CIVIC MACHINES LAB

Expert Recommendations for the Future of the Semiconductor Supply Chain

Discussion Paper

AUTHORS

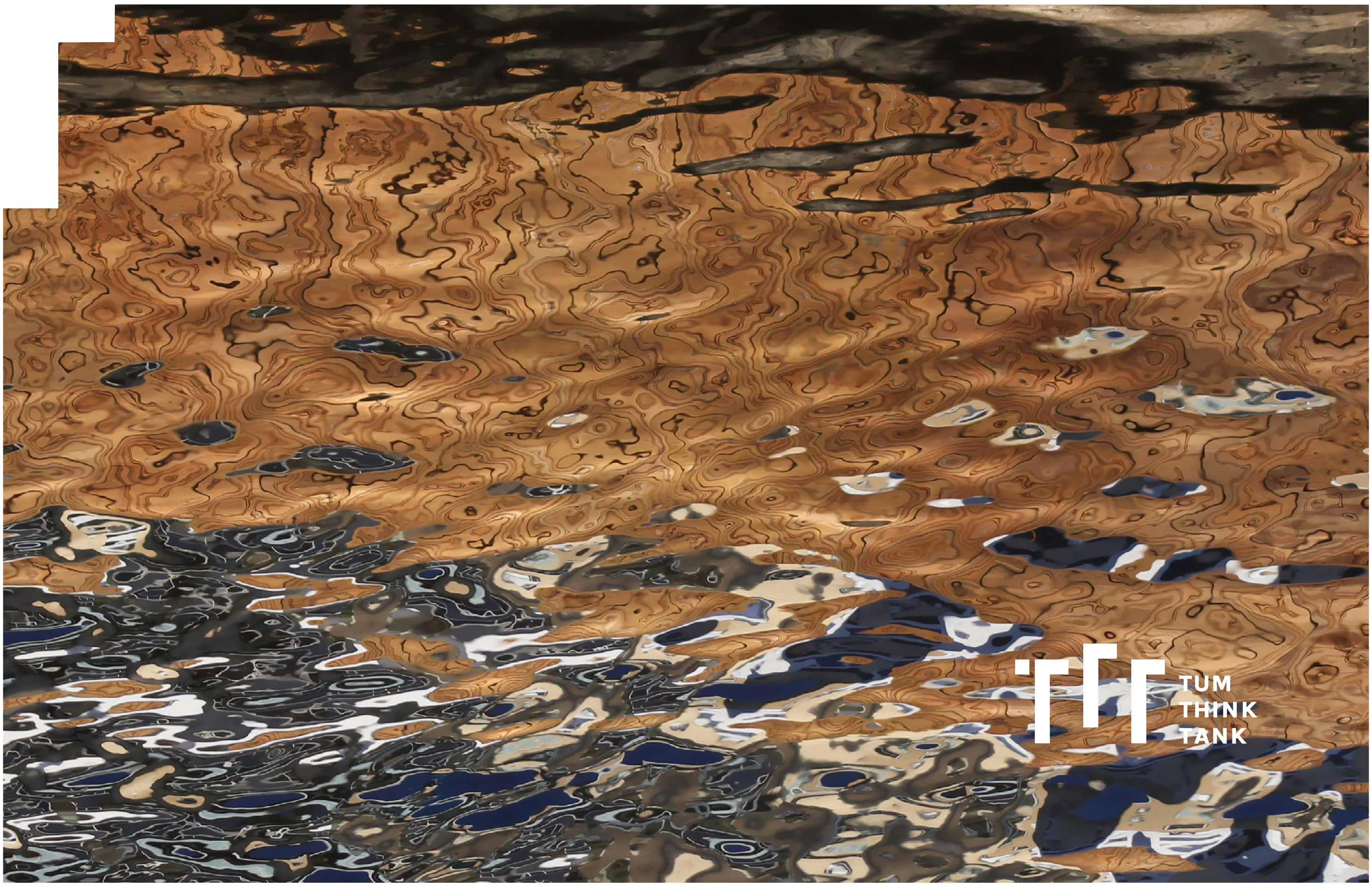
Naira Paola Arnez Jordan, Michel Hohendanner, Chiara Ullstein, Jens Großklags, Lorenzo Servadei, Alejandro Merino-Madrid, Fernanda Sauca, Orestis Papakyriakopoulos

CONTRIBUTORS

Dr. Steffen Klewitz, Dr. Sebastian Schams, Stanislav Huley, Michael Schönstein, Tristan Scheuermann, Edoardo Mosca

CONTACT

Civic Machines Lab
at the TUM Think Tank



CONTENT

EXECUTIVE SUMMARY

Semiconductors are the foundational infrastructure of the digital age, enabling fast-growing technologies such as artificial intelligence (AI), 5G, medical devices, and electric vehicles. Yet the semiconductor supply chain is highly complex, globalized, and resource-intensive, raising pressing ethical, environmental, and geopolitical concerns. This discussion paper **synthesizes insights from a two-day interdisciplinary workshop** hosted by the Civic Machines Lab at the TUM Think Tank, which brought together experts from academia, industry, and policy to explore these concerns and identify pathways toward more ethical, sustainable, and resilient semiconductor ecosystems.

Key challenges

A broad set of interconnected challenges across the semiconductor value chain were identified, including:

- **Environmental challenges**: Semiconductor production consumes vast amounts of energy and water resources while generating pollutants, emissions, and e-waste.
- **Facility migration challenges**: The re-establishment of semiconductor manufacturing capacity can create financial strain, disrupt local economies, and job security, while at times prioritizing economic incentives over ethical and environmental safeguards, particularly in regions with weaker regulations.
- **Transparency**: The semiconductor supply chain remains opaque—especially when it comes to tracing the origins of key materials—making full supply-chain mapping complex.
- **Industrial espionage and intellectual property**: High-value chip designs and manufacturing processes can potentially be targets of cyberattacks and theft, creating tension between IP protection and the need for transparency in ensuring safety and ethical compliance.
- **Education challenges**: The industry faces high levels of workforce shortages and uneven global access to technical knowledge, exacerbated by often outdated university curricula, limited mechanisms for knowledge transfer and limited sector appeal.
- **Competitive challenges**: Capital requirements, restricted access to tools and markets, cultural aversion to risk, and geopolitical dependencies create unequal conditions that inhibit fair competition and innovation.
- **Governance challenges**: Fragmented regulatory systems struggle to balance innovation, environmental protection, labor rights, and technological sovereignty globally.

- **Human rights challenges**: Workers, especially in outsourced and poorly regulated regions where raw materials are produced and extracted, face harmful chemical exposure, unsafe conditions, and inequitable distribution of risks and rewards along the beginning of the value chain.

- **External influences**: Geopolitical tensions, natural disasters and pandemics expose the semiconductor supply chain's reliance on a few critical regions, highlighting its vulnerability to global disruptions.

Recommendations

In response to these challenges, several key recommendations emerged:

- Clear reduction targets for emissions, water, and energy use per manufactured chip; transition to renewable energy; and the implementation of tools such as CO_2 "semaphores" or environmental impact ratings to track and communicate progress across the entire lifecycle of semiconductor-enabled devices.

- Stable policy frameworks that generate trust among companies, enabling innovation and sustainability; greater transparency without compromising competitive advantages; and increased technological autonomy through supplier diversification.

- International cooperation to reduce geopolitical dependencies; strengthening European market positioning through skills and investment; and ensuring fair access to key technologies via openness and anti-trust enforcement.

- Increased local innovation via targeted funding; attracting and exchanging expertise to close knowledge gaps; striving for European tech sovereignty by building international education partnerships and lowering barriers for talent mobility; and enabling startups to grow as key drivers of skills and knowledge diffusion.

- Improved ethical labor practices through targeted funding and safer working conditions in less developed countries; and harmonized labor laws across regions.

- Increased supply chain resilience through diversified suppliers, corporate buffer strategies, and cross-sector risk management networks.

Future outlook

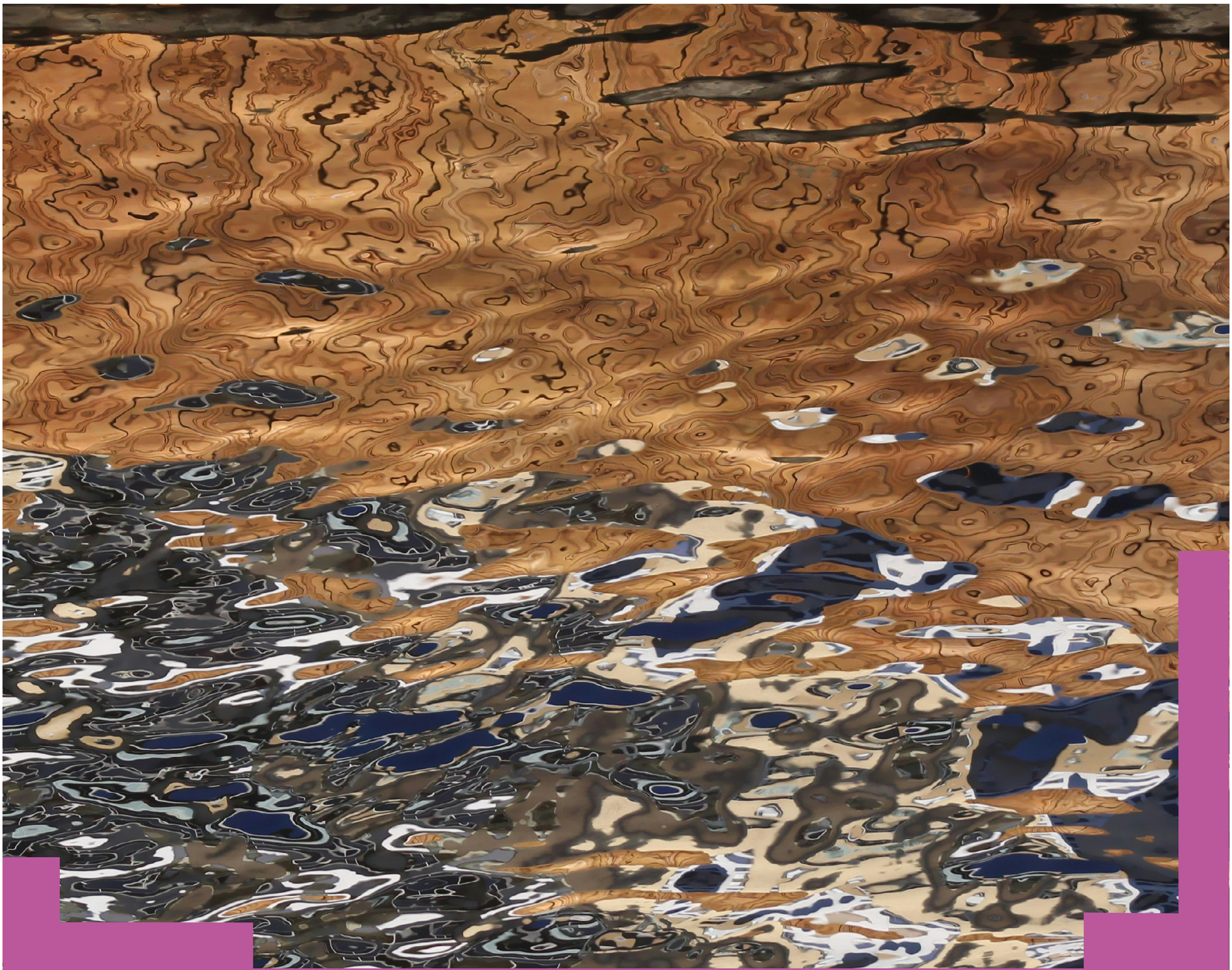
Participants envisioned potential futures for the industry by 2030 and beyond. Scenarios ranged from fragmented, protectionist markets to globally collaborative and sustainable ecosystems. **Two ideal scenarios** were developed:

1. **Climate-Driven Global Collaboration**: Climate urgency can drive global cooperation, circular economies, AI- and photonics-enabled innovation, and emissions transparency. Risks include automation-driven job loss and increased energy demand.

2. **Regulation-Led Sustainability and Resilience**: Strong regulatory leadership, especially in Europe, can shape a fairer, circular, and innovation-driven industry. Challenges include rising costs, slower adaptation, and risks of concentration of technological power.

To move toward these desired future scenarios, a set of measures aimed at key stakeholders across the semiconductor ecosystem were laid out, including stronger international cooperation, transparent and traceable supply chains, investments in green manufacturing and material circularity, expanded education and skills development, and regulatory frameworks that balance competitiveness, resilience, sustainability, security, and human rights.

The semiconductor supply chain sits at the intersection of technology, ethics, and sustainability. Addressing its challenges requires systemic thinking, cross-sector cooperation, and balanced governance. **This discussion paper serves as a catalyst for continued dialogue, informed policymaking, and research to build a semiconductor future that is responsible and resilient.**



1 Introduction

From edge devices to supercomputers, semiconductors form the invisible infrastructure of the digital age. The semiconductor industry powers innovations across sectors such as computing, telecommunications, and automotive, and has a pivotal role in enabling technologies like artificial intelligence (AI), 5G networks, medical devices, and electric vehicles. Among these, AI stands out not only for its transformative potential but also for the ethical, societal, and environmental questions it raises.

Understanding the semiconductor supply chain's role in the AI lifecycle is therefore critical, as the responsible development of AI systems is inseparable from the ethical and sustainable design and governance of the hardware on which they rely.

Yet, the semiconductor supply chain (Figure 1) is highly complex, involving resource-intensive manufacturing processes, high-precision engineering, and an interwoven network of suppliers and assemblers. Moreover, semiconductor development is characterized by long iteration cycles across nearly every stage of the supply chain. This complexity introduces a range of challenges and risks, ranging from an environmental to a human rights context. These challenges are not peripheral; they shape the values and constraints embedded into the technologies semiconductors ultimately enable.

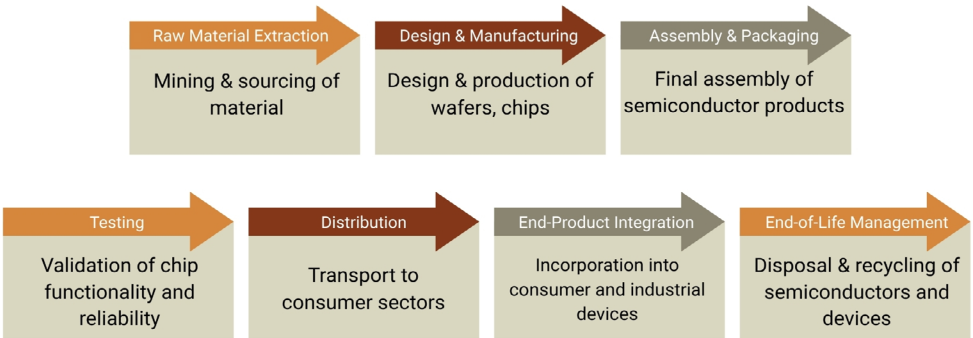
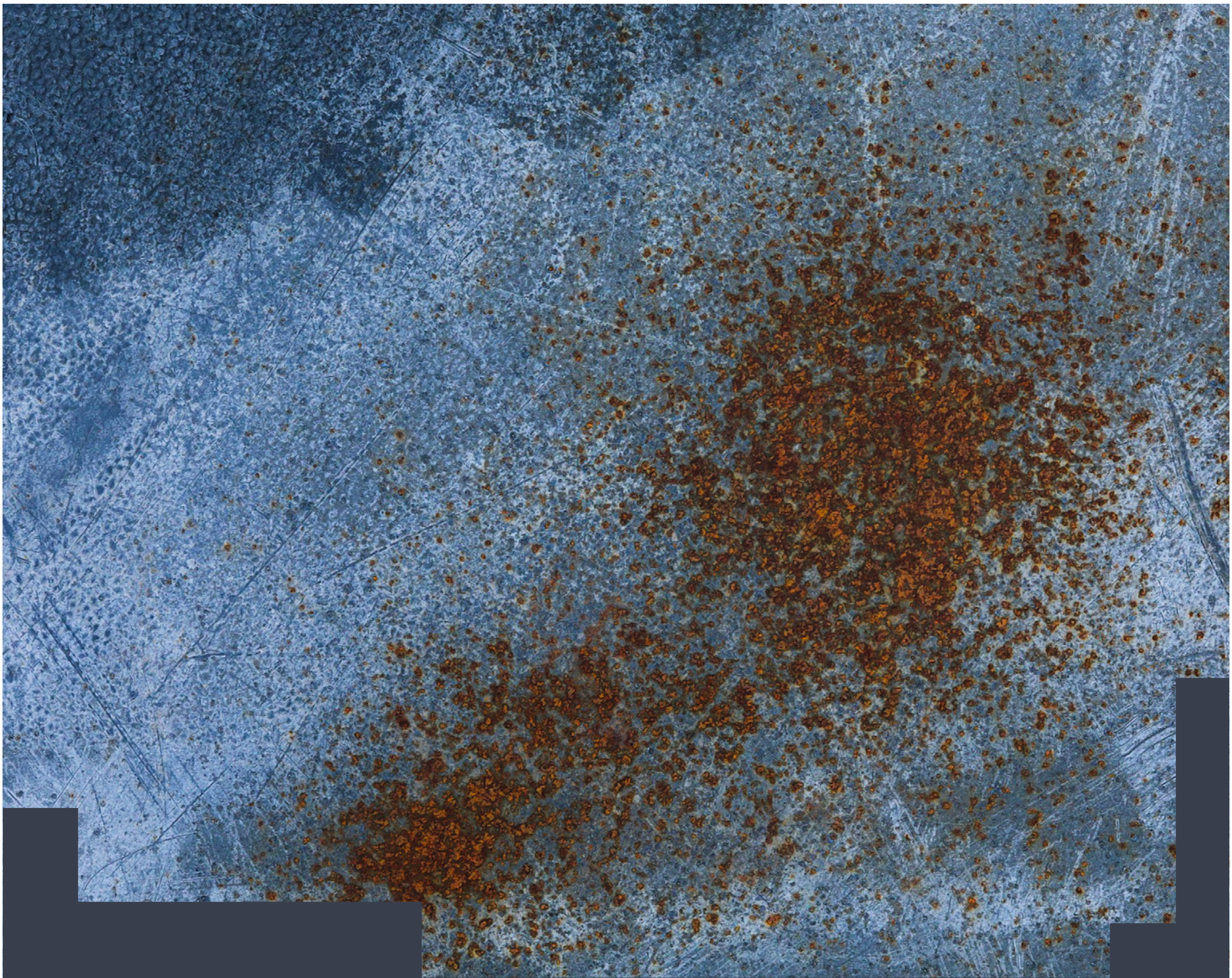


Figure 1: The semiconductor supply chain, as outlined in the two-day workshop

To explore these complexities and generate actionable insights, the Civic Machines Lab at the TUM Think Tank convened a two-day interactive workshop bringing together interdisciplinary experts from academia, industry, civil society, and the public sector. The aim was to foster dialogue on the ethics and sustainability of the semiconductor supply chain and to map shared concerns, solutions and diverging perspectives.

This paper presents a synthesis of the key viewpoints that emerged during the workshop. Rather than offering a singular narrative or set of policy prescriptions, it serves as a conversation starter, highlighting critical tensions, open questions, and promising directions for future research, governance, and innovation.



2 Challenges and Risks

Below, we present a deeper analysis of the workshop outcomes, drawing from a series of structured activities that brought together different perspectives on the ethical, political, and technological challenges in semiconductor development.

Participants collaboratively explored the semiconductor landscape using a series of visual tools and templates. These included mapping value chain vulnerabilities, assessing challenges and impacts, and identifying potential ideas of intervention. The aim was not only to map the challenges, but to explore the dynamics behind them and the levers that could drive change.

Unpacking core challenge areas

The challenges outlined in Figure 2 reflect the collective insights and experiences of the workshop contributors. The visual illustrates the interconnected nature of the challenges shaping the semiconductor ecosystem. It shows that challenges and risks—whether environmental, human rights–related, or governance-focused—are not isolated, but deeply intertwined with governance gaps, education deficits, and power asymmetries.

This network of interdependencies highlights the urgency of systemic thinking and cross-sector collaboration in navigating the ethical and geopolitical complexities of semiconductor development. In what follows, we introduce the central challenges identified during this exercise, offering non-exhaustive problem statements and illustrative examples.

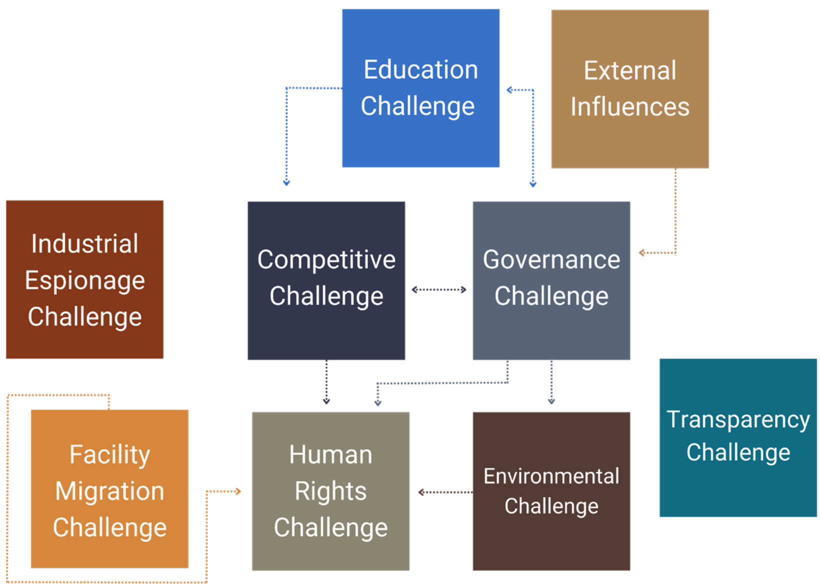


Figure 2: Overview of discussed challenges across the semiconductor supply chain

Environmental challenges

Identifying the issue: The environmental footprint of the semiconductor industry is both vast and complex, spanning excessive energy and water consumption, the use of hazardous chemicals, significant greenhouse gas emissions, and the accumulation of electronic waste—including millions of tons generated from replaced data-center hardware. As global demand continues to rise, so does the pressure on natural resources and ecosystems. Within this context, workshop participants identified several concrete environmental challenges, outlined below.

Resource consumption: Semiconductor production is extremely resource-intensive, particularly in its consumption of energy and water. Manufacturing processes require substantial amounts of **ultrapure water**, which is essential for rinsing and cleaning wafers during chip fabrication. This has raised concerns about water scarcity and local environmental degradation (World Economic Forum, 2024). In parallel, **energy use** in the industry has increased by 125% over the past eight years (Reuters, 2025). This contributes significantly to carbon and greenhouse gas emissions (Interface, 2025). The reliance on electricity and energy from non-renewable sources further intensifies the environmental burden.

Pollution: Pollution is generated along the supply chain, including the release of **"forever chemicals" (PFAS)** originating in raw material extraction. The use of **fluorinated greenhouse gases,** particularly in etching and cleaning semiconductor wafers, is another major concern given their high global warming potential. Emissions generated during the production and global distribution of semiconductors contribute significantly to the industry's overall carbon footprint. One participant highlighted this point, noting, "Before a semiconductor lands on our phone, it travels a lot, footprint is huge and that is an issue". Moreover, these pollutants often lead to **localized soil contamination**, with severe health implications. Inhalation or exposure to certain chemicals used in fabrication has been linked to reproductive health issues, cancer, and other serious illnesses (Kim, M.H., 2014).

Waste management: Challenges around waste and e-waste disposal were highlighted, particularly regarding the recycling and reuse of materials across the semiconductor lifecycle. Participants noted the **cost of recycling** as well as the **limited options for responsible waste disposal** as challenges. These issues are compounded by the short lifespan of electronic products and the **difficulty of reusing** valuable materials from discarded devices (Cucchiella, F., 2015). In addition, the **highly competitive nature of the industry** often deprioritizes investment in circularity and long-term sustainability, as companies tend to focus on speed, performance, and cost-efficiency. Reflecting on the issue, a participant noted, "It's so competitive, companies don't have the energy to recycle."

Facility migration challenges

Identifying the issue: The re-establishment of semiconductor manufacturing capacity, whether driven by geopolitical tensions, economic incentives, or efforts to diversify supply chains, presents a complex set of challenges. In the context of the workshop, participants identified such facility migration as a critical strategic and operational issue for the industry.

Financial costs: Establishing new fabrication capacity in alternative regions comes with substantial financial costs (DHL, 2022; McKinsey, 2025) including the **capital investment** required to build or retrofit new fabs, logistical disruptions, and the need to re-establish supply and labor networks.

Local community impact: Changes in fabrication operations also have profound social implications, particularly for local communities that have historically relied on semiconductor plants for **employment** and **economic stability** (Kucera, D., 2019). Participants raised concerns that emerging competitors in other regions may attract talent and investment away from established hubs, threatening the sustainability of local economies.

Additionally, relocating operations to a country with weaker labor protections can heighten risks such as unsafe labor conditions. But, not all re-establishments of semiconductor manufacturing capacity occur for the same reasons. It is important to distinguish between moves driven by labor-law arbitrage and those motivated by supply-chain resilience. The **cost of shifting production** remains a major barrier in either case, especially in sectors like advanced semiconductors that depend on highly specialized infrastructure and regulatory environments.

As countries compete to attract fabs with subsidies and tax incentives, re-establishment decisions are becoming increasingly entangled with broader questions of fairness, long-term industrial planning, and the unintended consequences for workers and communities left behind.

Transparency challenges

Identifying the issue: Transparency and its complexity across the semiconductor value chain is a persistent and multifaceted challenge (DHL, 2022; Porsche Consulting, 2023; Bui, T.D., 2024). Mapping the entire supply chain is extremely complex, involving thousands of suppliers, proprietary processes, and limited disclosure practices. As one participant noted: “We don’t know where our chips are built,” underlining the lack of visibility even for experts. Both macro-level and micro-level industry transparency and its complexities are identified.

Macro-level transparency: At the macro level, there is limited visibility into how global supply chains function, who the key actors are, and how power is distributed—reinforcing concerns about concentrated control. This was referred to as a “**monopoly industry by design**,” pointing to structural opacity that benefits dominant players while sidelining accountability and open access to information.

Micro-level transparency: At the micro level, transparency gaps appear in the details of production processes and material sourcing. Participants expressed the need for more **traceability of material origins**. There were also concerns around how production processes are organized and where critical equipment comes from, particularly with much of it sourced from Asia, which raises questions about regional dependencies and strategic vulnerabilities. Lack of transparency also refers to the **working conditions** of those involved in manufacturing semiconductors.

Industrial espionage challenge

Identifying the issue: Industrial espionage can be a potential threat to the semiconductor industry (Allianz Research, 2025), where innovation is closely tied to competitive advantage and national security. Intellectual property (IP) theft is a major concern, as the high value of proprietary designs, fabrication techniques, and process technologies makes semiconductor companies prime targets for corporate espionage and cyberattacks.

In an industry where knowledge is power, the leakage of sensitive information poses risks not just to firms, but to the broader ecosystem of innovation, trade, and security. At the same time, the lack of transparency regarding specific chemical components and processes can hinder proper risk assessment and the implementation of effective controls (Yoon C., 2020).

Education challenges

Identifying the issue: A robust semiconductor ecosystem relies not only on advanced technological infrastructure but also on a highly skilled and knowledgeable workforce. Deficiencies in either area can limit the industry's long-term resilience and competitiveness. This challenge manifests across three interrelated dimensions:

Lack of workforce: First, the **shortage of skilled workers**, especially for roles requiring manual assembly and specialized technical skills, hinders local production capacities. Without sufficient education capacity, many regions remain dependent on foreign labor and expertise, weakening efforts to build **resilient local industries**. The rising demand for electrical and mechanical engineers and technicians, driven by the expansion of the semiconductor sector, contrasts with a declining number of graduates and limited interest in this field in some regions (Semiconductor Industry Association, 2023; ZVEI, 2024). Beyond training access, the industry's low visibility and limited appeal, particularly in Western countries, make it less attractive than more prominent sectors like automotive or consumer electronics.

Uneven distribution of access to knowledge: Staying competitive requires access to **cutting-edge research** and **specialized training programs**, yet many regions face systemic disadvantages due to underfunded universities, limited international collaboration, and lack of investment in education infrastructure.

Knowledge gaps and transfer of know-how: Major gaps identified included a shortage of skills and education in **advanced packaging**, as well as limited capacity in **semiconductor testing** in the EU—areas often seen as outdated and underrepresented in university curricula. Moreover, newer paradigms are not well reflected in training programs, leaving engineers underprepared. These gaps are especially pronounced in countries with **limited technological sovereignty**, contributing to a broader innovation and geopolitical knowledge divide.

The education challenge is not simply a matter of workforce supply, it reflects deeper **structural inequalities,** capacity limitations, and fragmented global knowledge flows that threaten the industry's ability to adapt and innovate.

Competitive challenges

Identifying the issue: The semiconductor industry is shaped by intense global competition (ESPAS, 2022; Frank, J., 2024; Allianz Research, 2025). Workshop participants identified this challenge as a multifaceted barrier to equitable and sustainable innovation. This includes sociocultural barriers, accessibility issues, financial constraints, and geopolitical dependencies, all of which limit who can participate in or benefit from the semiconductor ecosystem.

At a broader level, the **race for market leadership**, technological dominance, and competitive advantage often leads to **missed opportunities** for regions and actors unable to enter the field early on. A lack of competitive advantage can result in falling behind in emerging technologies, weakening technological sovereignty and market influence.

Sociocultural differences: Some participants noted that cultural and regulatory tendencies in Europe, such as a **cautious approach to risk**, may influence the pace of technological development and contribute to regional differences in innovation capacity. At the same time, regulation can both constrain and stimulate innovation depending on the context. Although Europe lags behind some regions in certain semiconductor capabilities, attributing this primarily to a "risk-averse" regulatory culture oversimplifies the issue. Other factors such as investment levels, access to talent, industrial policy, and supply chain dynamics also play significant roles.

Accessibility and exclusion: Access to certain design tools is often restricted, whether due to regulatory barriers, geopolitical dependencies, or the inability to afford expensive licenses. These limitations prevent some countries, regions, and actors from participating fully in semiconductor innovation. As a result, **access to high-quality technologies** becomes uneven, reinforcing global inequalities and concentrating power among a few dominant players. Such exclusion may not only stifle innovation but also undermine the goal of building a diverse and resilient global semiconductor ecosystem.

Financial barriers: The cost dimension of the competitive challenge was also emphasized. Participants pointed to the **high capital expenditure (CAPEX)** required for entering or maintaining a presence in the chip industry. These financial barriers consolidate power among a few dominant players, and in turn, increase prices for end consumers. The burden of resilience investments (e.g., duplicating supply chains or sourcing alternatives) further contributes to monopolistic dynamics.

Geopolitical dependency: Dependence on countries or companies that control key technologies can create strategic vulnerabilities. Some participants expressed concern that nations may face significant exposure during crises that highlight the fragility of global supply chains.

Examples discussed included the **concentration of critical technologies** and the potential for **disruptions in one region to have cascading effects worldwide**—posing important governance and resilience challenges with broad implications.

The competitive challenge reflects not only the intense economic race in the sector but also the systemic exclusions and dependencies that determine who can innovate, access critical technologies, and hold influence in the global semiconductor landscape.

Governance challenges

Identifying the issue: The semiconductor industry operates within a highly complex governance landscape, where national and international regulations intersect with industrial, environmental, and geopolitical interests (Monsees, 2023; IndustriAll Europe, 2024; Sourceability, 2025). The governance challenge was identified as a critical issue for coordination, innovation, and ethical oversight in the sector. This challenge manifests through regulatory imbalances, exclusionary effects, unintended consequences, and weak enforcement of labor laws.

Geopolitical dependencies and power dynamics: Countries heavily reliant on **foreign-owned technologies** at critical stages of the semiconductor supply chain can become vulnerable during crises, reinforcing global asymmetries of power and control in the industry. These dependencies not only **constrain strategic autonomy** but also expose entire supply chains to external pressures and unilateral decisions. Participants also raised concerns about the increasing political influence that can arise from such dependencies, posing risks to security, innovation, and economic sovereignty.

Regulation: Regulation was identified as both a necessary tool and a potential source of tension. Participants highlighted the challenge of balancing regulatory objectives as a major governance issue, given the inherent trade-offs involved. A key example discussed was the **regulation of "forever chemicals" (PFAS)**, which underscores the complexity of protecting environmental and public health while minimizing unintended impacts on industries that rely on these substances for critical manufacturing processes.

Additionally, participants noted the challenge of maintaining **high regulatory standards** alongside **high-standard industry production**, especially when other countries do not impose comparable regulations. This creates uneven playing fields, where companies operating under stricter standards may face **competitive disadvantages**, while global supply chains remain vulnerable to **regulatory arbitrage**. Navigating such regulatory dilemmas requires careful coordination across sectors and regions to avoid overburdening innovation while upholding safety and sustainability standards.

Unintended effects of regulation: Participants warned that overregulation could inadvertently hinder innovation, development, and use of essential technologies. When applied too rigidly, such restrictions may have **counterproductive effects**. For instance, they may encourage competitors to develop their own alternative solutions, thereby diminishing the influence and market share of domestic suppliers.

Other consequences are the **exclusion of people and ecosystems** as a direct effect of regulation and the restriction of access to high-quality technologies in certain regions, particularly when products cannot be legally exported. This not only limits technological diffusion and collaboration but also reinforces global inequalities in access to innovation.

Misuse/Misplacement: A growing concern was the misuse and misplacement of semiconductor technologies, particularly their weaponization in both economic and military contexts. The **dual-use nature** of semiconductors means that chips can easily be repurposed for military applications, leading to ethical dilemmas and strategic tensions.

Beyond end-use risks, some participants also raised fears of countries "**weaponizing" raw material access**, using export controls as tools of geopolitical influence. Recent export controls on critical minerals, including rare earth elements, show how countries can strategically restrict access to key inputs, with significant implications for downstream industries. For instance, limits on rare-earth exports have already influenced innovation trajectories in areas such as European drone manufacturing, where shortages of neodymium magnets have become a growing concern (Rare Earth Exchanges, 2025).

Labor laws: Weak or uneven enforcement of labor protections, especially in regions hosting outsourced production, raises ethical concerns about workers' safety, rights, and fair compensation. While consumer countries, such as those in the EU, may have **strong labor standards domestically**, there is often **limited oversight** of labor conditions in countries further upstream in the supply chain.

Human rights challenges

Identifying the issue: Human rights were identified as a critical yet often overlooked challenge within the semiconductor industry—encompassing labor rights, worker health and safety risks, and broader concerns about equity and fairness across global production networks. As the industry expands across regions with different regulatory and labor standards, these disparities raise serious ethical concerns regarding working conditions, pollution exposure, and equal opportunity (Watterson, A., 2006; Electronics Watch, 2014; Kim, M.H., 2014; International Labour Organization, 2025; Yin, Y., 2025).

Labor rights: Under labor rights, participants highlighted violations related to **working conditions, occupational health and safety,** and exposure to **environmental pollution** in production facilities. Workers in some regions face hazardous environments due to insufficient regulation and poor enforcement of safety standards, leading to long-term health risks. The links between industrial pollution, toxicity in chip manufacturing, and health hazards at the workplace were especially emphasized as key human rights concerns. Workers also face risks in the context of **facility migration**. As companies relocate production to more cost-effective regions, workers often face **weaker labor protections**.

Equality: Equality was framed not only as a matter of individual rights, but also of global justice. Participants pointed to the need for **equality of opportunity across nations and populations**, where technological advancement should not come at the cost of disenfranchising those in less privileged regions. The semiconductor industry's current structure often reinforces global inequalities, where technological benefits concentrate in the hands of a few, while environmental and labor burdens fall on the many.

The human rights challenge in semiconductors spans both, direct labor concerns and systemic injustices tied to production, relocation, and global governance. Addressing it requires a coordinated approach to fair labor standards, environmental justice, and inclusive participation in the benefits of technological progress.

External influences

The industry's extensive reliance on globally distributed production networks makes the semiconductor sector highly vulnerable to **disruptions** arising from pandemics, natural disasters, geopolitical tensions, or major infrastructure failures.

As participants noted, the globalized supply chain lacks sufficient robustness; a shutdown in one region can rapidly trigger cascading effects worldwide—interrupting chip production, delaying deliveries, and destabilizing sectors that depend on reliable semiconductor supply. This fragility is further compounded by **geopolitical dependencies** and **limited regional redundancy**, making the system less resilient in the face of large-scale shocks.

3 Recommendations

This section summarizes the recommendations developed by participants to address the challenges outlined in the previous chapter. These recommendations were generated through collaborative expert discussions and subsequently organized by the research team into **eleven thematic categories**. Each category reflects a distinct area of strategic intervention: 1. Clear strategy and structure; 2. Transparency; 3. Supplier redundancy; 4. Funding; 5. Facilitating knowledge sharing; 6. Corporate buffers; 7. Collaboration; 8. Governance; 9. Environmental measures; 10. Technological measures; and 11. Innovation.

For clarity and coherence, the recommendations are **presented according to the specific challenge areas they aim to address**, allowing for a structured understanding of how different actions can respond to, mitigate, or improve each identified challenge.

Environmental challenges

A central recommendation was to establish **clear reduction targets** for emissions, energy use, and material waste per manufactured chip, thereby strengthening accountability and enabling progress to be measured over time. However, echoing the ZVEI (2024) study, participants emphasized that while the semiconductor industry itself may not be the largest source of emissions, it plays a critical enabling role in reducing carbon footprints in downstream sectors via energy-efficient innovations. In this sense, sustainability efforts should extend beyond manufacturing to encompass the **entire lifecycle** of semiconductor-enabled devices. Accordingly, participants emphasized the need for greater transparency around emissions, enabling governments, companies, and the public to better understand and address the industry's environmental impacts.

More broadly, participants recommended strengthening **sustainable sourcing practices** and accelerating the shift to **greener energy sources** to reduce the industry's overall carbon footprint. They also emphasized the need for **stricter measures** to contain materials and pollution in order to prevent the release of toxic substances and limit localized environmental harm. Beyond these measures, participants discussed **technical interventions** aimed at reducing waste across the semiconductor lifecycle. For **mature technologies**, they suggested that **wafer testing yields** should reach at least 97% to minimize unnecessary material loss, and that **thinning wafers** could further improve recyclability and support more circular material flows.

Governance challenges

To address the complex governance challenges within the semiconductor industry, participants proposed a set of measures aimed at fostering stability, accountability, and resilience. Central to this is the need for **stable and predictable policy frameworks** that foster trust, enable innovation, and support market growth, while remaining aligned with broader sustainability objectives. Well-designed regulatory environments can help prevent unintended consequences—such as overly restrictive rules that slow innovation—yet still ensure that environmental considerations are fully integrated.

Participants also called for a careful **balance in information sharing**, particularly around **transparency and trade secrets**. While openness is essential for accountability and ethical oversight, excessive disclosure requirements can hinder a country's competitive advantage and intellectual property. Governance mechanisms must **find an equilibrium** that supports public interest without undermining national competitiveness or industrial innovation.

In terms of reducing vulnerabilities linked to geopolitical dependencies or supply chain disruptions, **expanding second-sourcing options** and strengthening **technological autonomy** are key strategies. This involves diversifying suppliers and production regions across key stages of the supply chain, thereby building greater redundancy and resilience into the overall system.

Competitive challenges

To address competitive pressures in the global semiconductor sector, a range of strategic, financial, governance, and collaboration-oriented measures were proposed across three core areas: **reducing geopolitical dependencies**, strengthening timely and strategic **market positioning**, and **preventing monopolistic control** over critical technologies.

To mitigate geopolitical dependencies and pursue a balanced approach between local resilience and global integration, participants recommended advancing **international cooperation agreements and memoranda of collaboration** to foster international cooperation and reduce tensions within the sector. A clear and coordinated strategy is also essential to help Europe and Germany establish a sustainable and resilient market position without disconnecting from global networks. In light of potential deglobalization trends, developing contingency plans is critical to ensure supply chain continuity and maintain long-term strategic autonomy.

To counter the risk of falling behind in market positioning due to slow processes, limited resources, or talent shortages, participants highlighted the need to **invest in workforce development and skill-building** in the EU and Germany. The establishment of joint funding programs and strengthening of academic partnerships between institutions from the EU and semiconductor leaders, was viewed as a way to transfer critical know-how and accelerate learning.

Finally, to confront the risk of monopolies over key technologies, participants proposed promoting **open sourcing models** as a means to increase transparency and foster collaboration, especially in areas where knowledge and innovation are highly concentrated. Along with the enforcement of **"anti-trust practices"** to prevent the concentration of power among a small number of dominant semiconductor companies. These measures aim to ensure fair competition and broaden access to critical technologies.

Education challenges

Addressing education-related challenges, particularly the uneven access to knowledge and the shortage of skilled talent, requires a combination of financial, regulatory, collaborative, and structural measures. Dedicated **funding mechanisms** can support local startups and foster innovation ecosystems where knowledge is retained and expanded locally. Bridging existing knowledge gaps also involves bringing in **international experts** to share expertise and train local talent, complemented by regulatory measures that promote **structured knowledge exchange** across borders and institutions.

Additionally, participants called for the establishment of strong **international partnerships**, particularly between universities and training institutions, to facilitate collaboration and long-term capacity-building. **Structural change** was also highlighted, including lowering barriers for skilled workers, educators, and researchers to diversify and strengthen the talent pool. Finally, participants stressed the importance of **supporting startups** as they represent critical entry points for both talent development and knowledge diffusion in regions historically excluded from the semiconductor innovation pipeline.

Human rights challenges

To address human rights challenges, particularly those related to labor conditions in the semiconductor supply chain, participants proposed two key measures. First, the need for **targeted government funding** to support ethical labor practices such as investment in safer working environments, fair wages, and labor rights monitoring. Second, **optimize and harmonize labor laws**, ensuring that protections for workers are consistent and enforceable across regions. Strengthening these frameworks can help mitigate risks of poor labor conditions, reduce health risks, and promote fair employment throughout the global semiconductor value chain.

External influences

To address the challenge of a globalized yet non-resilient supply chain, a range of measures focusing on supplier redundancies, corporate buffers, and collaboration can enhance systemic robustness and preparedness.

Central to this approach is the creation of **corporate buffers**, including second- and third-sourcing strategies, which ensure that key components and services can be obtained from multiple regions rather than relying on a single supplier or country. **Regional diversification** across the supply chain can further reduce vulnerability to disruptions from geopolitical tensions, natural disasters, or global crises. In addition, the development of **cross-sector risk management networks** can strengthen overall resilience. Together, these strategies aim to build a semiconductor supply chain capable of withstanding and adapting to external shocks on a global scale.

Figure 3 presents each challenge alongside its corresponding recommendations, while Figure 4 maps these recommendations to broader thematic categories, offering a framework for understanding priorities and strategies across various domains.

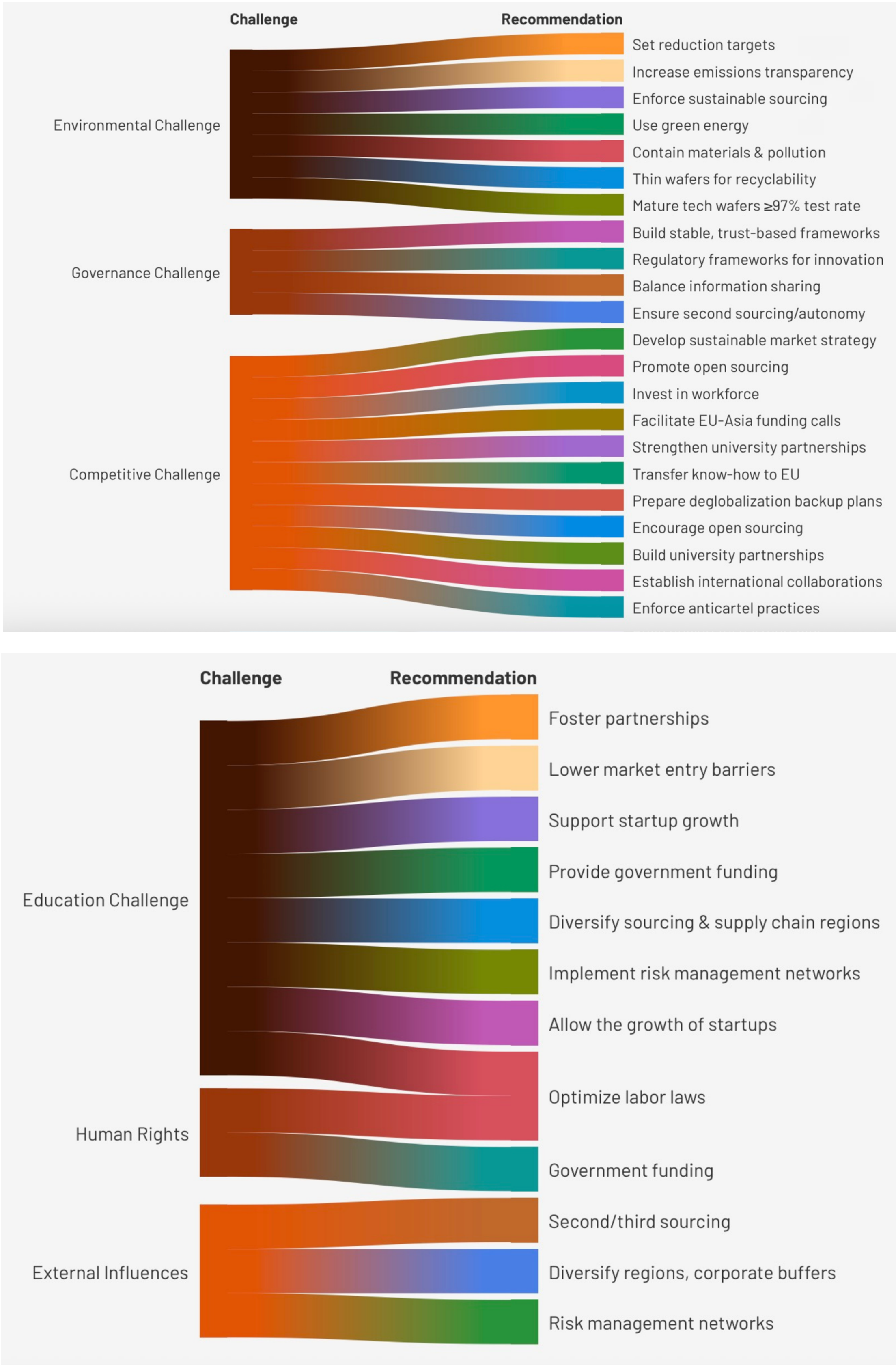


Figure 3: Overview of challenges and recommendations

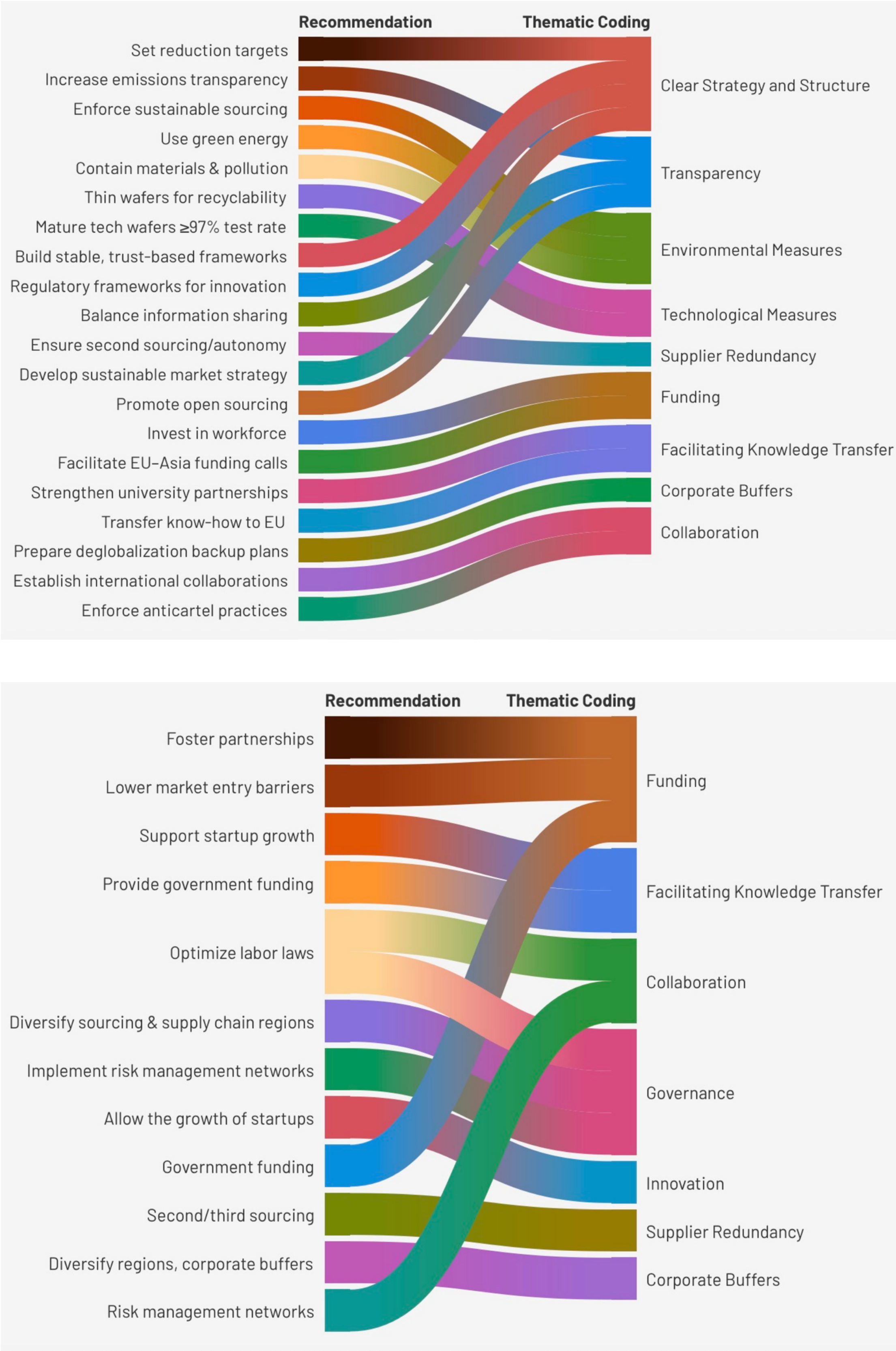
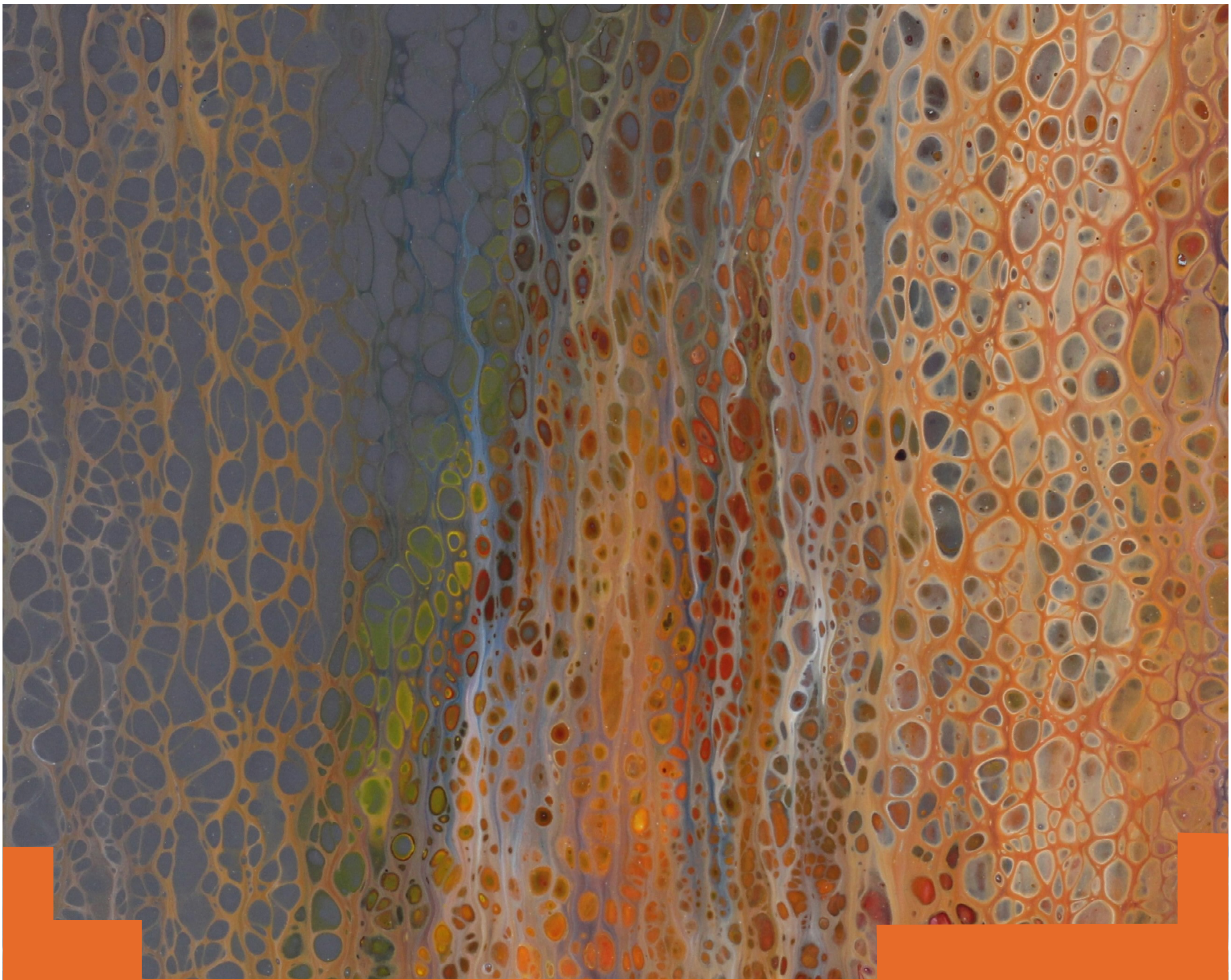


Figure 4: Overview of recommendations and mapped thematic categories



4 Future Outlook

Participants were invited to **envision different future scenarios** that describe potential trajectories for the semiconductor industry in 2030 and beyond. This foresight exercise aimed to explore plausible developments, shaped by current trends, challenges, and global dynamics and afterwards, aspirational visions of what the industry could become under ideal conditions.

In this section, we:

1. **Present the range of possible future scenarios** imagined by participants for the coming decade and beyond.

2. **Describe two ideal future scenarios** developed by participants that reflect shared aspirations across stakeholder groups, outlining the structures and practices that would define a more ethical, sustainable, and resilient semiconductor ecosystem.

Possible futures: 2030 and beyond

The future of the semiconductor industry is shaped by a complex interplay of environmental, geopolitical, economic, and technological forces. Participants explored how different aspects of the semiconductor industry might evolve by 2030 and beyond. They identified **five key dimensions:** the state of regulation, the state of sustainability, the state of technology, the state of the global market, and the potential for disruptions.

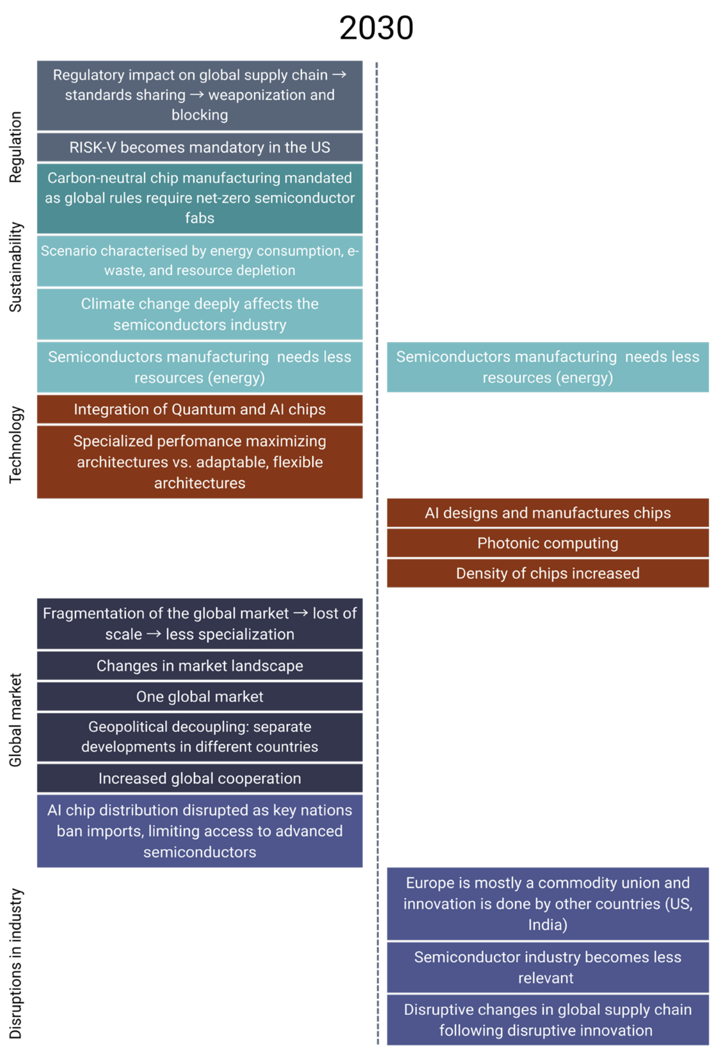


Figure 5: Possible future scenarios for the semiconductor industry

State of regulations

Looking ahead to 2030, participants anticipate that the regulatory environment will exert a stronger influence on the global supply chain, either through efforts to share standards or via risks of regulatory weaponization and strategic blocking. One scenario envisions RISK-V becoming mandatory in the U.S., potentially reinforcing technological sovereignty. Another scenario anticipates new global regulations requiring net-zero emissions from semiconductor fabs, offering a glimpse into a possible trajectory for sustainability.

State of sustainability

On the sustainability spectrum, potential scenarios for 2030 include climate change directly constraining semiconductor production, such as through water scarcity. Participants highlighted a scenario characterized by ongoing concerns over energy consumption, e-waste, and resource depletion. In a more optimistic scenario for 2030 and beyond, technological advancements could enable semiconductor manufacturing to use substantially fewer resources, lower energy requirements, and embed sustainability as a core design principle rather than an afterthought.

State of technology

Participants discussed the integration of quantum and AI chips into conventional semiconductor architectures as a potential scenario for 2030, a development that could significantly enhance processing capabilities and redefine performance standards. Reflecting ongoing tensions between optimization and versatility in hardware innovation, a second scenario envisions a divergence in chip design approaches, with the industry splitting between specialized, high-performance architectures tailored for specific tasks and more adaptable, flexible architectures suited for broader, reconfigurable applications.

Looking beyond 2030, another scenario projects AI taking on a more prominent role—not only in chip optimization but also in design and manufacturing—where AI could potentially design and produce chips autonomously. Additional scenarios highlight advances such as photonic computing moving from research into commercial applications for compute and data storage, and the possibility that increased chip density could reshape the technological landscape, expanding the boundaries of current hardware capabilities.

State of the global market

Looking ahead to 2030, participants anticipate shifts in the global semiconductor market along two main trajectories. The first trajectory envisions growing fragmentation, driven primarily by geopolitical decoupling. In this scenario, companies and regions could lose economies of scale, potentially requiring the local replication of entire supply chains rather than focusing on specialized stages of production. This would result in divergent developments across countries and a general decline in specialization.

In contrast, the second trajectory envisions a unified global market, sustained or revived through increased international collaboration and mutual dependence.

Disruption in the semiconductor industry

One scenario involved the disruption of chip distribution in Europe, as a coalition of leading nations bans imports, restricting access to advanced technologies and escalating regional disparities.

For a future beyond 2030, several more radical disruptions were proposed: Europe becoming primarily a commodity union, with innovation dominated by the U.S., India, or other regions; disruptive changes in technology or demand followed by disruptive innovations; and the semiconductor industry becoming less relevant.

Ideal scenarios

This subsection outlines two multidimensional ideal future scenarios developed by participants, covering technological, political, environmental, social, and ethical aspects.

Ideal future scenario 1: climate-driven collaboration

In this ideal yet realistic scenario, climate change acts as a catalyst for urgent decarbonization efforts within the semiconductor industry, driving international collaboration across governments, industry, and academia. Semiconductors play a pivotal role in enabling low-carbon electronics, while increased healthy global competition accelerates innovation and expands access to computational power. Unlike today's fragmented efforts, this future is marked by collaborative global action, with formal trade agreements, knowledge-sharing partnerships, and material exchange frameworks ensuring secure and equitable access to key technologies.

Technological advancements are driven by AI, emerging energy technologies (such as fusion energy), and photonic computing, with quantum technologies serving a complementary role. This scenario, however, faces challenges related to the supply of critical raw materials, including gallium and germanium. In response, resource reallocation is prioritized, governments implement mandatory circular economy policies, and regulations are introduced to enhance component durability and recyclability. A notable innovation is the introduction of a CO_2 scoring system for companies—akin to Germany's NutriScore but focused on emissions across different stages of the semiconductor supply chain. This system promotes transparency, encourages environmentally conscious decision-making, and raises consumer awareness, aiming to drive "green" purchasing behaviors.

The scenario anticipates substantial environmental gains, but it also introduces new challenges. Socially, the widespread adoption of more efficient and affordable AI technologies could drive higher energy consumption—a rebound effect—potentially increasing reliance on nuclear power. Additionally, automation in production may reduce manufacturing employment, a factor that should be anticipated and addressed in planning.

Ideal future scenario 2: regulation-led sustainability and resilience

In this scenario, the regulatory environment becomes the primary force shaping the global semiconductor market, influencing whether the landscape trends toward fragmentation or integration. As stakeholders recognize the long-term value of leading in a regulated environment, they invest heavily to stay ahead in the innovation race, but not without trade-offs. In the early stages this innovation race risks undermining sustainability goals, as market-driven incentives take precedence. However, by strategically partnering with key players and promoting R&D in both manufacturing and materials, Europe positions itself as a leader in sustainable and resilient semiconductor development. Achieving circularity is a central objective, reaching a tipping point where recycling becomes necessary for both environmental and strategic resilience. Innovation that avoids waste and developing technologies that consume less energy are prioritized.

In this future, regulation comes before innovation. Europe speaks with a more unified voice, ensuring better access to technologies, advancing a more sustainable and resilient landscape and approaching the market in an ethical way. The technologies central to this vision includes AI, photonics, quantum computing, alternatives to silicon, and power semiconductors. However, these advances still carry possible risks that must be accounted for: biases in AI, security vulnerabilities, and the monopolization of knowledge and infrastructure.

Politically, this scenario assumes a unified Europe with the capacity to enforce supply and value chain regulations, prioritize market stability, and enact targeted financial policies to support resilient and sustainable innovation. Protectionist measures are enforced to safeguard strategic interests. In this context, third poles are expected to prioritize equilibrium and resist the adoption of divisive or exclusionary policies, ensuring that cooperation and mutual benefit remain possible within a competitive geopolitical landscape.

Environmentally, this future promotes the conservation of raw materials, the adoption of energy-efficient technologies, and reduced CO_2 emissions. However, participants acknowledged that sustainability goals may be delayed as markets adjust to those new structures and priorities. Moreover, while innovations contribute to greater efficiency, the overall demand for power is expected to increase.

On the social and ethical front, this scenario envisions a better redistribution of wealth through reduced taxes, and stronger laws that support worker rights across the supply chain. However, several challenges remain: rising costs, less diversity of production and workforce, increased pressure on workers by technologies, and potential inequities in access to advanced technologies. Data privacy concerns also persist, particularly with regard to server location, underscoring the need for internationally aligned digital ethics frameworks.

5 Measures

To achieve the ideal future scenarios described in the previous section, participants outlined a **set of measures aimed at various stakeholders across the semiconductor ecosystem**. These measures are organized into **six thematic areas**: collaboration, environmental sustainability, transparency and awareness, governance, innovation and R&D, and knowledge transfer.

The following subsections present these recommendations, with a focus on which stakeholder groups are expected to take action: governments, industry, academia, NGOs, civil society and other stakeholders.

Measures for governments

Governments have a clear role in **setting direction, enabling cooperation, and ensuring accountability across the semiconductor ecosystem**. A key action for governments is ensuring that Europe speaks with one voice by developing a coordinated, unified strategy that strengthens its global position and resilience. Participants urged governments to actively promote international collaboration by creating frameworks for joint innovation, research, and supply-chain resilience.

To address environmental concerns, participants called on governments to establish **greater transparency** regarding the CO_2 consumption of electronic devices, alongside policies that make carbon pricing and recycling practices mandatory across the industry. They emphasized that such measures require mandatory and standardized approaches to CO_2 reporting, including unified metrics, clear reporting requirements, and robust verification procedures. It was stressed that without regulatory or industry-wide standards, proposed tools such as CO_2 scoring systems or green-to-red emission labels would remain inconsistent, difficult to compare, and challenging to enforce. In addition, governments should enforce policies on carbon pricing, recycling, and disclosure of environmental and labor practices, and support these requirements through strategic innovation policies that stimulate ethical, resilient, and sustainable technological development.

Finally, participants highlighted the need for **human resources goals**, such as policies that support education, training, and retention of skilled talent, especially in regions where the talent pipeline is underdeveloped.

Measures for industry

Industry actors are key in **advancing sustainability, resilience and social responsibility** within the semiconductor sector. A key recommendation was to strengthen **community integration**, not as a guaranteed safeguard against relocation, but as a way to reinforce local embeddedness through meaningful retention incentives and a clearer sense of social responsibility toward host communities.

To support environmental goals, industry actors were urged to provide **greater transparency in production**, particularly by disclosing the CO_2 consumption associated with their processes for tracking the environmental impact of products in a comprehensive, user-friendly way. Some examples were CO_2 scoring system or green-to-red emissions scale visible to regulators and consumers.

In parallel, companies are expected to **innovate in product design** to proactively meet emerging regulatory requirements, rather than responding reactively. Participants also encouraged firms to take more calculated risks and **increase R&D** in manufacturing techniques and materials science. Finally, to foster the next generation of experts was seen as essential. Industry must **invest in young talent**, supporting education, training, and early-career opportunities to ensure long-term competitiveness and resilience.

Measures for academia

Academia can be a key enabler of **long-term innovation, critical reflection, and international collaboration** in the semiconductor sector. Universities and research institutions are encouraged to build stronger collaborations with industry, acting as a bridge between research and application. Academia is also recommended to serve as a **counterweight to growing geopolitical and institutional division**, using cross-border partnerships to support global knowledge exchange and joint innovation efforts.

Academia can also play an active role in **raising awareness** on the semiconductor challenges, issues and risks, as well as contribute to policy assessment and advise governments on regulation, ethics, resilience, and sustainability. In addition, participants emphasized the role of academia as a hub of **research and technology transfer**, as well as the need for exploration of innovative design solutions that respond to emerging regulatory standards.

Beyond research, academia is tasked with educating individuals in different domains, fostering capacity building, and positioning itself as a stakeholder in shaping the future of the semiconductor industry. This includes investing in curricula development, training programs, and international knowledge-sharing initiatives to ensure that talent, insight, and innovation are widely accessible.

Measures for NGOs

NGOs can be vital players in **promoting accountability, ethical oversight, and public engagement** within the semiconductor industry. NGOs are encouraged to focus on raising awareness among consumers and stakeholders, making complex issues such as environmental impact, labor conditions, and supply chain ethics more visible to the public. They are also positioned to lobby governments, advocating for stronger regulatory frameworks and policies that promote social equity, resilience, sustainability, and human rights protections.

Additionally, the industry could benefit from NGOs taking on social and ethical risk assessments, offering recommendations on issues such as equality measures and worker protection policies to guide both public and private sector actions. By publishing guidance documents and standards, NGOs can establish benchmarks for responsible industry behavior. Acting as watchdogs, they can monitor corporate practices and hold stakeholders accountable. Participants also emphasized the potential for NGOs to serve as mediators in conflict situations, helping to bridge gaps between industry, government, and civil society when tensions or disputes arise.

Measures for society

Civil society plays an important part in shaping the future of the semiconductor industry through **consumer behavior, public pressure, and cultural change**. Individuals and communities can actively demand greener and more sustainable products, thereby creating market incentives and pressure for environmentally responsible manufacturing. Tools such as CO2 "semaphores" or environmental impact ratings, similar to cadastral systems, can help raise ecological awareness and enable more informed consumer choices.

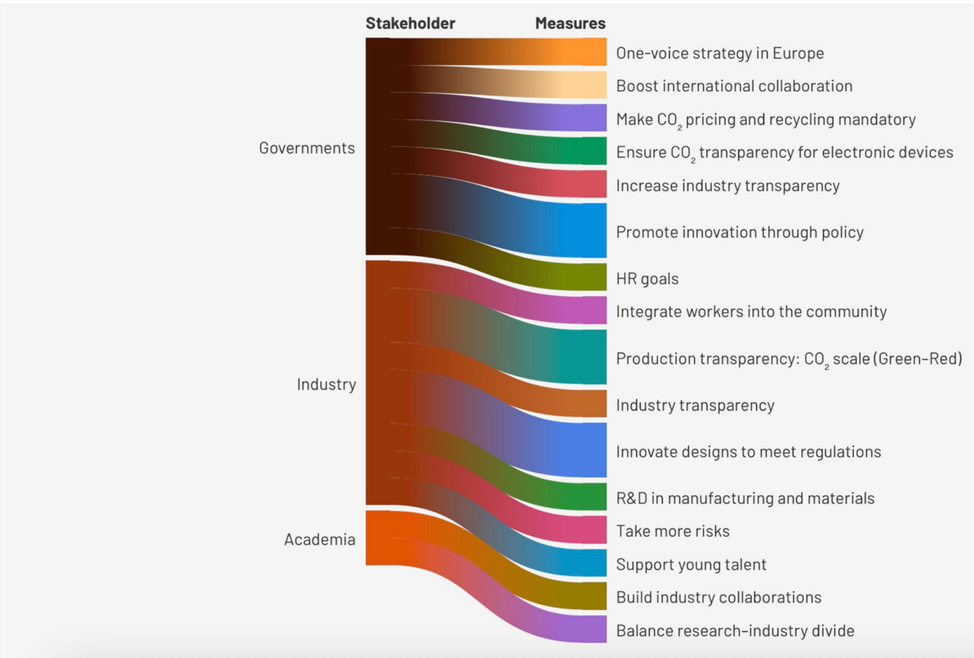
Beyond consumption, participants stressed the importance of education and public engagement to build ecological consciousness, encouraging a shift in mindset that leads to changes in behavior, which can drive more resilient and sustainable practices across the manufacturing and supply chain sectors. Society, in collaboration with NGOs, can also play a role in lobbying governments, advocating for missing environmental and ethical regulations.

Other cross-cutting measures

Beyond stakeholder-specific actions, participants highlighted several cross-cutting measures essential for a stable, future-oriented semiconductor ecosystem. They recommended that **third-party companies** adopt emerging technologies to drive innovation in less concentrated parts of the value chain. Participants also stressed the need for **stronger international collaboration** and **shared global standards** to ensure interoperability, ethical alignment, and collective progress.

Finally, they warned against a new "Cold War dynamic" in semiconductors, calling instead for diplomacy, cooperation, and balanced competition so technological advances benefit all.

Figure 6 presents the key measures proposed for each stakeholder group, outlining the concrete actions expected across the ecosystem. Figure 7 builds on this by categorizing each measure into a thematic area, showing not only what needs to be done, but also where coordinated action is required to strengthen the overall semiconductor ecosystem.



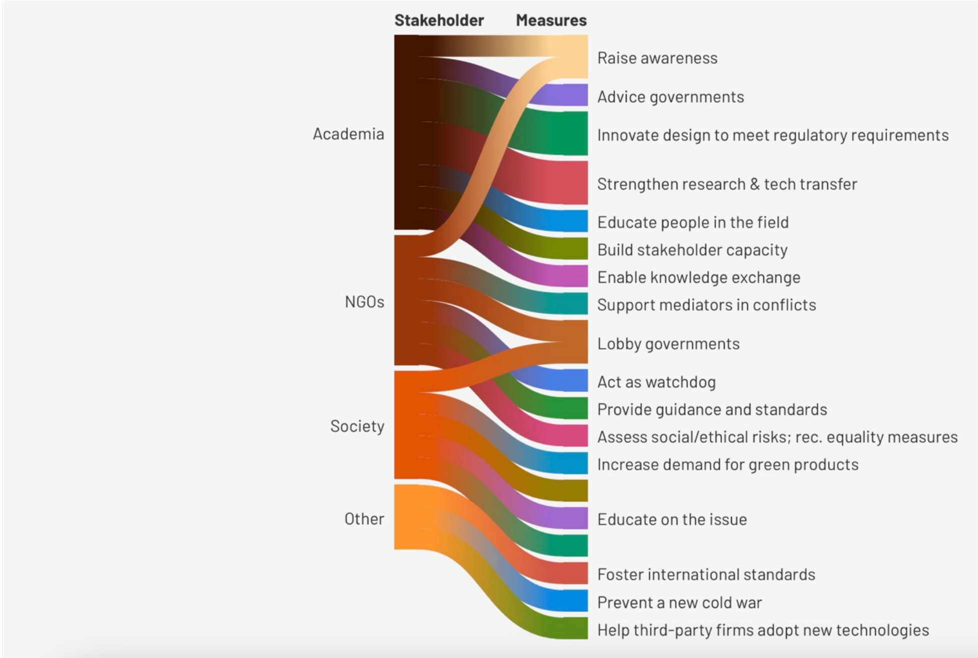
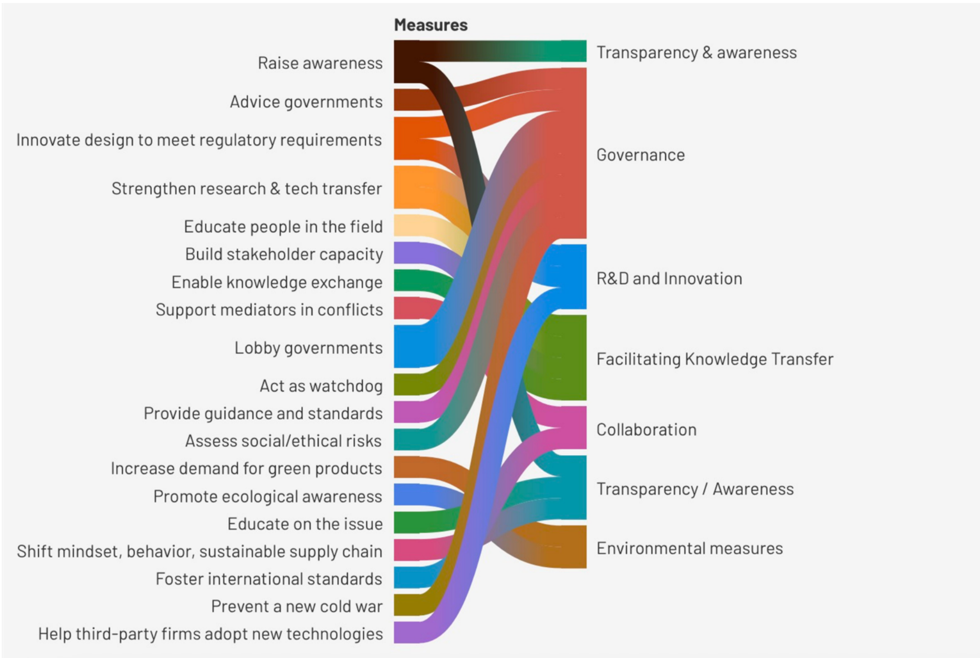


Figure 6: Overview of stakeholders and assigned measures



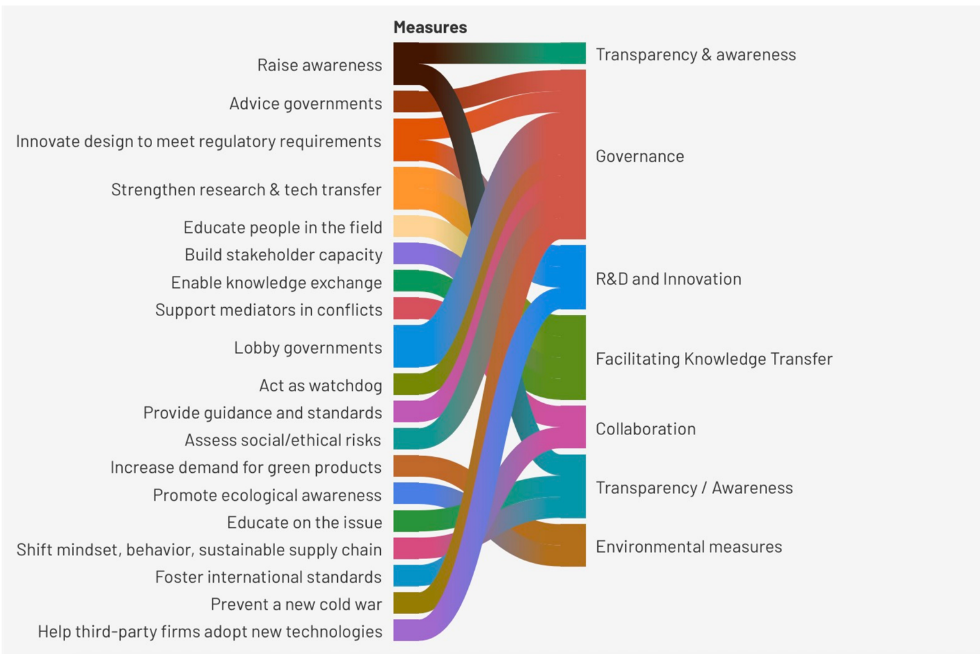
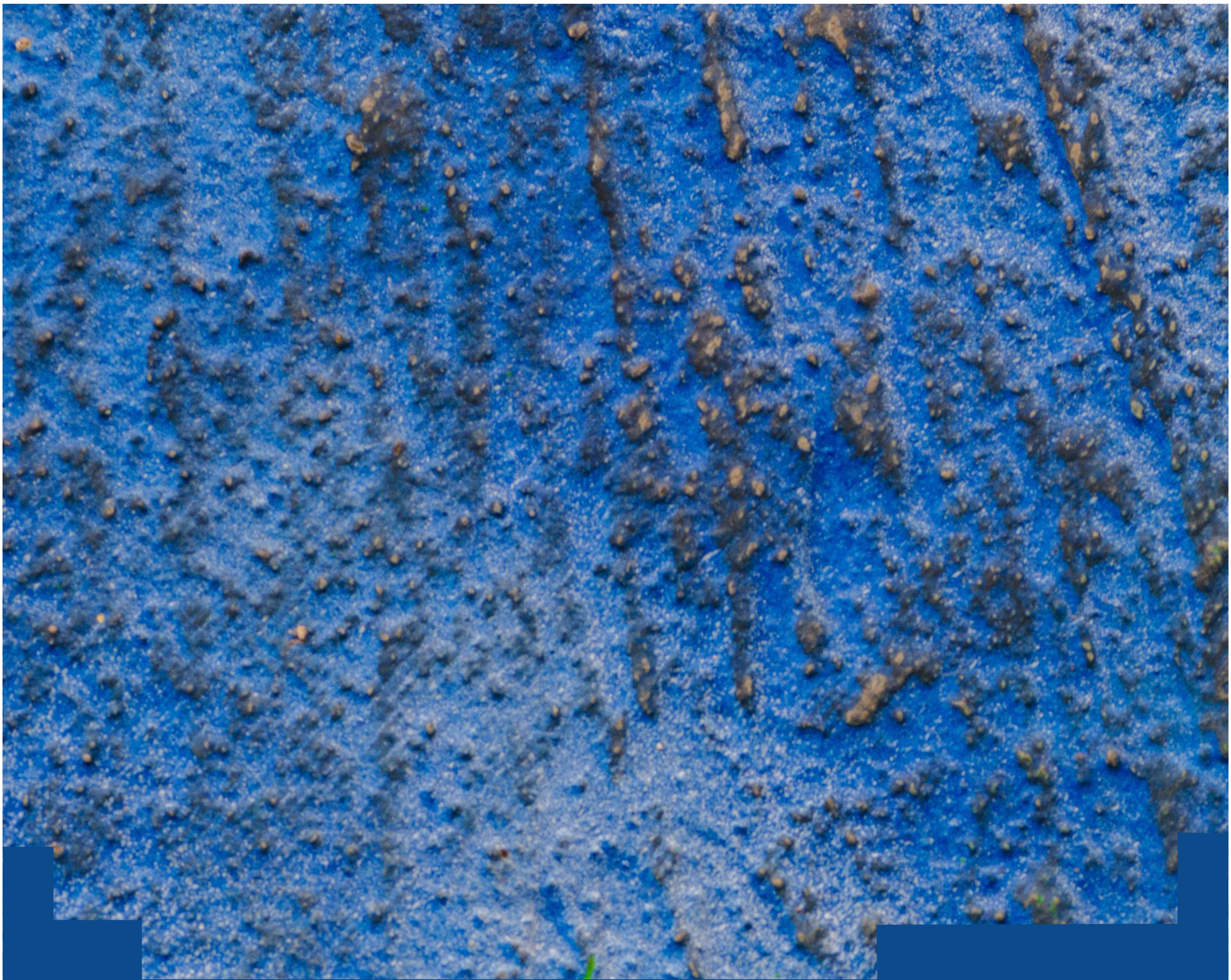


Figure 7: Overview of measures and assigned thematic area



6 Conclusion

Toward a responsible semiconductor future

The semiconductor industry sits at an inflection point. As the backbone of the digital economy, it underpins technologies ranging from AI to renewable energy systems, while also embodying many of the ethical, environmental, and geopolitical tensions that accompany globalized production. Discussions within the Civic Machines Lab's interdisciplinary experts workshop suggest that **addressing these tensions will involve more than advances in technology; it will also depend on how policy, governance, education, and markets evolve alongside them.**

The challenges identified throughout this paper—heavy resource demands, opaque supply chains, uneven labor conditions, and concentrated geopolitical risk—suggest that current approaches are reaching their limits. Addressing them will depend on closer alignment among governments, manufacturers, researchers, and civil society, as well as a willingness to confront tensions between efficiency, competitiveness, and responsibility.

The recommendations and scenarios presented here are not prescriptions but starting points. They illustrate how different forms of coordination could help the industry adapt to climate constraints, regulatory shifts, and growing expectations for fairness and transparency. Across both climate-driven and regulation-driven trajectories, participants emphasized a common set of enablers: clearer reporting of environmental and social impacts, mechanisms for sharing knowledge and reducing information asymmetries, and governance that supports innovation while safeguarding workers and ecosystems.

Looking ahead, the semiconductor supply chain may need to **revisit assumptions that prioritize short-term performance or cost minimization over longer-term resilience**. Alternative models—rooted in responsible resource use, circular material flows, and more balanced distributions of risk and reward—are already emerging, but they will require sustained commitment to take hold. Technological progress alone will not secure these shifts; they depend equally on continual reflection about the values guiding innovation.

REFERENCES

Allianz Research. (2025). The New Jedi Order: global chip war and the semiconductor industry. https://www.allianz.com/content/dam/onemarketing/azcom/Allianz_com/economic-research/publications/specials/en/2025/march/2025-03-06-Semiconductors.pdf

Bui, T. D. (2024). Assessing sustainable supply chain transparency practices in Taiwan semiconductor industry: A hierarchical interdependence approach. Supply Chain Management Journal. https://ideas.repec.org/a/eee/proeco/v272y2024ics0925527324001026.html?utm_source=chatgpt.com

Cucchiella, F., D'Adamo, I., Koh, S. C. L., & Rosa, P. (2015). Recycling of WEEEs: An economic assessment of present and future e-waste streams. Renewable and Sustainable Energy Reviews, 51, 263-272. https://doi.org/10.1016/j.rser.2015.06.010

DHL. (2022). Resilience of the Semiconductor supply chain. DHL Supply Chain Report. https://www.semi.org/sites/semi.org/files/2022-12/glo-csi-dhl-resilience-of-the-semiconductor-supply-chain.pdf?

Electronics Watch. (2014). Winds of change. https://electronicswatch.org/en/winds-of-change_788981.pdf?utm_source=chatgpt.com

ESPAS (European Strategy and Policy Analysis System). (2022). Global Semiconductor Trends and the Future of EU Chip Capabilities. ESPAS Report. https://www.espas.eu/files/Global-Semiconductor-Trends-and-the-Future-of-EU-Chip-Capabilities-2022.pdf

Frank, J. (2024). Chip War: The Battle for Semiconductor Supremacy. Technology Policy Review. https://aiipartners.ai/insights/chipwar

IndustriAll Europe. (2024). The semiconductor industry in Europe: between geopolitics and tech race. https://news.industriall-europe.eu/documents/upload/2024/9/638626809844508800_Semiconductors_policy_brief.pdf

interface (formerly Stiftung Neue Verantwortung). (2025). Semiconductor Emission Explorer: Tracking Greenhouse Gas Emissions from Chip Production (2015-2023). https://www.interface-eu.org/publications/semiconductor-emission-explorer

International Labour Organization. (2025). The future of work in more inclusive, sustainable and resilient electronics supply chains. https://www.ilo.org/sites/default/files/202506/The%20future%20of%20work%20in%20the%20electronics%20industry_WEB_Rev.%200625.pdf?

Kim, M. H. (2014). The health impacts of semiconductor production: An epidemiologic review. International Journal of Occupational and Environmental Health, 20(2), 95-114. https://doi.org/10.1179/2049396713Y.0000000050

Kucera, D. (2019). Automation, Employment, and Reshoring: Case Studies of the Apparel and Electronics Industries. https://heinonline.org/HOL/LandingPage?handle=hein.journals/cllpj41&div=14&id=&page=

McKinsey & Company. (2025). Semiconductors have a big opportunity—but barriers to scale remain. https://www.mckinsey.com/industries/semiconductors/our-insights/semiconductors-have-a-big-opportunity-but-barriers-to-scale-remain?

ZVEI. (2024). Mikroelektronik – Die Schlüsseltechnologie der Zukunft [Microelectronics – The Key Technology of the Future]. Zentralverband Elektrotechnik- und Elektronikindustrie e.V. https://www.zvei.org/fileadmin/user_upload/Presse_und_Medien/Pressebereich/2024-092_ZVEI-Studie_Halbleiterfoerderung-rechnet-sich-volkswirtschaftlich/ZVEI_Mikroelektronik_Studie_v19.pdf

Monsees, L. (2023). The paradox of semiconductors—EU governance between sovereignty and interdependence. Tylor and Francis Online. https://doi.org/10.1080/09557571.2024.2405915

Porsche Consulting. (2023). Strategic Semiconductor Management. Porsche Consulting Industry Report. https://www.porsche-consulting.com/sites/default/files/2023-04/221005_21_day_paper_strategic_semiconductor_management.pdf?#page=2.27

Rare Earth Exchanges. (2025). Drones, Robotics, and Rare Earths: Securing Supply Chains in a Global Tech Race. Rare Earth Exchanges Analysis. https://rareearthexchanges.com/news/drones-robotics-and-rare-earths-securing-supply-chains-in-a-global-tech-race/

Reuters. (2025). Semiconductor industry energy consumption increases by 125% over eight years. https://www.reuters.com/technology/europe-should-focus-sustainable-chip-production-sector-emissions-rise-study-says-2025-03-17/

Semiconductor Industry Association. (2023). Chipping away: Assessing and addressing the labor market gap facing the U.S. semiconductor industry. https://www.semiconductors.org/chipping-away-assessing-and-addressing-the-labor-market-gap-facing-the-u-s-semiconductor-industry/

Sourceability. (2025). The Semiconductor Industry's Biggest Hurdle in 2025: Regulatory Compliance. https://sourceability.com/post/biggest-hurdle-in-2025-regulatory-compliance?utm_source=chatgpt.com

Watterson, A. (2006). Regulation of Occupational Health and Safety in the Semiconductor Industry: Enforcement Problems and Solutions. International Journal of Occupational and Environmental Health. https://doi.org/10.1179/oeh.2006.12.1.72

World Economic Forum. (2024). The water challenge for semiconductor manufacturing and big tech: What needs to be done. https://www.weforum.org/stories/2024/07/the-water-challenge-for-semiconductor-manufacturing-and-big-tech-what-needs-to-be-done/

Yin, Y. (2025). Sustainable Transition of the Global Semiconductor Industry: Challenges, Strategies, and Future Directions. https://doi.org/10.3390/su17073160

Yoon, C. (2020). Chemical Use and Associated Health Concerns in the Semiconductor Manufacturing Industry. Safety and Health at Work. https://doi.org/10.1016/j.shaw.2020.04.005

A discussion paper by the **Civic Machines Lab at the TUM Think Tank**

PUBLISHER

TUM Think Tank
Civic Machines Lab

Munich School of Politics and Public Policy
Richard-Wagner-Str. 1
80333 Munich

tumthinktank@hfp.tum.de
tumthinktank.de

December 2025

AUTHORS

Naira Paola Arnez Jordan, Michel Hohendanner, Chiara Ullstein, Jens Großklags, Lorenzo Servadei, Alejandro Merino-Madrid, Fernanda Sauca, Orestis Papakyriakopoulos

PROJECT PARTNERS

Sony AI   Infineon

RECOMMENDED CITATION

Arnez Jordan, N. P., Hohendanner, M., Ullstein, C., Großklags, J., Servadei, L., Merino-Madrid, A., Sauca, F., Papakyriakopoulos, O. (2025). Expert Recommendations for the Future of the Semiconductor Supply Chain. TUM Think Tank.

DISCLAIMER

The content and views expressed in this paper represent solely those of the authors and should not be attributed to the TUM Think Tank as an institution, to its affiliated members, or project partners.