DATA BRIEF

Semiconductor Emission Explorer: Tracking Greenhouse Gas Emissions from Chip Production (2015-2023)

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Tech analysis and policy ideas for Europe

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Since 2014, our team has worked on building an independent think tank and publishing well-researched analysis for everyone who wants to understand or shape technology policy in Germany. If we have learned something over the last ten years, it is that the challenges posed by technology cannot be tackled by any country alone, especially when it comes to Europe. This is why our experts have not only focused on Germany during the past years, but also started working across Europe to provide expertise and policy ideas on AI, platform regulation, cyber security, government surveillance or semiconductor strategies.

For 2024 and beyond, we have set ourselves ambitious goals. We will further expand our research beyond Germany and develop SNV into a fully-fledged European Think Tank. We will also be tapping into new research areas and offering policy insights to a wider audience in Europe, recruiting new talent as well as building expert communities and networks in the process. Still, one of the most visible steps for this year is our new name that can be more easily pronounced by our growing international community.

Rest assured, our experts will still continue to engage with Germany's policy debates in a profound manner. Most importantly, we will remain independent, critical and focused on producing cutting-edge policy research and proposals in the public interest. With this new strategy, we just want to build a bigger house for a wider community.

Please reach out to us with questions and ideas at this stage.

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Executive Summary

As the cornerstone of technological innovation, economic growth and the recent AI boom, the semiconductor industry is currently set to become a trillion-dollar industry by 2030. At the same time, concerns over the sustainability of chip production are intensifying due to its high resource consumption, resulting in significant emissions, water and energy demands. But what is currently lacking is a quantitative understanding of the chip industry's ecological footprint, the fundament for effective actions toward decarbonization. The European Commission's recent regulatory shift – aimed at streamlining and reducing sustainability reporting obligations and due diligence requirements through the Omnibus Package – highlights the challenges of obtaining clear and effective data on companies' climate change mitigation efforts and their environmental impact.

This data brief seeks to address these challenges by introducing the **Semiconductor Emission Explorer**, an interactive database that tracks emissions trends across the three scopes of the Greenhouse Gas (GHG) Protocol. Updated annually, this tool not only provides critical insights into the industry's progress in reducing emissions from 2015 to 2023 but also identifies areas that require enhanced transparency and improved reporting standards. Our analysis is based on annually published corporate social responsibility (CSR) from 28 global chip manufacturers and reveals important trends related to the direct emissions, energy usage, indirect emissions, and upstream and downstream impacts in the global semiconductor industry.

Key findings:

- **Direct Emissions** increased from 15,4 million metric tons of CO2 equivalents (MMTCO2E) in 2015 to 27,2 MMTCO2E in 2021, before declining to 18,9 MMTCO2E in 2023.
- **Energy consumption** is clearly one of the biggest challenges in chip production. It has more than doubled over the past 8 years, from 58 326 gigawatt-hours (GWh) in 2015 to 131 278 GWh in 2023.
- **Indirect Emissions**: Despite a 125% rise in energy consumption, indirect (market-based) emissions increased by only 71%, from 22.7 MMTCO2E to 38,9 MMTCO2E, indicating an increased use of renewable energy certificates (RECs).
- **Upstream and Downstream Emissions**: Scope 3 emissions have grown sevenfold, from 11,7 MMTCO2E in 2015 to 87,4 MMTCO2E in 2023. This rise is likely due to improved reporting practices, though transparency in downstream emissions remains a challenge.

Conclusion:

- The ecological footprint of chip production can no longer be overlooked. Expanding the EU's manufacturing capacity will inevitably have significant environmental consequences. At the same time, continued dependence on fabs in East Asia means that the more ecologically harmful aspects remain outsourced. A long-term EU semiconductor strategy must integrate both takeaways to position the EU as a global leader in sustainable semiconductor production.

- ESG/CSR reporting currently suffers from significant gaps, limitations and loopholes, making a reliable evaluation nearly impossible. Without a standardized framework, interpreting CSR data in the complex chip industry will remain challenging, as it must be contextualised with additional factors, such as production yield and utilisation of manufacturing capacities. The primary challenge lies in achieving industry-wide alignment in implementing solutions that balance transparency with the protection of sensitive data that should be incentivized by governments.

Introduction

Context

The semiconductor industry is currently undergoing significant changes. Rapid advancements in general-purpose artificial intelligence (AI) have triggered a new surge in demand for semiconductors (Aasholm 2024). Simultaneously, governments are increasingly acknowledging the critical role of semiconductors in leading technological innovation and securing supremacy, resulting in ongoing reflections on their economic and national security implications.

This becomes apparent in intensified global technology rivalries, as evidenced by the United States' (US) most recent export controls targeting China (CN) introduced in December 2024 and in January 2025. Governments are striving to increase the resilience of chip value chains with substantial subsidy packages, such as the EU Chips Act aimed at diversifying and relocating global manufacturing capacities, as well as strengthening bi- and multi-lateral partnerships.

This reconfiguration is also shaping the industry's approach to and governments' awareness of sustainability. Governments are increasingly realising that the infrastructure needed to make wafer fabrication work is highly resource-intensive – ranging from high water and energy demands to the use of "forever chemicals". These concerns intersect with debates over the origins of critical raw materials and the broader push for transparency across supply chains.

This data brief is particularly timely, as the European Commission is introducing a new regulatory shift aimed at streamlining and reducing sustainability reporting obligations and due diligence requirements through the Omnibus Package. As outlined in the recent Competitiveness Compass, the proposed Omnibus Package signals a shift towards simplifying regulatory requirements and narrowing the scope of sustainability reporting obligations. While this may ease compliance burdens – particularly for smaller companies – and is intended to make sustainability reporting "more accessible and efficient", it raises concerns about whether these changes are based on a thorough evaluation of existing regulations to enhance their effectiveness and strengthen environmental accountability. Furthermore, the intersection of industrial competitiveness and decarbonisation – embodied in policies such as the new EU Clean Industrial Deal – is equally central to this paper. This initiative prioritises strengthening clean industries, reducing energy costs and advancing circular economy strategies, highlighting the crucial link between sustainability, economic resilience and competitiveness (Weise 2025).

Given the semiconductor industry's trajectory to becoming a trillion-dollar industry by 2030, coupled with growing chip demand, it has become increasingly urgent to address the ecological impact as a global concern. Analysing the semiconductor industry's market dynamics and trajectory can no longer rely solely on traditional metrics, such as revenue, sales and demand in specific segments. It must also incorporate an understanding of the industry's ecological consequences, as environmental impact becomes a critical dimension of sustainable growth and innovation and ecological metrics to evaluate financial decisions and investments are yet to be found. Nonetheless, a quantitative understanding of the chip industry's ecological footprint remains elusive, which makes it difficult to mitigate its ecological impact. Part of the reason is that the semiconductor sector's competitive and innovative nature makes granular and up-to-date data difficult to access, as such information is often deemed too sensitive to disclose and thus confidential.

Our first analysis, *mapping the ecological footprint of chip production,* published in June 2024, provides an overview of the various aspects of the semiconductor ecosystem that have an impact on the environment and climate (Hess 2024). A key takeaway from this sustainability primer is the realisation that publicly available data often fail to capture the complexity of chip production and its globally intertwined supply chains. However, climate-specific data based on the Greenhouse Gas (GHG) Protocol can be found in one valuable yet underutilised publicly available source – the corporate social responsibility (CSR) reports published annually by chip manufacturers. These reports, although varying in scope and detail, offer an opportunity to better understand the industry's GHG emissions and its ecological trajectory.

Analysing CSR reports makes it possible to distil aggregated trends in the global semiconductor industry in recent years while tracking individual companies' progress in emissions reduction. Furthermore, a detailed examination of what companies do and do not disclose – and how reporting practices vary – provides a unique opportunity to suggest improvements in data transparency and standardisation. Beyond this, accounting for the industry dynamics at play at the time of analysis offers a more contextualised picture – representing a critical industry analysis that incorporates the sustainability perspective. These insights could prove valuable for policymakers working on initiatives such as novel reporting directives or the digital product passport, as well as for evaluating companies' strategies for becoming carbon neutral. Industrial roadmaps and consortia, such as the International Roadmap for Devices and Systems (IRDS), can also use this information in their annual updates on environment, safety, health and sustainability (ESHS) in semiconductor facilities (IRDS 2023 Whitepaper). Our takeaways can also inform current discussions about the upcoming revisions of the GHG Protocol and the upcoming Global Circularity Protocol to consider circular economy criteria.

However, given its focus on GHG emissions and energy, this data brief does not include other high-impact environmental indicators such as water usage, toxicity concerns or impacts on ecosystems, to name just a few examples of environmental impacts that need further research.

Goals

Following this motivation, the purpose of this work is threefold:

- **Assess:** Analysing CSR reports is a complex task that is often hampered by issues such as opacity, inconsistent data and the absence of standardised reporting practices or clear metrics. This study addresses these challenges. Its methodology, interpretations and visualisations aim to transparently highlight data gaps and ambiguities. Additionally, the analysis incorporates market dynamics, such as unit shipments, to provide a more contextualised understanding of CSR data.
- **Improve:** This analysis aims to propose operationalisable steps to improve reporting and accountability. By addressing key gaps and inconsistencies, it seeks to identify effective solutions to compare emissions data across companies, years and regions without adding too many additional details. These recommendations are designed to support policymakers, industry stakeholders and academia in driving more robust and transparent reporting practices.
- **Track and update:** To date, no comprehensive, publicly available quantitative analysis has examined the development of global GHG emissions from chip production at both the aggregate and company levels. This study seeks to fill that gap by providing **an open interactive database called the "Semiconductor Emission Explorer"**, a tool that illustrates how chip manufacturers' carbon footprints have evolved over the past 8 years. It offers a centralised place where data can be compared and updated, showing aggregate trends across the three scopes of the GHG Protocol and displaying the progress of each company in the dataset. These data are crucial for assessing whether the industry is on track to meet its ambitious emissions reduction targets and to identify the most pressing challenges. Importantly, the interactive database will be updated on an annual basis with the latest CSR data and potential improvements.

It is important to note that in our dataset, we considered all companies with more than 100 000 wafer shipments per month, as identified in the SEMI World Fab Forecast 2023 (SEMI World Fab Forecast). This resulted in an initial dataset of 59 companies, covering 82% of the global manufacturing capacity in 2023. **However, we were able to collect useful data from only 28 companies (covering 68% of the total global manufacturing capacity in 2023).**[1] Thus, the total emissions and energy consumption of the global semiconductor industry are most likely much higher than displayed in this analysis, which is a common challenge of studies based on the analysis of CSR reports (see for example Roussilhe et al. 2024). We hope to increase this data coverage in the future with additional environmental indicators and the next round of annual CSR reports. We publish the data as well as the CSR reports we used on github.

Analysis of chip manufacturer emissions data

To measure emissions in the semiconductor industry, evaluate progress over time and compare data across competitors, CSR reports, often also known as environment social governance (ESG) reports, are an important publicly available source. CSR reports[2] typically measure GHG emissions in tons of carbon dioxide equivalents (CO2E), differentiating between three categories or scopes defined in the GHG Protocol (Hess 2024; The Greenhouse Gas Protocol Revised Edition):

- **Scope 1** covers direct emissions that companies are directly responsible for, such as the use of fluorinated gases.
- **Scope 2** focuses on indirect emissions from purchased electricity, steam or heating. **Energy** is the largest contributor in Scope 2 and overall emissions.
- **Scope 3** includes all other indirect emissions occurring upstream and downstream, including suppliers and customers.

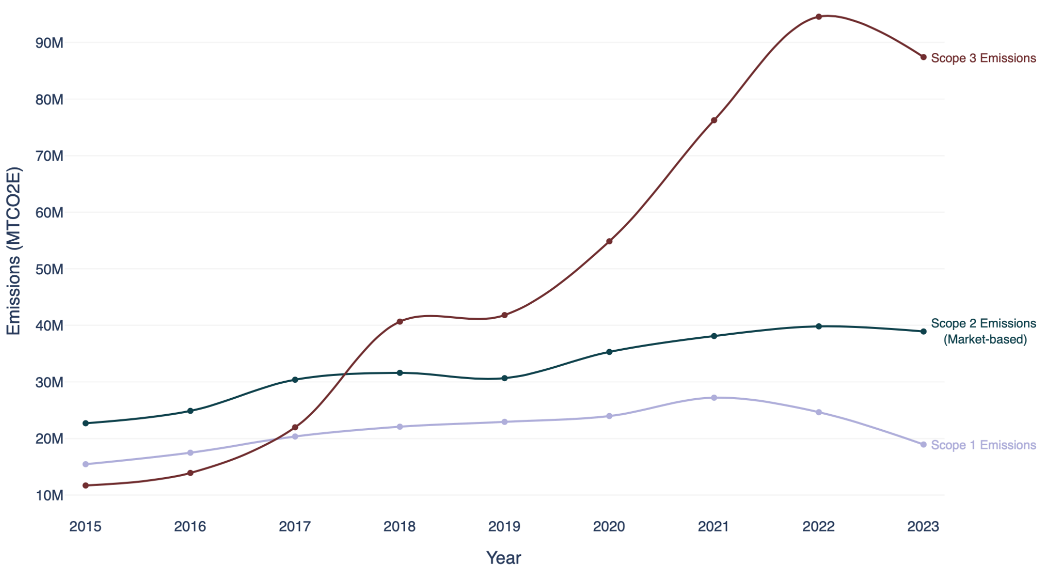
The goal of the analysis is not only to identify and explain notable trends but also to provide a transparent overview of how each company reported their CSR data between 2015 and 2023. In the section 4, an interactive chart allows readers to explore company-specific data for direct emissions, indirect emissions, energy consumption and value chain emissions.

Overview of key trends

This section summarises the key trends identified in our analysis. A detailed discussion of all charts can be found in section 5, which delves deeper into all three scopes.

1 For further information on our methodology and the limitations of our analysis, please refer to Annexe A and Annexe B at the end of the paper.
2 Analysing CSR reports presents many challenges. Please refer to the limitations section in Annexe B to learn more about this.

Chart 1: Three very distinct trends for direct, indirect and upstream and downstream emissions can be observed.



For a complete presentation of this graph, please see the online version of this publication.
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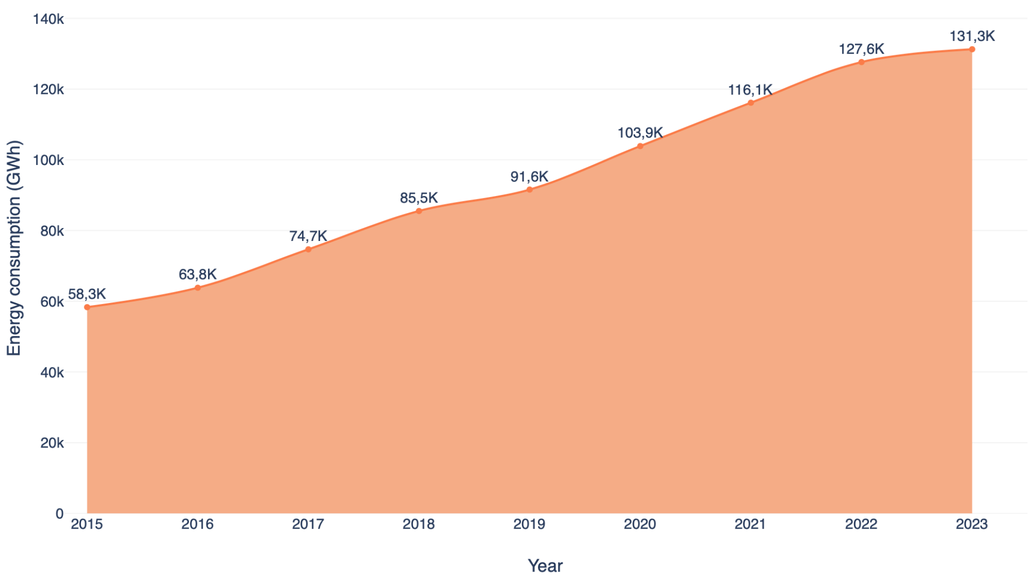
Chart 2: The total energy consumption of the chip industry has more than doubled (increased by 125%) in the last 8 years.



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Direct emissions

The trend in direct emissions from the companies representing the semiconductor industry shows a notable increase from 15,4 in million metric tons of CO2 equivalents (MMTCO2E) in 2015 to 27,2 MMTCO2E in 2021, followed by a significant decline to 18,9 MMTCO2E in 2023. The sharp decline in emissions between 2021 and 2023 is likely attributable to a combination of reduced utilisation rates during the industry downturn and the adoption of abatement systems.

Energy

Energy consumption is clearly one of the biggest challenges in chip production. In our sample of 28 chip manufacturers, it has more than doubled over the past 8 years, from 58 326 gigawatt-hours (GWh) in 2015 to 131 278 GWh in 2023. Renewable energy usage is not displayed in our analysis. However, differentiating between market- and location-based emissions provides initial insights into energy sourcing strategies.

Indirect emissions

Despite the rise in energy consumption by 125%, (market-based) indirect emissions “only” increased by 71% from 22,7 MMTCO2E to 38,9 MMTCO2E. The discrepancy between energy consumption and indirect emissions underscores the impact of energy sourcing strategies on the adoption of renewable energy certificates (RECs). The complex interplay between different trends in energy consumption, market-based and location-based Scope 2 emissions, further highlights the partly intransparent but growing challenge of balancing energy consumption with emissions reductions in the industry.

Upstream and downstream emissions

Scope 3 emissions, which include both upstream and downstream emissions, have seen a remarkable rise from the lowest scope in 2015 and 2016 to the highest since 2018, having grown sevenfold over the course of the last 8 years from 11,7 MMTCO2E to 87,4 MMTCO2E.[3] The most plausible explanation is the growing adoption of more detailed and comprehensive Scope 3 reporting practices by

3 We excluded Wolfspeed data in this chart. Please refer to the Section 5.4 for a detailed explanation.

companies over time. Whereas transparency in upstream emissions is gradually improving, downstream emissions – particularly those related to product use and end-of-life treatment – remain underreported and challenging to track accurately. Given the growing importance of downstream emissions in the overall environmental impact of semiconductor applications, such as data centres, further transparency and reporting improvements will be critical in capturing the full scope of emissions across the value chain and driving more sustainable practices in the industry.

Comparing Scope 1, Scope 2 and Scope 3 emission trends

Our comparison of the trends across the three scopes revealed distinct patterns: Scope 1 emissions, after a constant increase, have seen a significant trend reversal in recent years, potentially driven by reduced production utilisation and the adoption of abatement technologies. It remains to be seen whether the next industry upcycle will turn the trend towards rising emissions again. By contrast, Scope 2 emissions, largely stemming from energy consumption, have only slowly grown, despite the industry's strongly increasing energy use. This indicates that while energy consumption is rising, the industry has managed to offset some of the emissions through mechanisms such as RECs. Scope 3 emissions, however, have grown the most. This surge highlights the increasing importance of managing emissions across the entire value chain, from raw material sourcing to the use phase, end use and disposal of products.

Interactive charts: individual companies' CSR data

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This interactive chart encourages readers to explore individual company trends for the same categories discussed in the previous summary. The goal is to establish a tool that tracks progress on an annual basis by updating the data with future CSR reporting. It is also meant to inform discussions on how and what to prioritise regarding the decarbonisation of chip production.

In the top left corner, users can select from various metrics – energy consumption (in GWh), Scope 1 emissions (in MMTCO2E), Scope 2 market-based emissions (in MMTCO2E), Scope 2 location-based emissions (in MMTCO2E) and Scope 3 emissions (in MMTCO2E). On the right-hand side, companies are grouped by similar manufacturing capacities, enabling more meaningful comparisons among peers. The chart and the comparison across different groups illustrate the significant variation in emissions among companies, emphasising the importance of considering their manufacturing capacities when interpreting the data.

One salient observation is the several data gaps in the displayed trends. This chart has a dual purpose: first, to ensure complete transparency by highlighting instances where representative data was lacking, and second, to track and assess the progress of individual companies on their paths towards achieving net zero emissions.

A detailed analysis of individual company trends falls outside the scope of this paper. However, such analyses can, for example, be found in a previous Greenpeace Report (Rick and Luo 2023). For more information on specific data gaps and limitations related to individual companies, please refer to the table provided in Annexe B at the end of the paper.

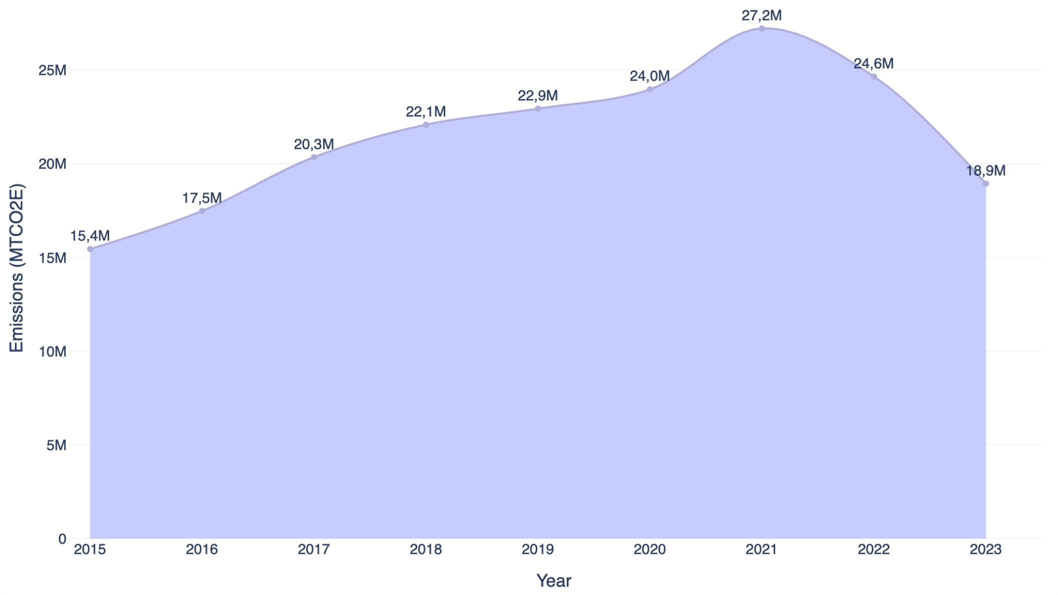
A detailed discussion of key trends

Direct emissions (Scope 1)

Direct emissions are attributed to sources owned or controlled by the company. In chip production, the biggest contributor is the use of chemicals. Depending on the energy set-up, a fab's on-site energy generation could also play a role. Other emission sources, such as fugitive emissions, fixed combustion or mobile combustion, are minor and not always rigorously measured (Nanya 2024).

Simply put, fluorinated gases and wet chemicals are the biggest challenges regarding direct emissions in wafer fabrication. They have a large climate footprint due to their high global warming potential (GWP), accounting for 80–90% of direct emissions in a fab. The main culprits are seven gases: tetrafluoromethane (CF4), octofluropropane (C3F8), octafluorobutane (C4F8), hexafluoroethane (C2F6), trifluoromethane (CHF3), nitrogen trifluoride (NF3) and hexafluoride (SF6) (Raoux 2021). Switching to more sustainable alternatives is a complex process that goes hand in hand with changes in the manufacturing process (Tyrwhitt 2023). One alternative to reducing Scope 1 emissions is the use of abatement systems to contain and destroy harmful components (Merck Group 2023).

Chart 3: Direct emissions from the 28 companies studied show a steep increase from 2015 to 2021, followed by a strong decline from 2021 to 2023.



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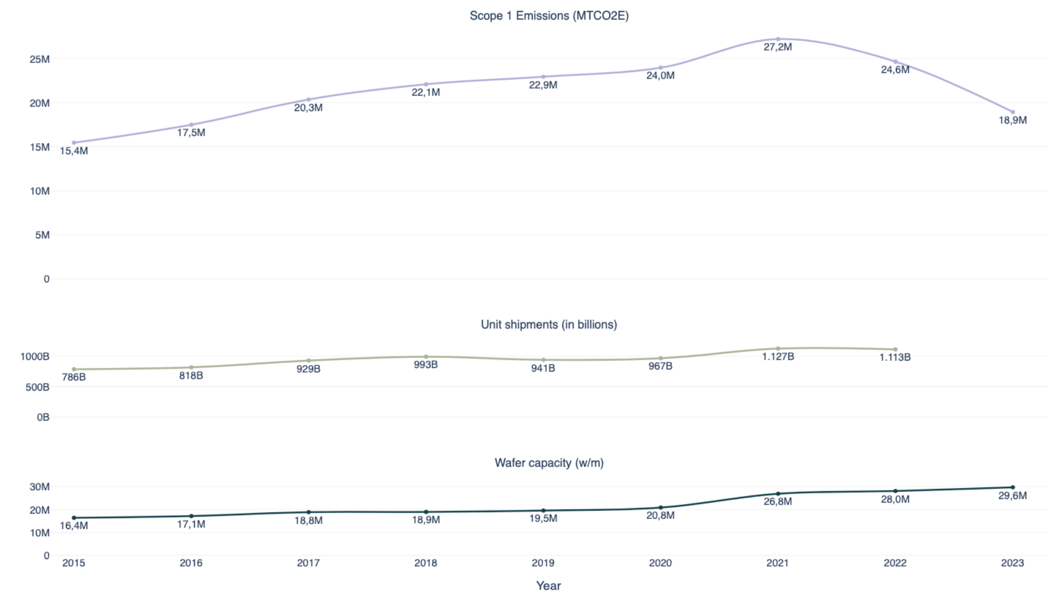
We analysed the direct emissions (in MTCO2E) of 28 chip manufacturers using data from their CSR reports. The chart illustrates that emissions nearly doubled from 15,4 MMTCO2E in 2015 to 27,2 MMTCO2E in 2021, followed by a steep decline by 30%, reaching 18,9 MMTCO2E in 2023.

Chart 4: Do unit shipments and wafer capacity match this trend?



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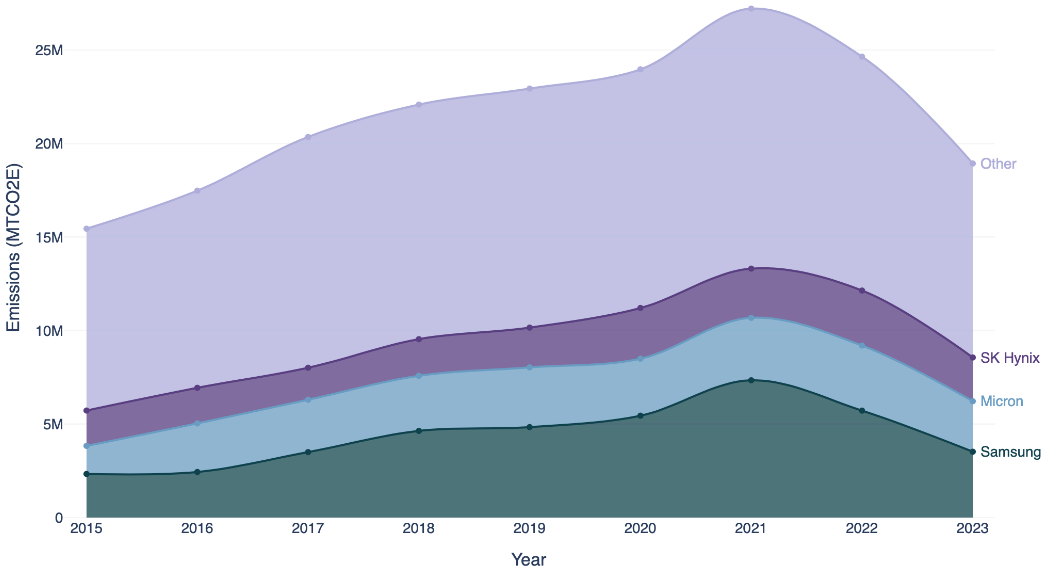
To account for industry dynamics that could potentially explain this trend, we compared it against data on wafer capacity and unit shipments. Wafer capacity strongly increased in the last 8 years, particularly in 2021 – rising from 16,4 million wafer shipments (in 200mm equivalent wafers) per month (w/m) in 2015 to 26,8 million (w/m) in 2021 and 29,6 million (w/m) in 2023 (data from publicly available press releases based on the SEMI World Fab Forecast). Unit shipments did not increase at the same pace. There was an increase from 786 billion unit shipments in 2015 to 1113 billion unit shipments in 2022, with minor fluctuations throughout the period (Semiconductor Industry Association 2023).

Chart 5: The three largest memory chip manufacturers account for nearly half (47%) of the overall direct emissions in 2023.



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To test whether the overall direct emissions trend was driven by memory chip manufacturers, we compared individual Scope 1 emissions from the three largest memory chip producers – Samsung (dark blue area), Micron (light blue area) and SK Hynix (dark purple area) – with the Scope 1 emissions of all other companies (light purple area) in the dataset. It becomes apparent that they not only account for a large portion of the overall emissions but that they also mirror the overall trend.

Understanding the trends

This section explains the trend in direct emissions observed in the previous three charts (2015–2023). It explores a variety of factors – including external factors representing industry dynamics and operational factors such as abatement efforts and fluorinated gas substitution. Finally, it highlights reporting factors, such as differing reporting methods.

From 2015 to 2021, direct emissions strongly increased, which is mirrored by a significant expansion of wafer capacity.

The semiconductor industry has experienced significant turbulence in recent years. Lessons from chip shortages, coupled with the escalating US–China technology rivalry, have prompted governments to introduce new subsidy packages aimed at boosting domestic semiconductor production. Additionally, the rise of general-purpose AI, the Internet of Things (IoT) and data centres has driven a surge in demand for advanced and cutting-edge logic and memory semiconductors (ZVEI 2024). These developments have further accelerated growth in these high-volume markets, which already account for the dominant share of the overall market (SIA Comment 2022).

While many of these greenfield investments are expected to come online in the coming years, the globally installed wafer capacity has already shown a steep increase. Over the entire analysis period, global wafer capacity has grown substantially – from 16,4 million (in 200mm equivalent wafers) w/m in 2015 to 29,6 million w/m in 2023 (SEMI World Fab Forecast). In conclusion, one plausible explanation for the sharp rise in direct emissions is the simultaneous increase in global wafer capacity, although somewhat lower in relation to direct emissions. This also supports previous studies' takeaways that efficiency improvements tend to be absorbed by more complex technology innovations, hindering a significant reduction in emissions (Bol, Pirson and Rémi 2021).

Whereas direct emissions increased by 77% from 2015 to 2021 and global wafer capacity increased by 63% during the same period, unit shipments only increased by 43%.

Global wafer capacity indicates how many wafers per month can potentially be produced all over the world at a certain point in time, but it does not reflect the actual production output. It is important to consider a metric such as unit shipments in accounting for challenges such as utilisation rates (how effectively the total available manufacturing capacity is being used) and yield (how much of what is being produced meets the quality standards), which are influenced by two major dynamics:

- **Fluctuating demand** in the chip industry varies significantly during the upcycles and downcycles. This can have a significant impact on the utilisation rate.
- **The introduction of new manufacturing processes** often requires major or minor adjustments as the process matures. These refinements can have a direct impact on production yield.

Therefore, to accurately assess whether direct emissions and wafer output follow a linear relationship, as observed in the previous paragraph, it is essential to account for a metric such as unit shipments. As unit shipments have only increased by 43%, there is reason to assume that direct emissions per unit have increased between 2015 and 2021. Thus, the steep increase in direct emissions from 2015 to 2021 cannot be entirely explained by a corresponding higher wafer output. Unfortunately, we could not analyse unit shipments for 2023, which would have been important to validate this assumption. Furthermore, as the CSR reports do not provide the technology node mix, it is very challenging to provide reliable explanations, as we will discuss in greater detail in Section 6. Most likely, it is a combination of higher output and a more complex manufacturing process.[4]

The steep drop in direct emissions from 2021 to 2023 could be connected to the industry downcycle at the same time.

The chip industry is known for its highly cyclical nature. During phases of high demand, production capacities quickly reach their limits as utilisation rates approach their maximum and demand outpaces supply. This was evident during the COVID-19 pandemic triggered by skyrocketing demand, which resulted in supply bottlenecks, long lead times and soaring prices, ultimately leading to widespread shortages (Kleinhans and Hess 2021). Such phases of shortages are typically followed by capacity expansion and high capital investments to meet the growing demand, which take several years to operate at high volume production (SEMI 2025). This complexifies the interpretation and contextualisation at a given time.

These push–pull dynamics were also evident in the announcement of subsidy packages, such as the EU Chips Act, by governments worldwide that suddenly wanted to relocate chip production. However, adding capacity alone is not a successful strategy for making the supply chain more resilient and agile in view of sudden demand increases. Once these additional capacities come online, demand often decreases, potentially leading to a phase of overcapacity and price corrections for specific market segments. During this phase, production is scaled back, or market adjustments are made to restore the balance between supply and demand, resulting in lower utilisation rates. Additionally, customers who stockpile inventories during high-demand periods often draw from those reserves instead of placing new orders, further amplifying market fluctuations (Kleinhans and Hess 2021).

These dynamics have been precisely in play in the last 3 years, and the decline has been even sharper than expected: The chip industry has been experiencing a strong downturn. In some industry segments such as AI, there are already signs for recovery, while in others such as automotive, 2024 still marked the process of "hitting a cyclical bottom, with certain target markets entering gradual recovery phases", as stated in Infineon's earnings call in the third quarter of 2024 (Infineon 2024).

Therefore, one plausible explanation for the sharp drop in Scope 1 emissions between 2021 and 2023 could be the lower utilisation of manufacturing capacity.

4 It is also important to note that comparing emissions per unit/wafer *versus* per transistor will most likely lead to very different results. Due to scaling effects, the transistor density per chip increases – and in turn – the emissions per single transistor would most likely decrease, while emissions per wafer increase. This will be explained in more detail in Section 6.

Lower demand and corresponding utilisation rates reduce the overall use of fluorinated gases, the main driver of Scope 1 emissions. With wafer fabrication no longer operating at high utilisation rates, the need for these gases decreases accordingly. However, it is important to note that lower utilisation rates do not influence the "fixed variables" of wafer fabrication, such as the need for constant maintenance or production lines that might still operate around the clock. As there is a lack of information from the outside to carefully assess the ratio and impact of these factors, it is difficult to make assumptions. Here again, data on unit shipments for 2023 would be very helpful in explaining whether the trend is going down due to a drop in demand (which would be visible by a drop in unit shipments).

Memory chip production was most affected by the industry downturn.

However, the industry downturn has not hit all sectors equally hard. While the logic, analog and discrete segments remained relatively flat in 2023, the memory market was hit with a 37% drop (Slimane 2024). Memory chips, such as dynamic random access memory (DRAM) and NAND flash memory, are commodities characterised by fluctuating prices; thus, production volume and economies of scale are key. During the shortages in 2021, customers stockpiled chips to meet the skyrocketing demand, which led to high inventory levels. When consumer electronics demand declined and inflation hit, customers first used their inventory. This led to collapsing memory prices (Chiang 2023), entering a period of massive overcapacity and utilisation rates in the 60% range (Patel and Wong 2023). One market analyst concluded that 2023 is "the worst supply and demand mismatch we have seen since 1997" (Patel and Wong 2023) in the memory segment.

Since then, memory companies have again grown significantly in profits and turnover, which can be explained by push–pull dynamics initiated by the hype for building out AI and datacentre infrastructure (Chiang 2023; O'Laughlin 2024). For example, Samsung's memory chip business sales in the third quarter of 2024 were twice as high as in the previous year (third quarter of 2023) (Trendforce 2024).

Memory chip production requires higher amounts of fluorinated gases.

The notable case of memory chips being significantly affected by the industry downturn warrants detailed examination, as such impacts may play a pivotal role in the observed decline in Scope 1 emissions in 2022 and 2023. Memory chips consist of numerous layers stacked vertically to maximise storage density, demanding highly selective etching to define nanoscale features within each layer and effective cleaning to remove residue and prevent contamination between layers. Fluorinated gases are essential for these processes. During etching, these gases precisely remove unwanted material, enabling accurate patterning of stacked layers, while during cleaning, they ensure ultrapure surfaces by eliminating residues from previous fabrication steps.

Particularly in 3D architectures, such as 3D NAND, increasing bit density is made possible by increasing layer counts of memory cells, leading to a taller memory stack, which in turn requires more deposition and etching materials, connected to an increase in fluorinated gas usage (Jones 2024). Consequently, the focus of innovation in memory chip manufacturing has shifted from lithography to deposition and etching processes, reflecting the growing complexity and material demands of advanced memory technologies (Patel and Wong 2023). Similarly, the introduction of the 3D DRAM process marks a shift towards increasing deposition and etch process gas usage, leading to emissions from fluorinated gases surpassing those from energy consumption (Jones 2024).

To summarise, the sharp decline in direct emissions is likely attributable to the significant downturn in the memory chip industry, which relies far more heavily on fluorinated gases than other semiconductor manufacturing processes. This also becomes apparent in the case of the three companies SK Hynix, Micron and Samsung. Together, they account for 95% of the DRAM market (Farooque 2024), and all of them showed a steep decline in Scope 1 emissions between 2021 and 2023, closely mirroring the overall trend (see Chart 5). Nonetheless, without having more granular information on the technology types (logic, memory, etc.) as well as nodes and a clear differentiation between front- and back-end practices, we cannot confidently conclude that the recent industry downturn, particularly in memory chips, is the driver behind the trend shown.

Abatement is another possible explanation.

However, there are other possible explanations for the sudden decline. The most common and effective way to decrease Scope 1 emissions is to use abatement systems to contain and destroy problematic compounds (Boakes et al. 2023). One study suggests that the average abatement efficiency is around 70% (Jones 2024). Thus, this is one straightforward explanation of the decreasing Scope 1 emissions that we have observed in the last 2 years.

Many companies also highlight technology improvements in abatement processes in their CSR reports. For example, Samsung states that it has “installed 16 new process gas treatment facilities on 4 production line buildings” (Samsung CSR Report 2024), Renesas points to the use of “perfluoro compound (PFC) gas abatement equipment” (Renesas CSR Report 2023) and GlobalFoundries refers to “near-universal use of point-of-use abatement equipment” (GlobalFoundries CSR Report 2024).

Abatement has its limits.

Fluorinated gases differ in their bond energies, which significantly influence their destruction and removal efficiencies (DRIE) (Lee and Chen 2017). For example, NF_3, which has the lowest bond energy, is relatively easy to abate, whereas CF_4, possessing the highest bond energy, is the most difficult to eliminate. Additionally, both the application of these gases and abatement processes can lead to the generation of other gases as byproducts (Lee and Chen 2017). As a result, no single solution can effectively abate all types of fluorinated gases. Thus, abatement is most likely not the only solution.

Another fact casts doubt that abatement is the main reason for the steep decline in Scope 1 emissions in the last 2 years: abatement systems require significant space and must be integrated into the production process. Due to the complex and finely tuned nature of production, where all process steps are meticulously optimised to work together, retrofitting such systems into older fabs is challenging. Consequently, in older fabs, abatement equipment is typically installed only at specific process steps where integration is feasible. Modern abatement systems, which span the entire production process, are primarily integrated into the design and construction of newly built fabs (GlobalFoundries CSR Report 2024).

The industry has made progress in reducing emissions from fluorinated gases.

The semiconductor industry faces the tremendous long-term challenge of finding gases with a lower GWP, which will—depending on the respective gas and usage – take another 5–20 years. However, in the last few years, companies have already found ways to decrease their emissions from fluorinated gases by (1) switching to viable alternatives, (2) avoiding low efficiency gases and (3) optimising fluorinated gas usage. Several companies indicated in their CSR reports that they were successful in finding lower GWP alternatives (see for example CSR Report Infineon 2023; Micron CSR Report 2023; SK Hynix CSR Report 2023).

One effective substitution took place by switching all chemical vapour deposition (CVD) cleans from C2F6 to NF3 as an alternative cleaning gas that reaches 95–99% efficiency because it is more reactive (D’Souza 2023; GlobalFoundries CSR Report 2024; SK Hynix CSR Report 2023). By contrast, C2F6 is a typical low-efficiency gas that only reached 30% reactivity, leaving 70% of the gas unreacted (D’Souza 2023). This means that 70% of the gas is released into the environment, increasing GHG emissions. As NF3 has a higher GWP than C2F6 and creates F2 as a byproduct, it is crucial to optimise its usage and establish adequate abatement and cleaning systems (D’Souza 2023; Martín-Torres 2020). Among others, SK Hynix reported in the latest CSR report that it has “completed the optimisation of 13 processes that involve the use of nitrogen trifluoride (NF3) for cleaning, utilising time-of-flight mass spectrometry (ToF-MS) for process gas analysis”, leading to a “decrease of 12,029 tCO2Eq of annual greenhouse gas emissions” (SK Hynix CSR Report 2023).

Finally, it is important to reflect on different reporting methods.

NF3, a gas used as a substitute for C2F6, as previously mentioned, has a significant

GWP, 17400x greater than CO2 and accounted for 22% of total emissions in 2020 (Hess 2024). Only CF4, which comprises 32% of the total emissions, represents a larger share. However, not all companies include emissions from NF3 in their Scope 1 reporting, which could have a significant impact on the accuracy and comprehensiveness of the overall emissions data (Samsung CSR Report 2023).

Energy

Energy consumption makes up the largest share of indirect emissions (Scope 2). Thus, it is worthwhile to look at energy consumption before diving deeper into indirect emissions in general. Chip production is an energy-intensive process and represents the single largest source of all emission sources, arising from both direct and indirect energy consumption. Emissions from a fab's own energy generation – whether through on-site fossil fuel combustion and heating or small-scale on-site renewable energy generation such as wind or solar – are tracked in Scope 1 as direct emissions. Indirect energy consumption, sourced from external power suppliers, falls under Scope 2 as indirect emissions (Raoux 2021; Infineon CSR Report 2023).

A significant portion of these emissions is driven by the electricity demands of front-end manufacturing. Notably, 56% of electricity usage stems from energy-intensive equipment, such as lithography machines needed for wafer fabrication, while the remaining 44% is attributed to facility operations and utilities (Rick and Luo 2023). These include heating, ventilation and air conditioning systems, which are critical for maintaining the controlled environment of cleanrooms (Lian et al. 2024). Among these systems, chillers alone consume, on average, 25% of a fab's electricity to regulate temperature, humidity and air exchange rates (D'Souza 2023).

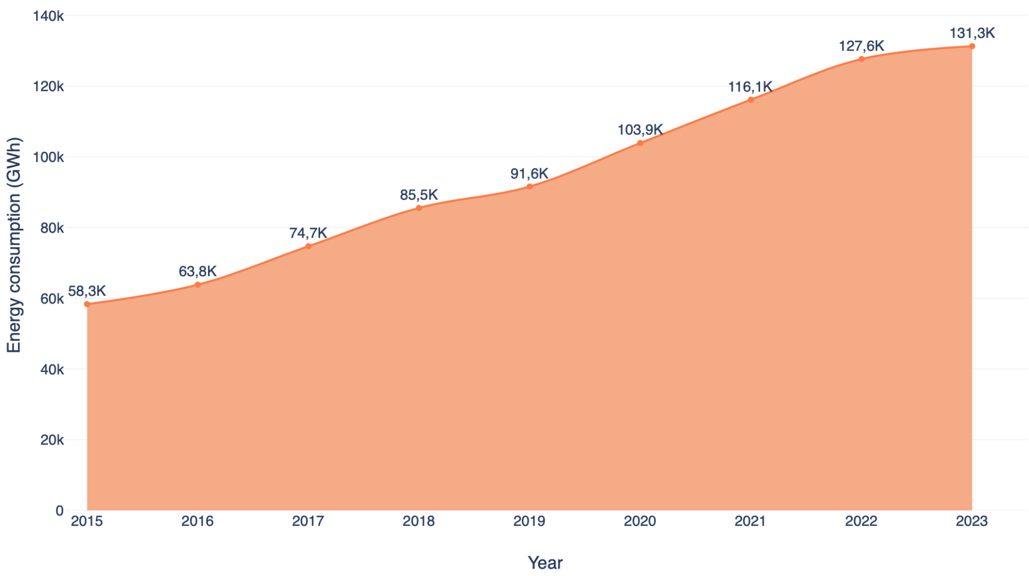
Thus, the geographical climate in which a fab operates also plays a pivotal role in energy consumption, as the electricity mix depends on the location of the manufacturing site (Pirson 2023). Cleanroom environments require precise control, and in certain climates, such as tropical climates, maintaining these conditions can drive electricity usage significantly higher. Research suggests that climate-related factors could account for over 40% of a fab's electricity consumption, and relocating operations to a more favourable climate could result in energy savings of up to 20% (Lian et al. 2024).

The following section will primarily focus on *final energy consumption* in gigawatt hours (GWh), as there is no common definition or practice of how companies track their *electricity* consumption. These companies do one of the following:

- Differentiate only between direct and indirect energy
- State explicit values for electricity consumption

- Use energy and electricity consumption synonymously
- Give electricity purchased rather than electricity consumed
- Omit specifying whether their electricity values are for electricity purchased or consumed

Chart 6: The total energy consumption of the chip industry has more than doubled in the last 8 years.



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We analysed the energy consumption in GWh trends of 28 chip manufacturers using data from their CSR reports. The chart illustrates how in the last 8 years, energy consumption increased from 58 326 GWh in 2015 by 125% to 131 278 GWh in 2023.

Chart 7: Do unit shipments and wafer capacity match this trend?

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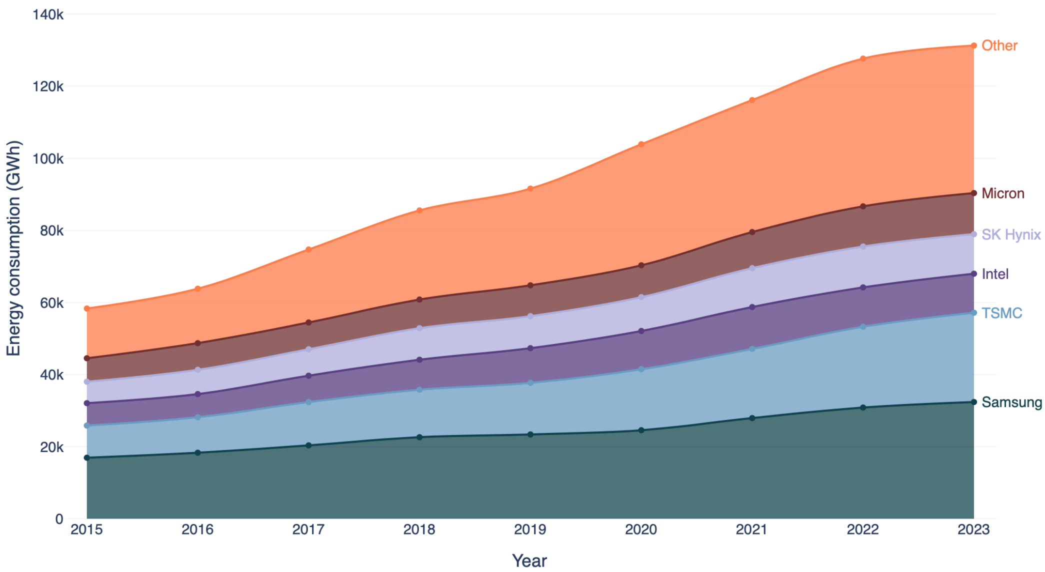
To account for industry dynamics that could potentially explain this trend, we compared it against data on unit shipments and wafer capacity. Neither wafer capacity (80% growth rate) nor unit shipments (42% growth rate) increased at the same pace.

Chart 8: The five largest energy consumers (from our dataset) account for 69% of the total energy consumption.



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To ensure that the trend is representative, we compared it against data from the five largest energy consumers from our dataset. This comparison not only reveals a similar trend but also highlights that Samsung (dark blue area), TSMC (light blue area), Intel (purple area), SK Hynix (light purple area) and Micron (brown area) account for a significant share – that is, 69% – of the total energy consumption. The two companies with the largest production capacities in 2023 – TSMC and Samsung – also exhibit the highest energy consumption.

Understanding the trends

This section examines possible explanations based on external and operational factors for the steep increase in energy consumption observed in the previous three charts (2015–2023).

Globally installed wafer capacity, unit shipments and energy consumption did not increase linearly.

In the previous section on direct emissions, a similar comparison between wafer capacity and unit shipments was drawn to interpret the CSR data. In this case, the comparison shows that the sharp rise in energy consumption cannot be attributed solely to higher production output. Once again, it would be much easier to deduce plausible explanations if more granular information were available that helps to understand whether energy consumption is influenced by metrics such as utilisation rates (Pirson 2023).

One reason for the growing energy consumption could be the growing complexity of manufacturing processes.

To increase the computational power of a chip and increase economic profitability, particularly in advanced logic chip production, innovation is still rooted in the goal of node shrinkage to increase the number of transistors on one chip. This leads to the ability to perform more calculations or take care of parallel tasks, which is key to advances in AI and consumer electronics. According to chip manufacturers and market analysts, the aforementioned uptake in areas such as server AI processors could lead to the global semiconductor industry becoming a trillion-dollar industry by 2030 (TSMC 2024; ZVEI 2024).

However, the problem is that more computing power increases the complexity and electricity requirements in the manufacturing process, specifically regarding the energy usage of advanced lithography equipment. Several studies have pointed out that this is particularly evident for extreme ultraviolet (EUV) lithography machines, the most advanced form of lithography required to manufacture the most advanced chips to date. One study pointed out that EUV uses approximately 10 times as much electricity as conventional 193 nm immersion lithography (imec 2022). A more recent study says that total energy consumption has increased nearly 3 times from N28 (32 nm) to A14 (5 nm) due to the increasing total number of process steps, multiple patterning for feature size scaling and an increase in the number of metal layers to enable more complex systems (Boakes et al. 2023). Thus, current research and development efforts are looking into ways to reduce the overall electricity consumption to offset the significantly higher energy usage of EUV lithography by consolidating multiple process steps to one single exposure while maintaining the same patterning designs. EUV technology at the 7 nm node has already achieved a net reduction in electricity usage (Boakes et al. 2023; Jones 2024). In summary, for 7 nm manufacturing processes, using the older generation of deep ultraviolet lithography machines consumes more energy than 7 nm high-numerical aperture (NA) EUV machines (ASML 2024).

The increased energy consumption in lithography equipment is mirrored by the five largest energy consumers presented in Chart 6, which account for 69% of the total energy consumption. All of them are active in very advanced wafer fabrication for logic and memory chips. Thus, for logic chip production, the biggest single source of Scope 2 emissions is electricity, and this will continue to pose a challenge in the transition towards more sustainable manufacturing practices (Jones 2024). Studies focusing on the Taiwanese semiconductor industry stress this finding by identifying carbon emissions and electricity consumption of the electronics industry as the biggest challenge in Taiwan's economic development (Chou et al. 2019), with the electronics sub-sector accounting for 18,7% of the total energy consumption in 2020 (Roussilhe et al. 2024).

To summarise, one plausible explanation for the increase in energy consumption is the more energy-intensive manufacturing equipment needed for more advanced manufacturing processes, which was also pointed out in several scientific studies (see e.g. Pirson et al. 2022).

An additional driver of increased energy consumption in chip production is abatement equipment.

Given the great detail provided on this topic in the previous section 5.1, the discussion of abatement systems will be kept brief here. With the growing recognition that finding alternatives to fluorinated gases will take considerable time, companies have increasingly adopted abatement equipment to reduce their direct Scope 1 emissions. However, advantages in reducing Scope 1 emissions by improved but energy-intensive abatement practices also have the downside of increasing Scope 2 emissions. For example, burn/wet point-of-use gas abatement, a commonly employed method, works by breaking down harmful gases into less damaging compounds. This process requires maintaining consistently high temperatures, making it a particularly energy-demanding solution (D'Souza 2023; McCoy 2024). One way to tackle this problem is to find integrated treatment methods instead of installing equipment for each process (SK Hynix CSR Report 2023).

Renewable energy usage

The single largest source of GHG emissions is energy usage, and energy consumption is constantly increasing. Thus, it is plausible to suggest a straightforward solution: transitioning to renewable or "green" energy. Although this idea seems simple in theory, the reality is far more complex, particularly in the main chip manufacturing hubs located in Asia, where access to renewable energy is not often guaranteed (Roussilhe et al. 2024). We initially planned the analyses of the CSR reports of the largest chip manufacturers to include the amount of renewable energy used by each manufacturer and in aggregate. However, this proved to be unfeasible due to the lack of a standardised framework for defining and reporting renewable energy usage. Without clear and consistent guidelines, it was impossible to draw reliable comparisons or provide an accurate picture of the role that renewable energy plays in reducing emissions across the industry. This gap underscores the need for more transparent and uniform reporting practices to better assess the industry's progress towards sustainability.

The main challenge lies in the varying interpretations of "renewable energy" usage.

This can range from purchasing RECs or Power Purchase Agreements (PPAs) to utilising renewable electricity supplied by the local grid or sourcing renewable energy directly through on-site generation. Many manufacturers often consolidate these approaches into a single figure, making it difficult to discern the specific ratio between them and accurately evaluate their renewable energy strategies (see e.g. CSR Report Intel 2024; CSR Report TSMC 2023; CSR Report UMC 2023), which leads to higher shares of renewable energy. On the other hand, several companies only count renewable energy from the local grid based on wind and solar power, which leads to lower shares of renewable energy (see e.g. CSR Report Texas Instruments 2023; CSR Report Micron 2023). In rare cases, companies are completely transparent about the ratio between renewable and non-renewable energy purchases (e.g. CSR Report Wolfspeed 2024).

An alternative to analysing renewable energy shares is to examine the reporting of market-based and location-based emissions in Scope 2 (indirect emissions). This approach provides insight into how emissions are influenced by energy sourcing strategies and the local energy grid mix. This concept will be explored in greater detail in the next section.

Indirect emissions (Scope 2)

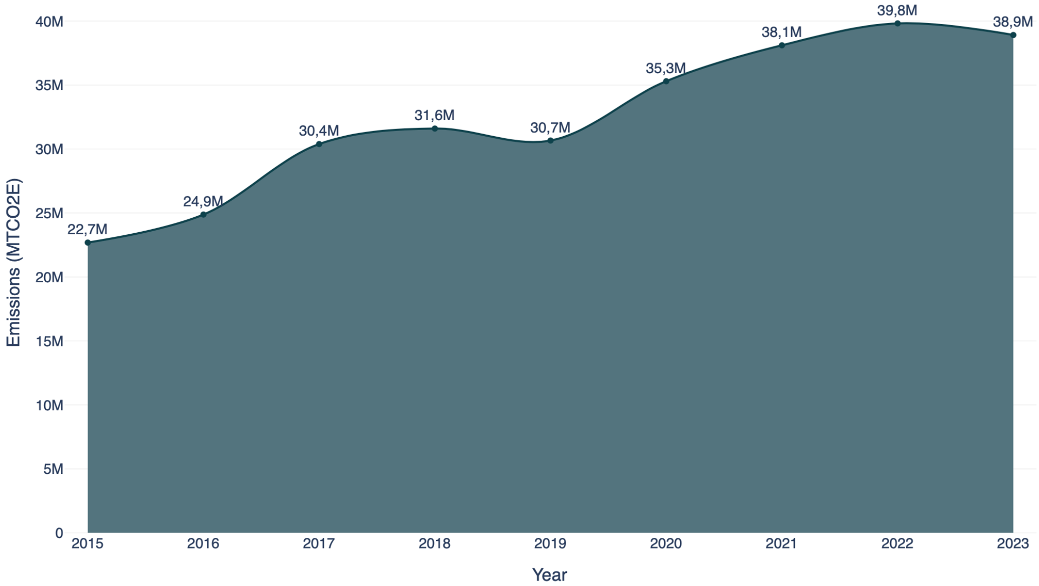
The difference between market- and location-based emissions

For indirect emissions (Scope 2), the largest share is attributable to energy (mostly electricity) sourced from external energy suppliers by the fab. Externally sourced electricity can be reported as either location- or market-based.

- **Location-based emissions** are based on the average emission intensity of grids at the location where electricity is used, accounting for the energy mix that is accessible.
- **Market-based emissions** are based on the intended companies' procurement strategies, including electricity purchases, supplier offerings, RECs, etc. This allows companies to source a specific energy mix, even if it is not aligned with or cannot be matched by local grid resources (Rick and Luo 2023). In summary, reporting market-based emissions leads to an underestimation of actual emissions, as companies could report zero emissions in corporate GHG inventories if they matched their power consumption with RECs (Bjørn et al. 2024). Although some RECs – such as unbundled ones from different geographies or years – face criticism for not representing true renewable energy use or adding capacity, companies that focus on PPAs or source RECs close to where they are produced adopt more credible approaches to reducing emissions from electricity consumption (Bjørn et al. 2024).

According to the GHG Protocol, companies should apply dual reporting if they have "any operations in markets providing product or supplier-specific data in the form of contractual instruments" – clearly differentiating between market- and location-based reporting (GHG Protocol).

Chart 9: Total market-based emissions strongly increased from 2015 to 2023.



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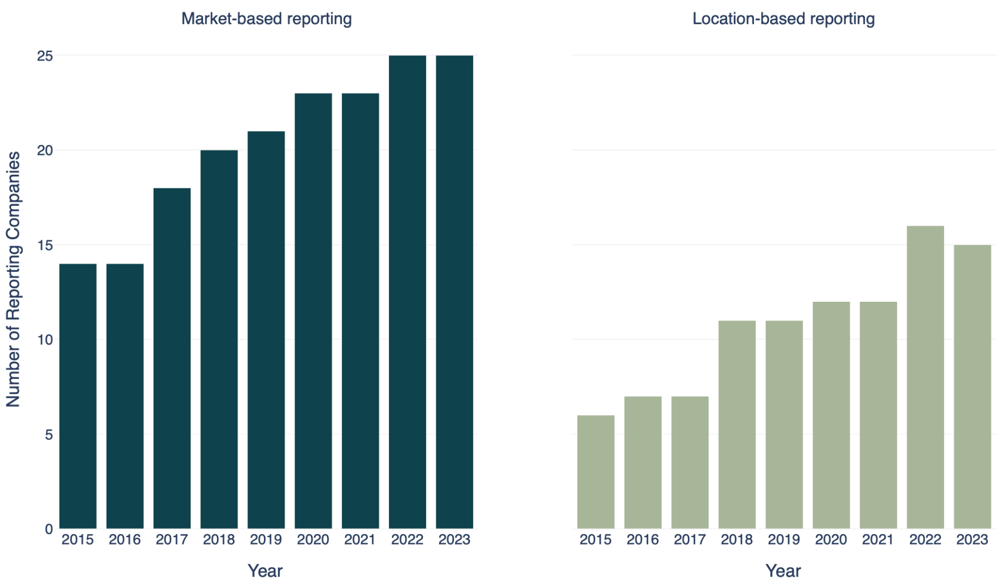
The overall trend of indirect emissions (market-based) shows an increase of 71% from 22,7 MMTCO2E in 2015 to 38,9 MMTCO2E in 2023. Interestingly, there is a small drop in 2019, followed by a steep increase in 2020.

Chart 10: In recent years, more and more companies have started reporting location-based emissions.



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We counted the number of companies reporting market- and/or location-based emissions. The bar chart on the right shows a constant increase in the number of companies publishing their Scope 2 location-based emissions. Starting in 2015, only 6 companies included location-based reporting, while in 2023, 15 companies reported location-based data. By comparison, 25 companies reported market-based data in 2023.[5]

Chart 11: Location-based values are significantly higher than market-based values.

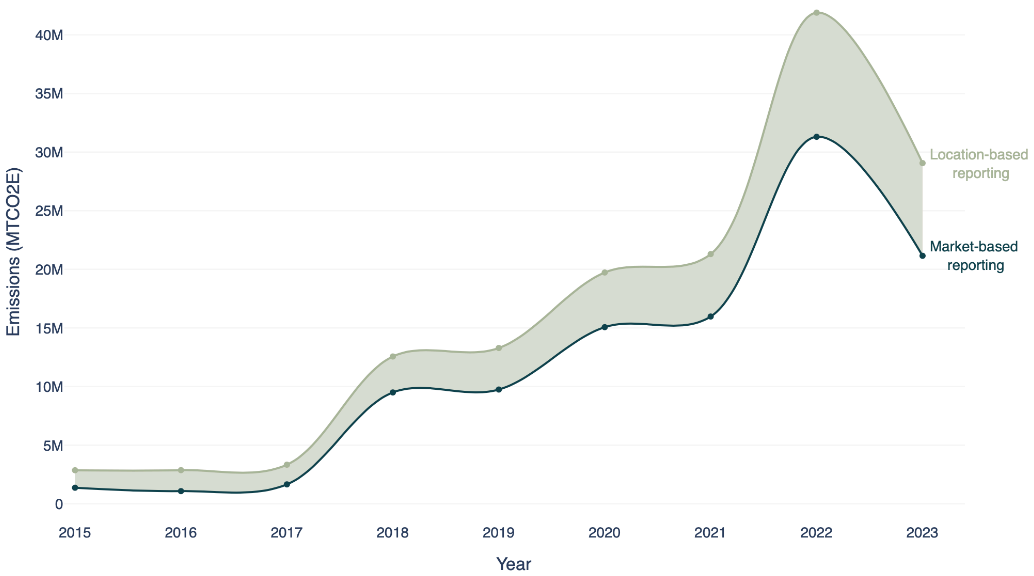

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Chart 11 presents the results of the analysis of companies that reported both annual market- and location-based data. It becomes apparent that there are growing discrepancies between these values with location-based emissions being 50% higher than market-based emissions in 2023.

Understanding the trends

This section examines possible explanations for the steep increase in indirect emissions observed in the previous three charts (2015–2023). Analysing potential

5 If companies did not specify whether the indirect emissions reported are market- or location-based, we assumed them to be market-based.

reporting factors highlights why it is important to differentiate between market- and location-based reporting. The insights from this analysis can assess the progress of companies reporting location-based data, compare the trends in energy consumption and indirect emissions and highlight the double-edged role of RECs in Scope 2 emissions.

Differentiating between market-and location-based emissions is crucial to identify carbon offsetting.

To report indirect emissions, companies use a market- and/or location-based method. As previously stated, while location-based reporting of Scope 2 emissions refers to the emissions factors of the local grid from which the electricity has been sourced, market-based reporting includes contractual agreements, such as RECs, that are independent of the average grid mix.

Location-based Scope 2 data provide a clear picture of the actual energy a company consumes during chip production. This approach calculates emissions based solely on the average emission intensity of the local grid from which the company sources its power, treating all companies using the same grid equally. Measures such as purchasing RECs are not included in this calculation. Apart from sourcing renewable energy available in the local grid, ways to reduce location-based emissions are improving energy efficiency, decreasing the overall electricity consumption, generating renewable energy on-site or a combination of the different factors at the same time.

However, if a company operates in a region without access to renewable energy infrastructure but still seeks to adopt sustainable practices, RECs become necessary to reduce emissions. These are accounted for under the market-based method, allowing the company to claim emission reductions from renewable energy sources rather than applying the grid's emission factor, as is done in the location-based method.

This distinction makes comparing market- and location-based emissions in Chart 11 a powerful tool for understanding a company's energy procurement strategies and identifying whether reported sustainability efforts align with actual energy use (Carbon Credits 2023; GHG Protocol).

The steep increase in energy consumption (by 125%) is not matched by the trend of total market-based Scope 2 emissions (increase by 71%) over the last 8 years. This could potentially be explained by the more frequent use of RECs in previous years.

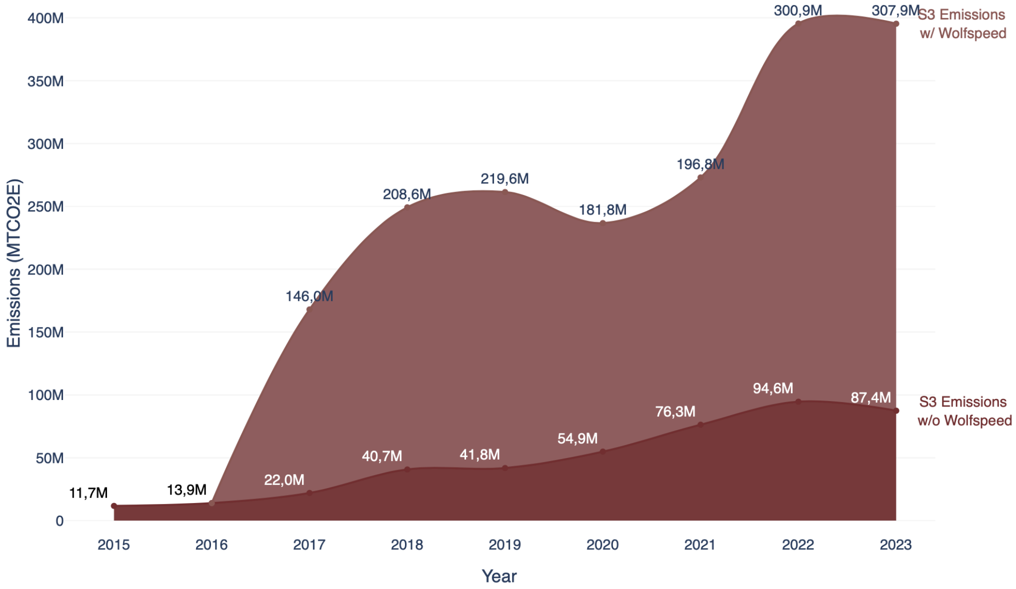
If a company's location- and market-based emissions are closely aligned, it suggests that the energy mix it purchases mirrors the local grid. If market-based emissions are higher than location-based emissions, this could indicate that the company sources power from suppliers with a more fossil fuel-heavy mix than the regional grid average. However, the most common scenario is that location-based emissions exceed market-based emissions, which could indicate that the company is purchasing RECs. If location-based emissions are much higher, it may indicate that a company purchases RECs to a larger extent.

This discrepancy is particularly evident in data reported by several companies in 2023. Intel had the highest discrepancy, as its location-based emissions were six times higher than their market-based emissions (Intel 2024). This was followed by Infineon and STMicroelectronics reporting location-based emissions that were more than three times higher than their market-based emissions (Infineon 2023; STMicro 2023). Such significant gaps underscore the reliance on RECs to offset grid-based energy emissions. For the entire industry, a recent Greenpeace Report points out that 84% of the renewable energy sourced by the company is based on RECs (Rick and Luo 2023). As purchasing RECs does not require additional renewable energy to grid, the semiconductor industry currently relies on the least impactful form of renewable energy consumption (Pirson 2023).

Upstream and downstream emissions (Scope 3)

According to the GHG Protocol, Scope 3 (indirect) emissions are defined as including all upstream and downstream emissions and are not controlled by the company – including the emissions originating from the high energy consumption of refining certain raw materials (upstream) as well as those originating from the operation phase of a chip in a specific end product, such as graphics processing units consuming high energy during operation in a data centre (downstream). Additionally, the transport of critical inputs and finished chips falls under this scope (Ranganathan et al. 2004). From a total of 15 categories – comprising specific downstream activities – a company can decide which of them to report on, or it can choose to report only accumulated data in Scope 3 or not report them at all. One resulting phenomenon is that companies that report more transparently and extensively on Scope 3 have – at least on paper – much higher total GHG emissions.

Chart 12: Are upstream and downstream emissions sky-rocketing?



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The chart depicting the trend of aggregate Scope 3 emissions from 2015 to 2023 paints a striking picture. Starting at nearly negligible levels (11,7 MMTCO2E), reported emissions have surged 34-fold over the span of 8 years, reaching 395,3 MMTCO2E in 2023.

Chart 13: More companies are reporting granular data on their Scope 3 emissions.

Scope 3 emissions reporting across categories for 28 companies

	2015	2016	2017	2018	2019	2020	2021	2022	2023
Purchased goods and services	2	2	4	4	7	10	12	16	16
Capital goods/assets	1	3	2	3	4	7	7	12	12
Fuel- and energy related activities	2	3	5	5	6	7	9	14	14
Upstream transportation and distribution	3	4	6	7	8	10	11	14	16
Waste generated in operations	1	4	6	6	7	9	10	13	15
Business travel	4	7	7	7	9	12	13	16	16
Employee commuting	2	4	5	6	7	8	9	14	15
Upstream leased assets	0	0	0	0	2	3	3	5	5
Downstream transportation	2	2	5	5	6	7	4	9	10
Processing of sold products	0	1	1	1	1	1	1	4	4
Use of sold products	0	0	2	2	3	3	5	7	7
End-of-life treatment of sold products	0	0	1	1	1	1	1	3	3
Downstream leased assets	1	1	1	1	1	1	1	5	6
Franchise	1	1	1	0	0	0	0	0	0
Investments	1	1	1	1	1	1	1	2	2

Reporting in scope 3 varies significantly between the individual categories. There is a clear trend that companies are increasingly reporting their upstream emissions (C1-C7).

The above chart counts how many of the 28 companies in our dataset reported on a single Scope 3 category in a specific year. For example, in 2016, only two companies reported upstream emissions from the first category, “purchased goods and services”. In 2023, 16 of the 28 analysed companies reported emissions from the first category. The chart proves the assumption that there is a growing trend of chip companies reporting on an increasing number of categories in Scope 3.

Understanding the trends

This section explores potential reasons due to reporting factors for the sharp rise in upstream and downstream (Scope 3) emissions shown in the previous charts (2015–2023). It highlights Wolfspeed’s significant Scope 3 emissions, the role of increased transparency, explains variations in manufacturers’ Scope 3 emissions based on voluntary reporting across 15 categories and analyses how the differing trends in direct, indirect and upstream and downstream emissions can be explained.

Transparency regarding emissions throughout the value chain increases slowly, particularly in upstream operations.

Both the analysis of the aggregate emissions as well as of the different categories included in CSR reports show that many companies are improving their transparency in Scope 3. This is mostly the case for upstream emissions. For example, critical materials and chemicals are reported in the first category, 'purchased goods', and equipment is categorised as 'capital goods' in the second category (Nagapurkar and Nimbalkar 2024). One plausible explanation for greater transparency in upstream operations could be increasing pressure from customer industries (B2B) such as consumer electronics, due to the growing demand for sustainable products from end users (B2C) and due diligence directives initiated by governments globally (Apple 2023).

By contrast, any emissions generated downstream – considering the use phase (enabled emissions) or the end-of-life treatment of a product – are much less transparent. Arguably, emissions from downstream activities are very hard to track but can have a significant ecological footprint when considering the specific products into which the chip is integrated. For instance, the same microcontroller could power an electric car, a data centre server or an industrial robot, with vastly different energy consumption and emissions based on usage and lifespan. Additionally, companies may apply different average use-phase scenarios for the same application type. In summary, if more granular and transparent reporting practices were to be expanded to downstream operations, emissions would most likely increase drastically. This also becomes evident by considering Wolfspeed's Scope 3 emissions. The company produces silicon carbide (SiC) technologies, which are key to improving the energy efficiency of, for example, electric vehicles. It is the only company that reported high emissions that occurred during the use phase of chips, leading to more than 100 MMTCO2E emissions only for this one category in 2023 (CSR Report Wolfspeed 2024). On paper, the company has by far the highest Scope 3 emissions, exceeding more than 300 MMTCO2E in 2023, which is 13 times higher than that of Intel (CSR Report Intel 2024), the second-highest emitter of around 23 MMTCO2E in 2023, followed by Samsung with 18 MMTCO2E in 2023 (CSR Report Samsung 2024). The reason why Wolfspeed has much higher Scope 3 emissions is that it is one of the few companies reporting enabled emissions – which are emissions that can be attributed to the use phase of the end product – into their Scope 3 reporting. Beyond this, their application in industries such as automotive, industrial and renewable energy are characterised by very long life-cycles. Thus, in Chart 1 at the beginning of this paper, we decided to exclude Wolfspeed to allow for a more representative comparison of the trends we observed for the three scopes.

Scope 3 emissions continue to have significant gaps in reporting. Out of the 28 companies that were analysed, only 8 companies reported aggregate Scope 3 emissions for all 8 years. Furthermore, the number of reported categories changed annually, and it was not always clear which categories are included, since many companies only reported aggregated data. Additionally, companies did not apply standardised methods. Some used internal data, while others used external market data to measure their emissions throughout the value chain.

The need for clear environmental metrics

As previously mentioned in “Understanding the trends” of Section 5, although chip manufacturers are often discussed collectively, they vary significantly in several key aspects:

- **Chip/technology type and node** (e.g. logic, memory and analog)
- **Wafer size** (e.g. 300 mm vs. 200 mm)
- **Business models** (e.g. outsourcing of front- or back-end manufacturing)
- **Manufacturing processes** (e.g. varying degrees of complexity and differing innovation pathways)
- **Manufacturing capacities** (e.g. low vs. high volume markets)
- **Production yield** (e.g. affected by maturity of the process: introduction of new process nodes vs. experienced mass production)
- **Fab utilisation rates** (e.g. influenced by inventory levels, market cycles, such as up- and down-turns, emerging growth markets like AI)
- **Manufacturing locations** (e.g. fabs in Europe vs. Asia affecting energy mix in the local grid)

To summarise, evaluating energy consumption and emissions trends solely through CSR data fails to account for critical market dynamics and data limitations. Including these unique factors and features as metadata accompanying annual CSR reports would greatly help to effectively track emission trends and the biggest challenges with regard to specific technology types and respective manufacturing processes. These metrics are essential for accurately tracking progress within the semiconductor industry, but accounting for market dynamics, particularly at the company level, is tricky. The semiconductor industry’s competitive and innovative nature makes granular data, for example, on wafer/unit shipments, difficult to access, as such information is often deemed too sensitive to disclose. One solution is to buy expensive market reports from market analysts. This gives valuable insights into the industry’s overall dynamics, as well as trends in specific segments and applications. Part of these data, for example, on global wafer capacity or unit shipments, were used to give potential explanations for the aggregate trends depicted in the previous sections.

However, the available data are not sufficiently granular to allow meaningful comparisons between manufacturers producing the same chip types or assessment of a manufacturer's progress over the years. Furthermore, comparisons across individual companies are limited because we lack critical publicly available information, such as the number of wafers actually fabricated on a monthly, quarterly or annual basis.

Consequently, these findings underscore the lack of agreement on a set of environmental metrics and one common functional unit. Over the last few years, several studies have included calculations that consider these aspects, based on publicly available data and paid market reports (Boakes et al. 2023; Pirson 2023; Wang et al. 2023). Such normalisation can either be done with respect to the number of transistors, the weight of the chip or the silicon die area in cm^2 (Pirson 2023). Particularly in the case of foundries, the latter is a common functional unit and is easier to obtain in publicly available company reports and market data than the number or weight of transistors (Pirson 2023). In many cases, the scientific literature (e.g. Bardon et al. 2020), life-cycle analysis databases (e.g. the eco-invent database) and industry-led tools such as the imec.netzero modelling emissions for advanced wafer fabrication, even provide node-wise trends based on silicon die area.

Although these studies vary significantly in scope, they all show a correlation between node shrinkage and emissions. The smaller and more advanced the technology, the higher the emissions per cm^2, whereas the emissions per transistor decrease. Thus, differentiating between technology nodes in terms of normalisation seems to be an important category. Another critical distinction involves examining product types in greater detail to enable comparisons across similar manufacturing processes with distinct characteristics. For instance, as previously mentioned, EUV lithography is associated with significantly higher energy usage, while memory wafer fabrication tends to consume larger quantities of fluorinated gases. Such differentiation is essential for accurately assessing and addressing the unique ecological challenges tied to specific production methods.

In CSR reports, this level of granularity and harmonisation is currently lacking. In 2023, companies reported, for example (non-exhaustive):

- emission intensity per wafer layer (e.g. TSMC CSR Report 2023; Winbond CSR Report 2023)
- emissions per unit product (e.g. UMC CSR Report 2023; STMicroelectronics CSR Report 2023)
- emissions unit of wafer area (e.g. Renesas CSR Report 2023)
- emissions intensity by sales (e.g. SK Hynix CSR Report 2023)
- emissions per unit of revenue (e.g. Infineon CSR Report 2023; onsemi CSR Report 2023)
- normalised Scope 1 and Scope 2 emissions in gramCO2E/MI (e.g. GlobalFoundries CSR Report 2024)

The lack of a semiconductor-specific reporting standard that specifies how to calculate emissions per unit leads to inconsistencies in how companies calculate and report emissions, making comparisons difficult. Many rely on internal calculations, reporting percentage reductions from a base year without providing absolute values. Additionally, most companies do not differentiate between Scope 1, Scope 2 and Scope 3 emissions, often aggregating Scopes 1 and 2 into a single value. This focus on showcasing company progress in emission reduction, rather than transparency, further limits cross-company comparability. Furthermore, as highlighted in the limitations section, companies frequently use their own metrics and methods across various areas, including normalised emissions, making CSR data difficult to compare at a glance.

A common framework for normalised emissions

Following the comparison of methods for normalisation applied in scientific literature, life-cycle analysis and company CSR reports, the following three adjustments would significantly enhance the comparability between manufacturers, their manufacturing processes and their emission reduction progress over time:

1. **Establishing a functional unit and standardised metric for normalisation**
   A standardised approach to normalisation is essential for meaningful comparisons. The industry should agree on a single functional unit, such as the number of transistors, the chip's weight, or the silicon die area (cm^2). Among these, the silicon die area is the most straightforward metric to standardise across various chip types and manufacturing processes, enabling greater comparability. Absolute values, by contrast, are an important detail for differentiating between high- and low-volume manufacturing, which directly influences the environmental costs per wafer.
2. **Differentiation by chip type and technology node**
   To address the ecological challenges tied to manufacturing processes, emissions reporting must account for the specific type of chip being produced (e.g., logic, memory, analog) and the associated technology node. This distinction is critical to highlight the environmental impact of advanced manufacturing techniques and to promote transparency around the unique challenges of each chip type and process.
3. **Clear differentiation of Scope 1, Scope 2 and Scope 3 emissions**
   As demonstrated throughout this paper, Scope 1, Scope 2 and Scope 3 emissions have followed distinct trajectories over the last 8 years. Breaking down emissions by scope, combined with normalisation linked to specific chip types and nodes, would provide crucial insights into the areas requiring targeted solutions. This level of transparency is vital to identifying where the largest ecological challenges lie and how to address them effectively.

However, implementing this as a standardised framework in the semiconductor industry would be a complex endeavour. Success would depend on collaboration with key industry stakeholders, standardisation bodies and academia to ensure companies can provide consistent, accurate and comparable data based on uniform methodologies – while safeguarding proprietary information.

If such a framework were adopted, it would not only establish a clear industry benchmark but also reduce ambiguity in interpreting CSR data. Industry dynamics, such as wafer capacity or unit shipments that were needed in this analysis to make sense of the CSR data, would already be incorporated into the normalisation, making the data far more transparent and actionable. Such a framework would also be a meaningful tool for informing policy decisions. Moreover, it would also help to align companies' individual actions towards decarbonising chip production, could enhance a collective push and foster healthy competition among manufacturers to lower emissions, as standardised metrics would enable straightforward comparisons across companies and processes. This shift could significantly enhance accountability and drive sustainability efforts across the semiconductor sector.

Conclusion: Why this matters for policymakers

As highlighted in the summary of key trends in section 3, the global climate footprint of semiconductor manufacturing has grown significantly in recent years. This pressing reality is yet to be reflected in either EU industrial policy initiatives or technology and climate diplomacy actions. However, the EU Commission and Member States are working to evaluate and strengthen the sustainability of products and their value chains. Upcoming initiatives and regulations stemming from the EU Green Deal, EU Clean Industrial Deal and the Circular Economy Action Plan are setting ambitious goals that directly address the critical need for increased transparency, accountability and comparability in the industry.[6] Nevertheless, currently discussed simplification efforts in fields such as finance reporting, sustainability due diligence and taxonomy via the Omnibus Package show the complex endeavour of finding effective and straightforward ways to obtain the right information about companies' actions towards climate change mitigation and their impact on the environment.

In fact, this transparency is highly complex due to the unique characteristics of transnationally intertwined value chains, such as the semiconductor value chain. To ensure that efforts to enhance transparency and accountability regarding the climate and environmental impacts of company operations drive meaningful change – rather than merely adding a bureaucratic burden or watering down goals set in the Green Deal – it is crucial to identify what type of information policymakers need to effectively track progress towards sustainable production. This involves not only

6 Three examples are:

developing metrics and standards that are applicable across industries but also creating sector-specific frameworks that address the complexity of particular products and value chains, something the omnibus package wants to put red tape on.

In the current state of ESG/CSR reporting, one clear trend is that reports are becoming increasingly lengthy, which may hinder their utility in providing actionable insights or fostering meaningful comparisons across companies and sectors. Companies continue to add new categories and metrics to their ESG/CSR reports, likely driven by evolving reporting obligations or investor demands. However, this trend towards expanding reports risks prioritising quantity over quality. To enhance transparency and comparability, it is essential to take a step back and focus on identifying a concise set of standardised metrics. These metrics should allow for meaningful comparisons across companies and enable interpretation at the product level, ensuring that reporting aligns with both policy goals and industry realities.

Importantly, these frameworks and standards must be harmonised internationally to prevent the proliferation of competing frameworks and excessive compliance burdens. International alignment is particularly crucial given that the EU heavily relies on imports of products with high ecological footprints, such as semiconductors manufactured in South Korea or Taiwan. Establishing global standards would ensure consistency, enhance accountability across borders and address the environmental impact of products throughout their entire value chain.

This data brief concludes with three key takeaways for policymakers:

- The quantitative analysis of aggregated trends and the interactive chart of individual companies demonstrate that the ecological footprint of chip production can no longer be overlooked. We observed that more advanced manufacturing processes often lead to a higher ecological footprint per chip. Expanding the EU's manufacturing capacity will inevitably have significant environmental consequences. At the same time, to a large extent, we will continue to stay dependent on fabs in East Asia, sourcing out the "dirty side" of chips. A long-term EU semiconductor strategy must address these challenges and integrate them into actions, aiming to position the EU as a global leader in sustainable semiconductor production.
- ESG/CSR reporting currently suffers from significant gaps, limitations and loopholes, making a reliable evaluation of all three scopes nearly impossible. The use of unbundled RECs and the absence of standardised approaches to upstream and downstream emissions hinder the creation of a representative picture. The complexity of tracking emissions across entire value chains, especially downstream emissions, highlights the need for a more robust framework. A detailed assessment of the 15 categories within Scope 3 reporting is essential to improving harmonisation and ensuring more accurate and comparable emissions tracking in the CSDDD, CSRD and the DPP.
- Without a standardised framework and a common functional unit, interpreting CSR data in the complex and dynamic chip industry will remain challenging, as it must be contextualised with additional factors, such as production yield and utilisation of manufacturing capacities. Including values per unit of production will be essential to accurately reflect real market developments. The primary challenge lies in achieving

industry-wide alignment in implementing solutions that balance transparency with the protection of sensitive data.

Annexe A: Methodology

Our analysis is based on data published in the annual CSR reports of the largest global semiconductor manufacturers (based on production capacity) from 2015 to 2023. Prior to 2015, only a handful of companies provided information on CSR. We focus on gathering data published on the following environmental indicators: direct (Scope 1), indirect (Scope 2) and upstream and downstream emissions (Scope 3) according to the GHG Protocol. To maintain consistency, we excluded chip manufacturers focused primarily on optoelectronics, such as LEDs, because their manufacturing processes differ significantly from those for logic, memory, analog and other chip types (OECD 2024).

We analysed chip manufacturers' reporting based on the GHG Protocol. The GHG Protocol is a standardised framework for global carbon disclosure and serves as guidance for companies and other organisations to measure and manage GHG emissions (Greenhouse Gas Protocol 2024). It covers the accounting and reporting of seven GHGs according to the Kyoto Protocol (UN Climate Change 2025): carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF6) and nitrogen trifluoride (NF3) (Ranganathan et al. 2004). The initiative is rooted in a multi-stakeholder partnership of businesses, non-governmental organisations and others. It was founded by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBSCD) in 1998 (World Business Council for Sustainable Development 2004). Even though the GHG Protocol itself is not a binding regulatory framework, it has been widely adopted across several industries as part of their voluntary sustainability and emissions management efforts. Furthermore, emission-heavy industries, such as aluminium and cement, partnered with the initiative to develop industry-specific calculation tools (World Business Council for Sustainable Development 2004). Additionally, some regulatory bodies, such as the European Union Emissions Trading System or the United Kingdom's GHG reporting programme, have already referenced and incorporated elements of the GHG Protocol into their regulations or standards (Department for Energy Security; European Commission).

In our dataset, we considered all companies with more than 100,000 wafer shipments per month, as identified in the SEMI World Fab Forecast 2023 (SEMI World Fab Forecast). This resulted in an initial dataset of 59 companies, covering 82% of the global manufacturing capacity in 2023. However, we were able to use the necessary data from only 28 companies (covering 68% of the total global manufacturing capacity in 2023) for the following reasons:

- Lack of published CSR reports
- Insufficient granularity in the available data
- A primary business focus outside our predefined scope
- Absence of semiconductor-division-specific reporting

To ensure transparency, in the following section, we include a table that details each company's inclusion or exclusion. This allows readers to fully understand the scope and constraints of our dataset. In addition to the challenges and data gaps encountered with specific companies, we identified broader limitations when analysing CSR data overall, particularly when comparing data across different years and between companies, which can be found in the next sections.

Methodology for manually calculated values for Samsung

We manually calculated the data due to missing details for specific years in Samsung's CSR reports, as excluding these gaps would have significantly affected overall trends. In any other case, we did not estimate values for missing data points over the years. The interactive chart transparently depicts missing data points for specific companies. Please refer to the attached Excel sheet for further details.

Samsung, the largest manufacturer by global capacity, operates in two divisions: Device eXperience (DX), which produces finished products (e.g., TVs, washing machines and smartphones), and Device Solutions (DS), representing the chip production segment (Samsung CSR Report 2023). Before 2020, Samsung reported aggregated CSR data for both divisions. Since 2020, they have provided separate figures for the DS division for Scope 1 and Scope 2, as well as energy consumption. Since 2022, they have also provided separate figures for Scope 3. To estimate DS-specific data for 2015–2020 for Scope 1, Scope 2 and energy consumption as well as DS-specific data for 2015–2021 for Scope 3, we used ratio-based allocation, deriving proportions from 2020–2023 division-specific data.

On average (2020–2023), DS accounted for 95,45% of direct emissions (S1), 91,31% of indirect emissions (S2) and 86,92% of energy consumption. For upstream and downstream (S3) emissions, the average for the years 2022 and 2023 was 13,47%. Using these ratios, we applied the mean values to the aggregated CSR data for direct emissions, indirect emissions and energy for the years 2015–2020 and Scope 3 emissions for the years 2015–2021:

Samsung Calculation

(light purple: Values found in reports)

	electricity			energy			scope 1	
	ds division	**total**	**%**	**ds division**	**total**	**%**	**ds division**	**total**
2015	13563	15368	88,25%	16930	19478	86,92%	2333635	2445
2016	14638	16587	88,25%	18316	21073	86,92%	2437670	2554
2017	16283	18450	88,25%	20355	23419	86,92%	3500930	3668
2018	18143	20558	88,25%	22623	26028	86,92%	4633864	4855
2019	18674	21160	88,25%	23380	26899	86,92%	4836208	5067
2020	19654	22916	85,77%	24556	29024	84,61%	5448000	5726
2021	22624	25767	87,80%	27926	32322	86,40%	7341000	7604
2022	25249	28316	89,17%	30850	35177	87,70%	5718000	5972
2023	27042	29956	90,27%	32384	36399	88,97%	3522000	3733
average	**88,25%**			**86,92%**			**95,45%**	

For a complete presentation of this table, please see the online version of this publication.
https://www.interface-eu.org/publications/semiconductor-emission-explorer

Methodology for manually calculated values for unit shipments

To collect data on unit shipments per year, we used the chart provided by SIA titled "Sales and unit shipments 3 month moving average Jan. 2001–Nov. 2022" in their Blog post Despite Short-Term Cyclical Downturn, Global Semiconductor Market's Long-Term Outlook is Strong. To estimate the values from the graph provided, we used an online data extraction tool. Specifically, we took data points at equally spaced intervals of 4 months. We averaged these values for each year, which left us with an estimate of the average monthly value for that year. Multiplying this by 12 gave us an estimate of the units shipped that year. The data can be found on github.

Annexe B: Limitations of CSR data

Key challenges in collecting CSR data

The following is a non-exhaustive summary of the key challenges encountered in general:

- **Changes in the reporting of (voluntary) categories**
  The GHG Protocol has three scopes: direct emissions (Scope 1), indirect emissions (Scope 2) and upstream and downstream emissions (Scope 3). It allows some flexibility in reporting, leading to variations in granularity across areas like the reporting of fluorinated gases in direct emissions, renewable energy, indirect emissions (market- vs. location-based) and upstream and downstream emissions (Scope 3). Reporting the latter is currently optional, only requiring companies that report on Scope 3 to follow the Scope 3 standard (Greenhouse Gas Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard). It is important to note that the GHG Protocol itself does not have the goal of comparing companies with each other. Thus, as companies often alter their reporting annually, making consistent comparisons across companies, as they are depicted in the interactive visualisation, is challenging. To address these data gaps, we included a table in the next section and an interactive company CSR database to guide the careful interpretation of our findings.

- **Inclusion of subsidiaries**
  According to the GHG Protocol, companies need to account for 100% of emissions from operations over which they have control, so for owned subsidiaries, they need to report data. If it is a joint operation, they can either apply an equity share or control approach. The equity share approach means that if a company owns 50% of a joint venture, it accounts for 50% of total emissions. The control approach, by contrast, only obligates it to account for emissions it has (financial or operational) control over (The Greenhouse Gas Protocol Revised Edition). One approach must be selected and applied consistently.
  In most cases, this level of granularity is not provided. Often, companies make the inclusion of subsidiaries in their CSR reporting transparent, noting this practice in footnotes, unless stated otherwise. Some companies also provide more transparency by assigning separate values to their subsidiaries. However, in certain cases, it is unclear which method they chose and whether subsidiaries were included in the reported data. Importantly, when companies acquire or divest subsidiaries, the GHG Protocol framework allows the revision of historical data retrospectively to reflect these changes. For consistency, we assumed that subsidiaries were included in the reported figures and used the latest available data for the analysed years.

- **Changing emission calculation methods**
  As previously mentioned, a key challenge when analysing CSR reports is that companies often revise their data. These revisions may be due to mergers and acquisitions, updates to global warming potential (GWP) values or the inclusion of additional GHGs, to name just a few. In addition, indications regarding these changes are often hard to find. These data revisions often go hand in hand with the recalculation of base year emissions as recommended by the GHG Protocol (The Greenhouse Gas Protocol Revised Edition). Our analysis always attempts to use the latest available data to maintain consistency.

- **Absence of a clear definition of (renewable) energy**
  Companies do not use a common definition of energy. This leads to the challenge that some companies use energy and electricity interchangeably, while others use energy purchased rather than energy consumed. The interpretation of “renewable energy” or “green energy” also varies among manufacturers, with some including RECs and PPAs (reported in Scope 2), while others focus on local grids or on-site generation, such as wind and solar power (reported in Scope 1). This can be explained by the GHG Protocol guidance to include a variety of instruments – RECs and PPAs, among others – as “green power programs” in market-based emissions in Scope 2 without defining what should constitute “green energy” (GHG Protocol Scope 2 Guidance). Thus, aggregating very different definitions into a single figure often obscures specific contributions and inflates renewable energy shares. As a result, we chose not to display the renewable energy usage of individual companies in the charts.

- **Inclusion of non-manufacturing sites**
  Companies vary in how granularly they differentiate emissions from manufacturing (front- and back-end) versus non-manufacturing parts, such as offices. Since non-manufacturing sites typically have much lower emissions, this limitation likely has a minimal overall impact.
- **Differentiation front- and back-end**
  Similarly, it is often unclear whether companies focus exclusively on front-end manufacturing in their reporting. A clear differentiation between the ecological footprints of these two stages is rarely provided, although strong evidence suggests that front-end manufacturing has a much greater impact (Hess 2024).[7]
- **Different primary energy factors (PEF)**
  Analysing data from CSR reports is challenging due to varying metrics and primary energy factors (PEFs)[8] across countries. For instance, while the basic conversion from gigajoule (GJ) to megawatt-hours (MWh) is fixed (1 MWh = 3,6 GJ), the amount of primary energy required to generate electricity varies by country. This is due to differences in energy sources, power plant efficiency and national standards for calculating PEFs. For example, Korea applies a different PEF (2.67) compared to the EU (1.9), reflecting its energy mix and grid efficiency. These inconsistencies complicate direct comparisons, so we carefully adjusted the data to ensure consistency and accuracy.

Company data selection

Table 1: Company data selection – overview of all companies sorted alphabetically (covering 82% of the global manufacturing capacity in 2023)

In the following table, we list all companies that were in our initial dataset. In the right column, we specify whether they are included in the analysis.

Companies were excluded from the dataset for one or more of the following reasons:

- Absence of English CSR report publicly available
- Absence of semiconductor-division-specific reporting
- Products do not fit our definition (e.g. LED)

7 Front-end manufacturing – the process of manufacturing integrated circuits (also known as dies) onto the wafer – is the most complex production step in semiconductor manufacturing to date. It is highly automated and requires more than 50 types of equipment and around 300 types of chemicals in more than 1000 process steps. Thus, front-end manufacturing has a significantly higher ecological footprint due to the repetitive use of hazardous fluorinated chemicals and the energy-intensive production cycle, which lasts three months or longer. Back-end manufacturing, on the other hand, only takes around one month and is based on more manual steps, involving chip separation, testing, and assembly. The two different stages usually take place in geographical locations and are often performed by different companies (Roussilhe et al. 2024). It is important to note that innovation in areas such as advanced packaging also increases the complexity in back-end manufacturing, which likely leads to higher emissions (Fraunhofer IZM).

8 The PEF expresses how much primary energy is needed to deliver one unit of final energy. For example, if the PEF for electricity is 2,5, then producing 1 MWh of electricity requires 9 GJ of primary energy (1 MWh × 3,6 GJ/MWh × 2.5 PEF). However, this factor is not universal – PEFs differ across countries and energy sources. Fossil fuels tend to have higher PEFs due to losses in generation and transport, while renewables like wind and solar have PEFs closer to 1 since they do not rely on fuel combustion. Additionally, improvements in energy efficiency and policy decisions can cause PEF values to change over time. In EU, the PEF was last revised on December 15, 2022, to a default PEF for electricity to 1,9 (EU Commission 2023).

- Main business segment that lies outside the scope of our definition

Company selection (sorted alphabetically), including native names	CSR data
ams OSRAM AG	INCL.
Analog Devices, Inc. (ADI)	INCL.
Beijing YanDong MicroElectronic Co., Ltd. (YDME) 北京燕东微电子有限公司	EXCL.
CanSemi Technology Inc. 粤芯半导体技术股份有限公司	EXCL.
ChangXin Memory Technologies (CXMT) 长鑫存储技术有限公司	EXCL.
China Resources Microelectronics Limited (CR Micro) 华润微电子有限公司	EXCL.
DB HiTek Co., Ltd. 주식회사 디비하이텍	EXCL.
Diodes Incorporated	EXCL.
Episil-Precision Inc. 漢磊科技股份有限公司	EXCL.
Fuji Electric Co., Ltd. 富士電機株式会社	INCL.
Fujian Jinhua Integrated Circuit Co. Ltd. (JHICC) 福建省晋华集成电路有限公司	EXCL.
GalaxyCore Inc. 格科微有限公司	EXCL.
GlobalFoundries Inc. (GF)	INCL.
Hua Hong Semiconductor Limited 华虹半导体有限公司	INCL.
Huali Microelectronics Corporation (HLMC) 上海华力微电子有限公司	EXCL.
Infineon Technologies AG	INCL.
Intel Corporation	INCL.
Japan Semiconductor Corporation 株式会社ジャパンセミコンダクター	EXCL.
Jiangsu JieJie Microelectronics Co Ltd. 江苏捷捷微电子股份有限公司	EXCL.
Kioxia Holdings Corporation キオクシアホールディングス株式会社	INCL.
Microchip Technology Incorporated	INCL.
Micron Technology, Inc.	INCL.
Mitsubishi Electric Corporation 三菱電機株式会社	EXCL.
Nanya Technology Corporation 南亞科技股份有限公司	INCL.
Nexchip Semiconductor Corporation 合肥晶合集成电路股份有限公司	EXCL.
Nichia Corporation 日亜化学工業株式会社	EXCL.
NXP Semiconductors N.V.	INCL.
ON Semiconductor Corporation (Onsemi)	INCL.
Powerchip Semiconductor Manufacturing Corporation (PSMC) 力晶積成電子製造股份有限公司	INCL.

Renesas Electronics Corporation ルネサス エレクトロニクス株式会社	INCL.
Robert Bosch GmbH	EXCL.
Rohm Co., Ltd. ローム株式会社	EXCL.
Rong Semiconductor (Ningbo) Co., Ltd. 荣芯半导体有限公司	EXCL.
Samsung Electronics Co., Ltd. 삼성전자 주식회사	INCL.
Sanan Optoelectronics Co. Ltd. 三安光电股份有限公司	EXCL.
Semiconductor Manufacturing International Corporation (SMIC) 中芯国际集成电路制造有限公司 (中芯国际)	INCL.
Shanghai GTA Semiconductor Co., Ltd. 上海积塔半导体有限公司	EXCL.
Shindengen Electric Manufacturing Co., Ltd. 新電元工業株式会社	EXCL.
Silan Microelectronics Co., Ltd. 杭州士兰微电子股份有限公司	EXCL.
Soitec S.A.	EXCL.
SK Hynix Inc. 에스케이하이닉스 주식회사	INCL.
Sony Group Corporation ソニーグループ株式会社	EXCL.
STMicroelectronics N.V.	INCL.
Taiwan Semiconductor Manufacturing Company Limited (TSMC) 台灣積體電路製造股份有限公司	INCL.
Texas Instruments Incorporated	INCL.
Toshiba Memory Corporation (TDSC) 東芝メモリ株式会社 [data can be found in Kioxia]	INCL.
Tower Semiconductor Ltd. טאואר סמיקונדקטור	INCL.
Unisonic Technologies Co., Ltd. (UTD) 友顺科技股份有限公司	EXCL.
United Microelectronics Corporation (UMC) 聯華電子股份有限公司	INCL.
United Nova Technology Co., Ltd. (UNT) 芯联集成电路制造股份有限公司	INCL.
Vanguard International Semiconductor Corporation (VIS) 世界先進積體電路股份有限公司	INCL.
Winbond Electronics Corporation 華邦電子公司	INCL.
Wingtech Technology 聞泰科技股份有限公司	INCL.
Wolfspeed, Inc.	INCL.
Wuhan Xinxin Semiconductor Manufacturing Co., Ltd. (XMC) 武汉新芯集成电路股份有限公司	EXCL.
X-FAB Silicon Foundries SE	EXCL.
Yangtze Memory Technologies Corp. (YMTC) 长江存储科技有限责任公司	EXCL.
Yangzhou Yangjie Electronic Technology Co Ltd. 扬州扬杰电子科技股份有限公司	EXCL.

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