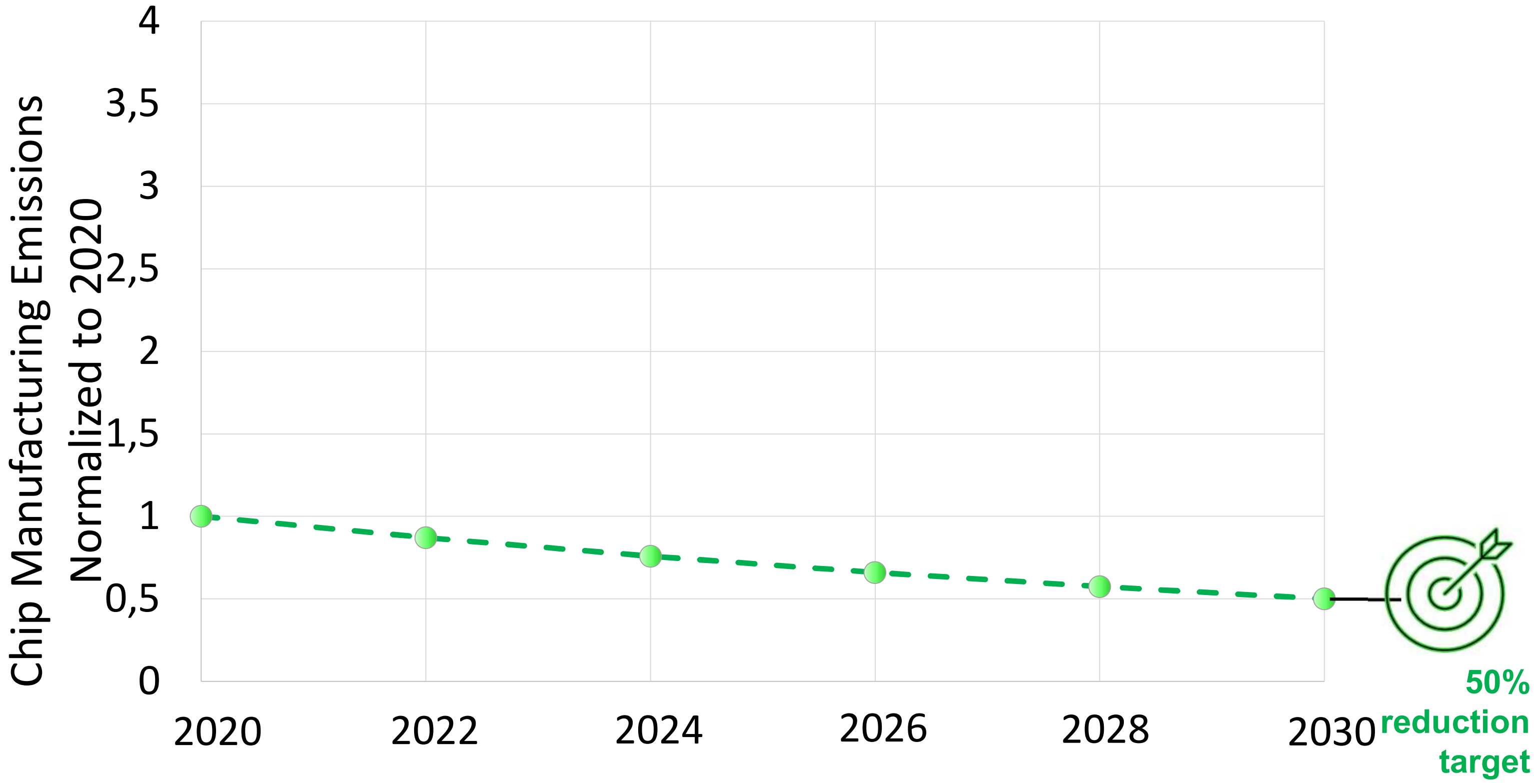
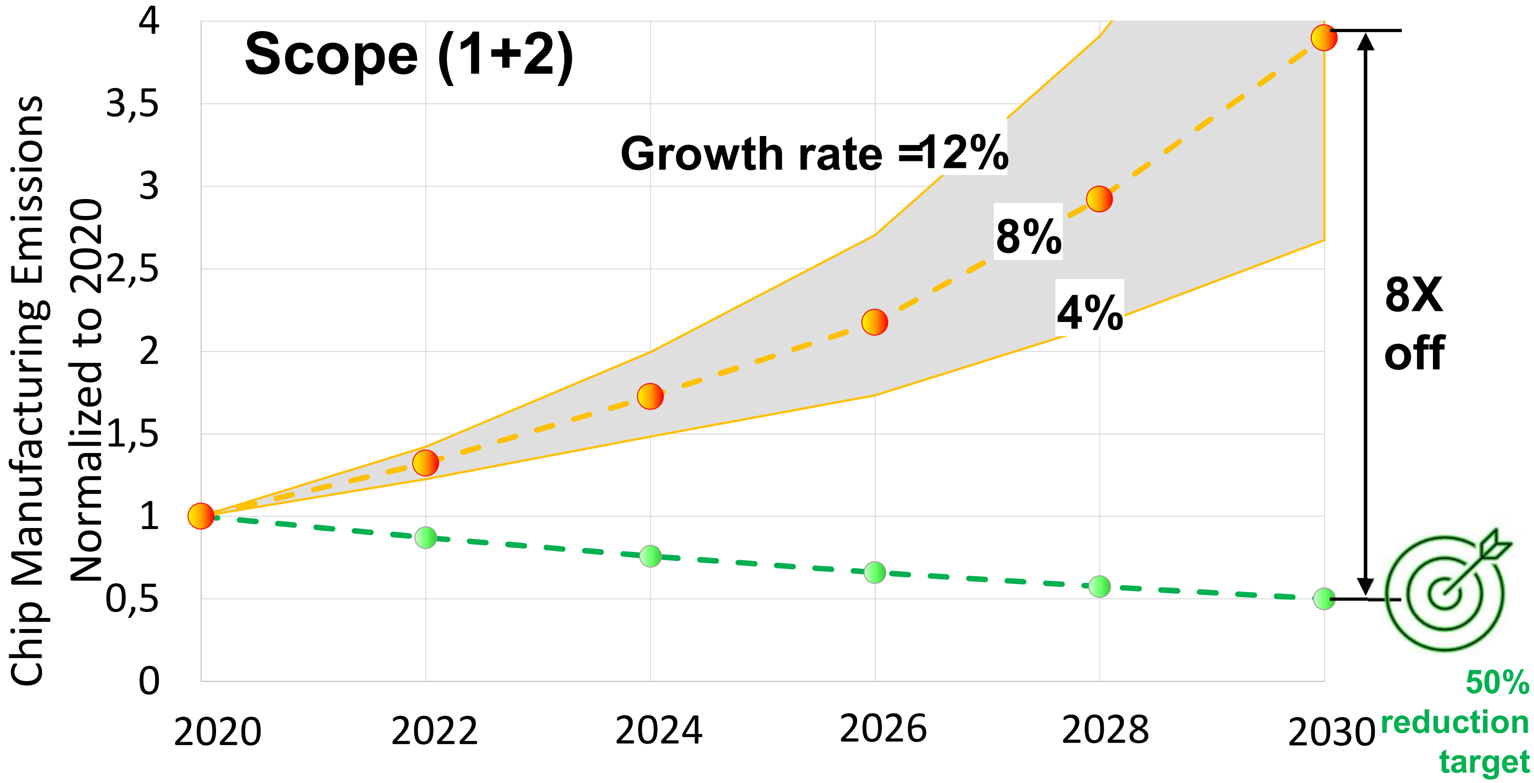


Photo by Laura Ockel on Unsplash

Ideal climate impact scenario for Semiconductor Manufacturing



“Do Nothing” Scenario for Semiconductor Manufacturing

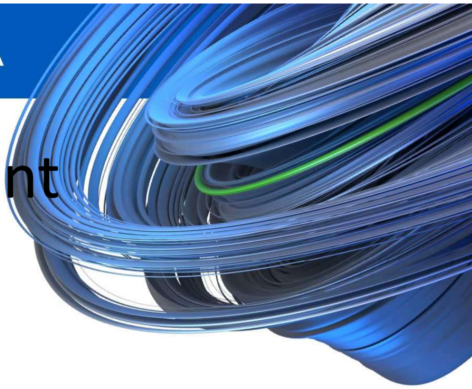


Projection includes:

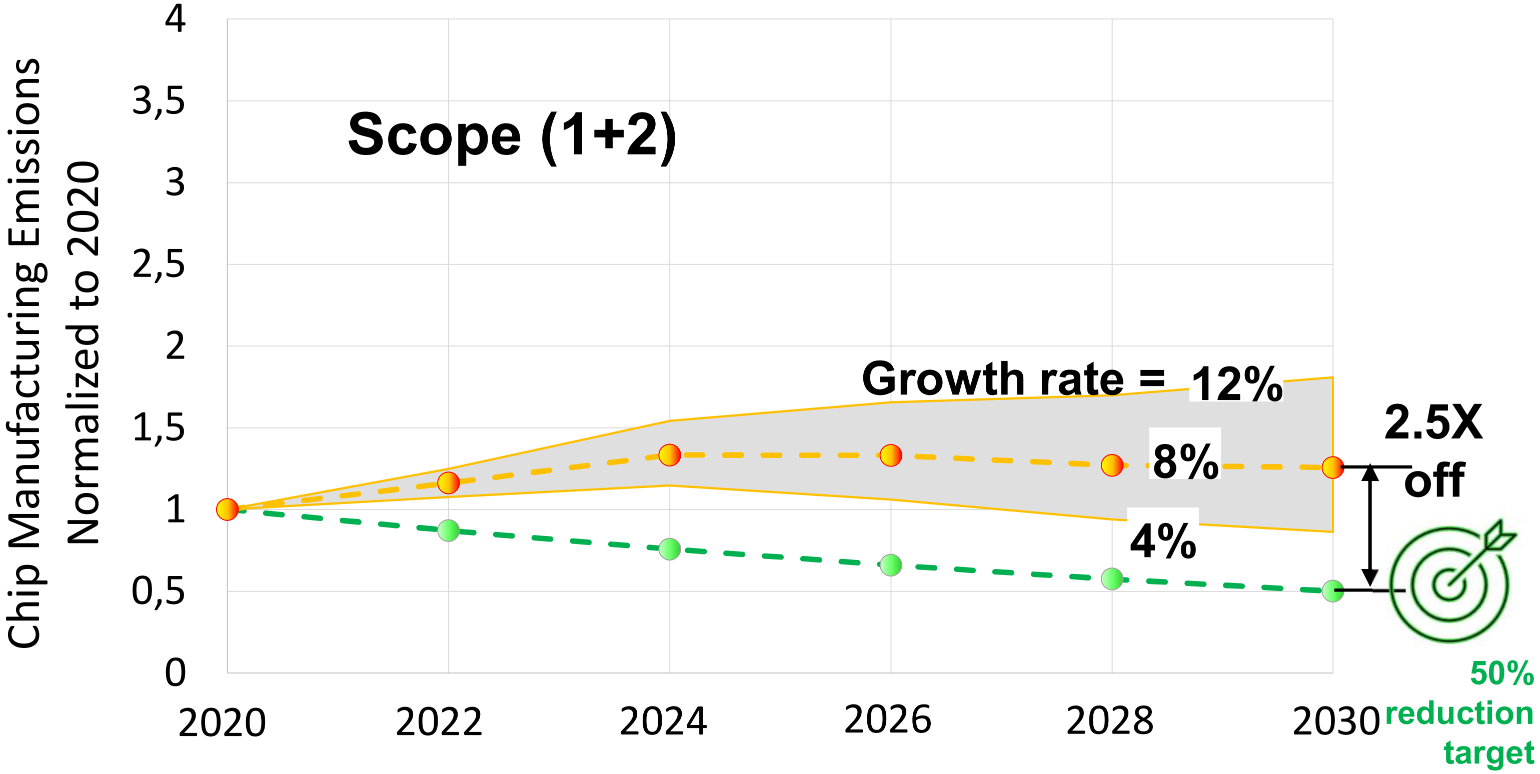
- Evolution of technology mix
- Increase in technology complexity
- ICT Market growth

Electricity mix and abatement not evolving.

Constant electricity mix (0.49 kCO2eq/kWh), Tier 2C Abatement (2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories) and GHG global warming potential (IPCC AR6). Volume technology mix from IBS “Foundry Market Trends and Strategic Implications” Vol 30, N 12 , Dec 2021. Logic nodes only.



With Renewable Energy and State-of-the-Art GHG Abatement

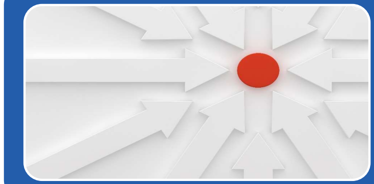


Projection includes:

- Evolution of technology mix
- Increase in technology complexity
- ICT Market growth
- Renewable energy deployment
- State-of-art abatement from 2026 onwards

Adding to previous slide: Renewable Energy deployment according to IEA and abatement according to IPCC assumed for the years 2020-2024, State-of-the art Abatement from 2026.

Call to Action



Adopt 50% emissions reduction this decade as target

Must-do for fabs: renewables, best abatement

- New research: materials, equipment, fabs, device makers

Report transparently including scope 3

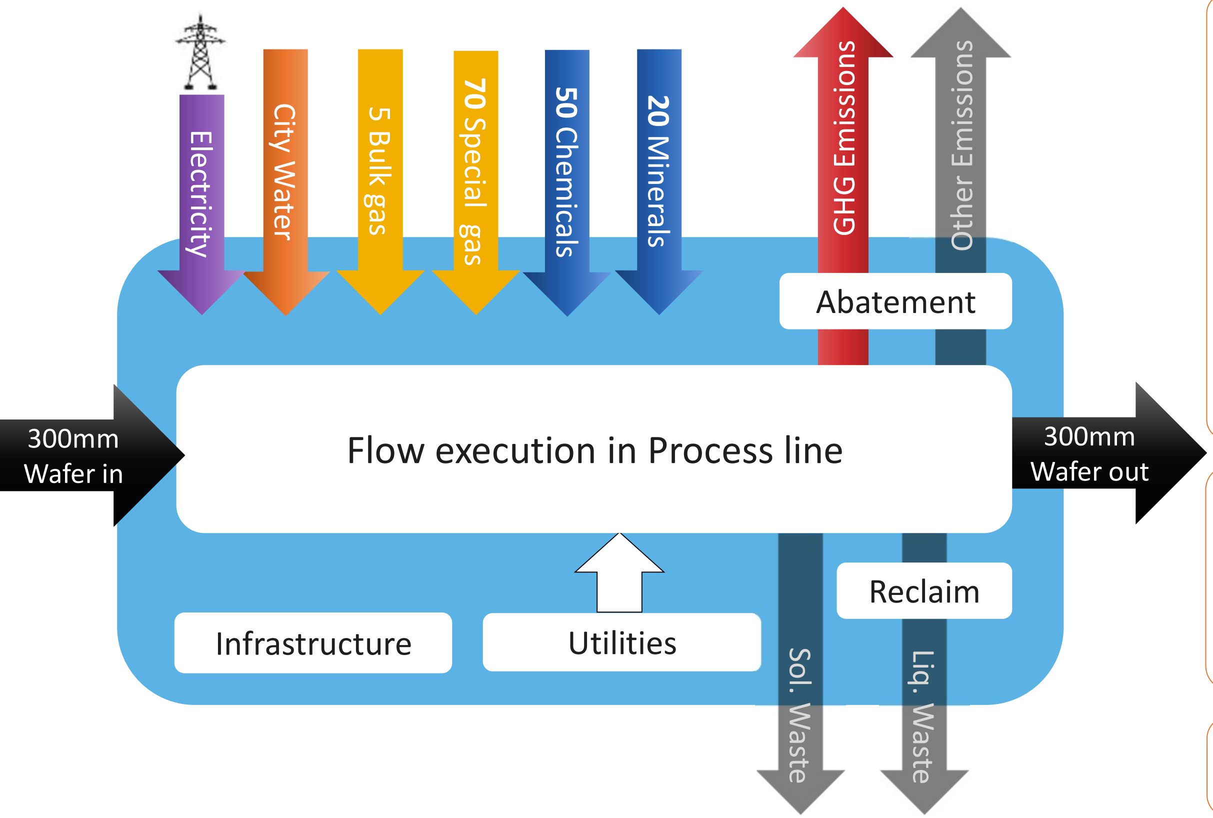
Share best practices openly

Thank You

Cedric.Rolin@imec.be

ANNEX

Gate-to-gate HVM Fab Life-Cycle Inventory



Material and Energy input flows

Flow of material/energy ***i*** *:*

$$\text{Flow per wafer}_i = \sum_{p}^{\text{Full process flow}} \frac{\text{Resource consumption}_{i,p}}{\text{Process Throughput}_p}$$

Utilities: Consumption tracked at process step level.

Infrastructure: Top-down approach.

Direct emissions

Direct emissions of GHGs are calculated by modelling **tool utilization** and **abatement**.

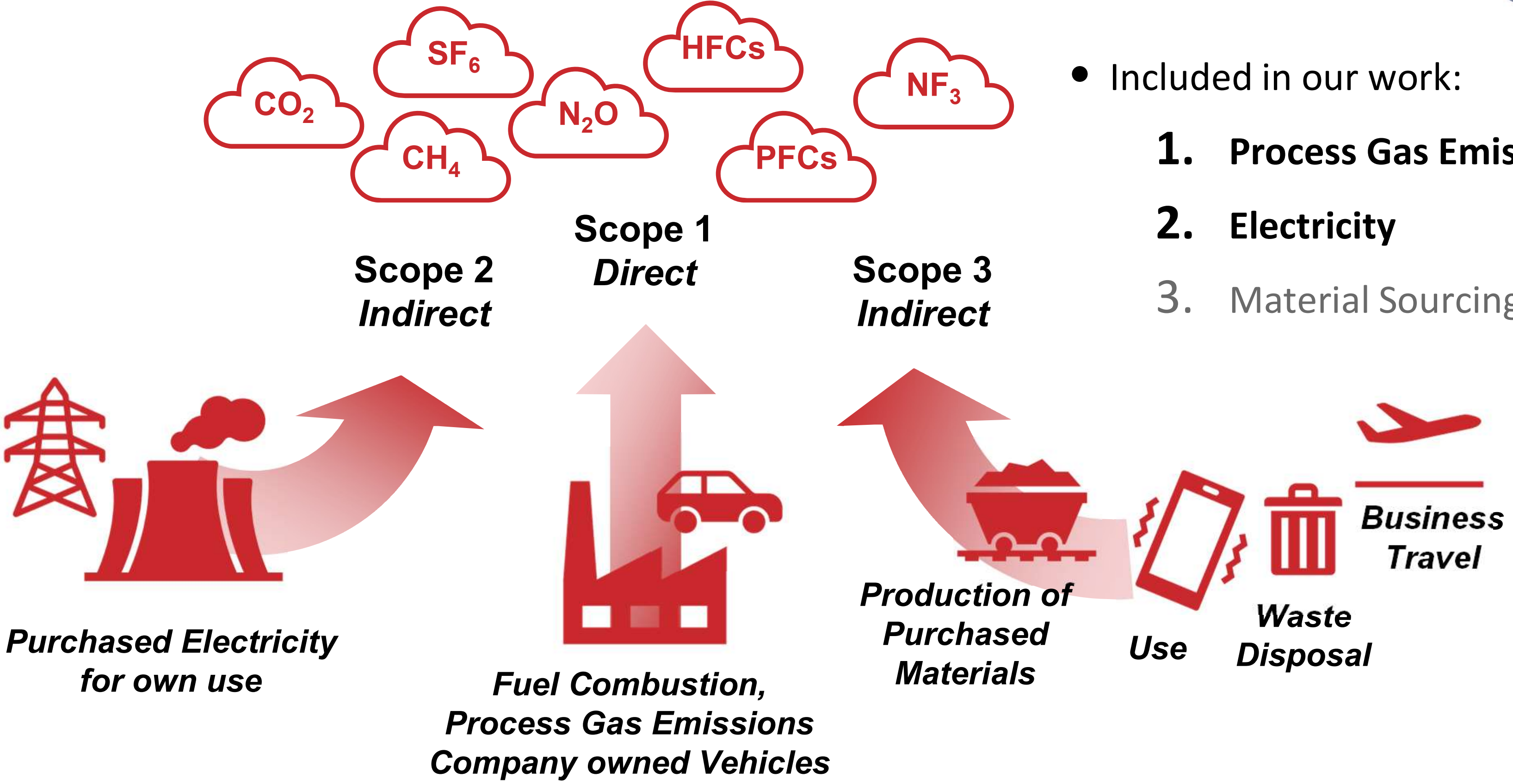
The direct emission of other gases is currently not tracked.

Output wastes

The release of waste streams is currently not tracked.

The Greenhouse Gas Protocol: Scopes 1-3

The case for Semiconductor Manufacturing of Integrated Circuits



CO_2 SF_6 CH_4 N_2O HFCs PFCs NF_3

Scope 2
Indirect

Scope 1
Direct

Scope 3
Indirect

Purchased Electricity for own use

***Fuel Combustion,
Process Gas Emissions
Company owned Vehicles***

Production of Purchased Materials

Use

Waste Disposal

Business Travel

- Included in our work:
  1. **Process Gas Emissions**
  2. **Electricity**
  3. Material Sourcing (in progress)