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Semiconductor Chips for Sustainable Development

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Policy Recommendations

- Improve Resource Productivity and Waste Minimization
- Implement Sustainable Semiconductor Manufacturing Methods
- Implement Sustainable Supply Chains
- Ensure Digital Access
- Transfer Semiconductor Technology that Facilitates Sustainable Development to the Global South
- Develop Sustainably Targeted Application-Specific Integrated Circuits (ASICs) Industries
- Collaborate and Partner to Inclusively Develop Semiconductor Industry
- Ensure Access to Semiconductor Technology
- Develop Mechanisms and Incentives to Promote Sustainable Semiconductor Industries

Introduction

The purpose of this technology brief is to recommend policy shifts that align with tangible developments in semiconductor chips. Attainment of sustainability must be centred on policy changes or fostering initiatives. Chips, or small semiconductors with an embedded electronic circuit that transmits data signals, are essential for many technologies, including smartphones, electric vehicles, and medical devices.[1] They are also crucial for developing new technologies, such as artificial intelligence (AI) or the Internet of Things (IoT), with applications for industries such as renewable energy, healthcare, precision agriculture, and aerospace for instance. Chips and their applications are crucial for sustainable development. Sustainable development approaches are long-term plans that seek to meet the requirements of the present without compromising resources and possibilities for future generations.

1 Marwala, T. (2023) When the chips are down — the increasingly cutthroat political economy of computer chips. https://www.dailymaverick.co.za/opinionista/2023-08-23-when-the-chips-are-down-the-increasingly-cutthroat-political-economy-of-computer-chips/

The current global semiconductor supply chain is extremely concentrated in a few nations, such as the USA, China including the province of Taiwan, and South Korea.[2] This supply concentration makes the industry susceptible to disruptions when unfortunate events happen, like the COVID-19 pandemic and the recent conflict in Ukraine. Moreover, it raises concerns about the security and resilience of the global supply of semiconductors, and the call to expand this supply chain and increase the production of chips should be addressed.[3, 4] Supply concentration is of high-risk based on the inherent potential to cause disruptions with large impact across various sectors globally and should be made more decentralized and sustainable. This does not even account for the immense possibilities associated with the next revolutions in the area through analog (semiconductors designed to process and manipulate continuous electrical signals), AI chips (semiconductors designed to perform the complex mathematical calculations required for AI efficiently), and quantum chips (semiconductors based on the principles of quantum mechanics).[5, 6, 7]

Problem Statement

The increasing demand for chips has led to increased complex-manufacturing, which may result in environmental degradation, resource depletion, and assets distribution disparities. In addition, the growing reliance on processors emphasizes the need to promote sustainable practices in the semiconductor industry to protect the environment and care for socioeconomic prospects.

Global Distribution of Chips

There are varying degrees of distribution of chips globally. TSMC, the world's largest semiconductor foundry in the province of Taiwan, is the global leader in semiconductor manufacturing.[8] Samsung, another significant manufacturer, is headquartered in South Korea.[9] Japan has a significant semiconductor presence with companies like Kioxia and Sony Semiconductor Solutions. China's semiconductor industry is growing rapidly and has become a prominent player in recent years.[10, 11] The United States, where the semiconductor industry was first developed, continues to be a significant player with companies such as Intel, NVIDIA, Texas Instruments and Micron.[12] Other nations with semiconductor manufacturing capabilities include Germany, The Netherlands, France, and Singapore. Notably, in addition to semiconductor manufacturing, these countries also excel in semiconductor and high-end equipment design and simulation. In addition, these countries are home to prestigious companies, universities and research institutions that are seminal to developing new semiconductor technologies.

Typically located in Africa, Asia, Latin America, and the Caribbean, the Global South is a term used to characterize developing nations.[13] Typically, these nations have lower economic development levels and greater poverty than nations in the Global North. There are some notable players in the Global South with semiconductor capabilities. For example, Semicondutores Pro Eletrônica (SPE) is a Brazilian company that designs and manufactures integrated circuits for many applications. Semiconductor Complex Limited (SCL) in India is a government-owned corporation that designs and manufactures semiconductors for the Indian military and aerospace industries.[14] Malaysia is home to the semiconductor foundry Silterra Malaysia, which manufactures memory, logic, and analog chips, among others.[15] Several other countries in the Global South are expanding their semiconductor industries, including but not limited to Argentina, Chile, Colombia, Egypt, Mexico, Morocco, and Tunisia.

2 Mohammad, W., Elomri, A. and Kerbache, L., 2022. The Global Semiconductor Chip Shortage: Causes, Implications, and Potential Remedies. *IFAC-PapersOnLine, 55*(10), pp.476-483.

3 Attinasi, M.G., De Stefani, R., Frohm, E., Gunnella, V., Koester, G., Tóth, M. and Melemenidis, A., 2021. The semiconductor shortage and its implication for euro area trade, production and prices. *Economic Bulletin Boxes, 4*.

4 Gopal, S., Staufer-Steinnocher, P., Xu, Y. and Pitts, J., 2022. Semiconductor Supply Chain: A 360-Degree View of Supply Chain Risk and Network Resilience Based on GIS and AI. In *Supply Chain Resilience: Insights from Theory and Practice* (pp. 303-313). Cham: Springer International Publishing.

5 Ulmann, B., 2023. Analog Computing for the 21st Century. *arXiv preprint arXiv*:2309.03971.

6 Fuketa, H. and Uchiyama, K., 2021. Edge artificial intelligence chips for the cyberphysical systems era. *Computer, 54*(1), pp.84-88.

7 Nikandish, R., Blokhina, E., Leipold, D. and Staszewski, R.B., 2021. Semiconductor quantum computing: Toward a CMOS quantum computer on chip. *IEEE Nanotechnology Magazine, 15*(6), pp.8-20.

8 Moore, S.K., 2019. Another step toward the end of Moore's law: Samsung and TSMC move to 5-nanometer manufacturing-[News]. *IEEE Spectrum, 56*(6), pp.9-10.

9 Pelcat, M., 2023. *GHG emissions of semiconductor manufacturing in 2021* (Doctoral dissertation, Univ Rennes, INSA Rennes, CNRS, IETR–UMR 6164, F-35000 Rennes).

10 Park, S.A., 2023. Shifted paradigm in technonationalism in the 21st century: The influence of global value chain (GVC) and US-China competition on international politics and global commerce—A case study of Japan's semiconductor industry. *Asia and the Global Economy, 3*(2), p.100063.

11 Choung, E. and Koo, M.G., 2023. China's dream for chip supremacy: Seeing through the lens of panel display-related IC patents. *Business and Politics, 25*(2), pp.117-132.

12 Weinstein, J., 2023. Semiconductors and the Calculation of the Balance of Power. https://knowledge.uchicago.edu/record/6118

13 Yeung, H.W.C., 2022. Explaining geographic shifts of chip making toward East Asia and market dynamics in semiconductor global production networks. *Economic Geography, 98*(3), pp.272-298.

14 https://www.scl.gov.in

15 https://www.bloomberg.com/profile/company/1064Z:MK

It is important for the Global South to develop its semiconductor industry purposefully and actively. This will help developing nations become less reliant on imported semiconductors. It will generate jobs and stimulate economic growth in developing nations. It will also aid in developing novel semiconductor technologies that can address problems disproportionately impacting developing nations, such as poverty, hunger, and disease. Creating a wider network in the Global South also allows for the entrenchment of the principles of transparency and accountability.

The Role of Chips in Sustainable Development

Chips can contribute significantly to sustainable development in several ways.[16, 17] For instance, more technologically advanced chips can contribute to increased energy efficiency, reducing greenhouse gas emissions, and combating climate change by enhancing the energy efficiency of devices.

They can also contribute to the creation of novel renewable energy technologies. Chips are indispensable for developing solar panels, wind turbines, and other renewable energy technologies. These form an essential dimension of our commitment to renewable energy resources and combating the impact of climate change while simultaneously creating employment opportunities and spurring economic growth.

Elsewhere, they can help enhance the efficiency of transportation. Chips are used to optimize performance in electric vehicles, self-driving automobiles, and other transportation technologies that reduce our dependence on fossil fuels.

Additionally, they can assist in enhancing healthcare and precision machinery. For instance, intelligent chips used in novel medical devices can enhance the lives of millions of people, such as pacemakers and insulin pumps.

These are just some examples of the convergence between chips and sustainable development.

Semiconductor Pollution

While chips offer many advantages to sustainable development, they can also contribute to global warming and environmental degradation. Harmful substances are emitted into the environment during the production and disposal of semiconductor devices.[18, 19] This is called semiconductor pollution. Despite the significant role they play in modern existence, semiconductor production and disposal can significantly negatively affect the environment.

One of the primary sources of semiconductor pollution is the reliance on hazardous chemicals by the manufacturing process. These compounds can be released into the air, water, and soil, where they pose a threat to human and animal health. Hydrofluoric acid is used in semiconductor manufacturing, and this acid is highly destructive and can cause severe burns and respiratory complications.

The disposal of semiconductor devices is another source of semiconductor pollution. Chips containing semiconductors contain a variety of heavy metals, including lead, cadmium, and arsenic. These metals are toxic and can contaminate the environment if not disposed of properly. For instance, semiconductor chips are usually disposed of in landfills, where they can leach into the ground and water. Environmental and human health can be adversely affected by semiconductor pollution.

There are numerous ways to reduce semiconductor pollution. These include developing more eco-friendly semiconductor manufacturing techniques. This may involve using less hazardous chemicals and developing more efficient recycling methods for semiconductor circuits. Improving the disposal of semiconductor chips is another method to reduce pollution. This may involve the creation of innovative recycling and incineration technologies. Governments and the semiconductor industry can also contribute to minimizing semiconductor pollution. For example, governments can regulate the semiconductor industry and set emission and refuse disposal standards.

Global South and Semiconductor Value Chain

The Global South is a significant supplier of the basic materials used to manufacture semiconductors.[20] For instance, the Democratic Republic of the Congo (DRC) produces approximately 70% of the world's cobalt, an essential component of lithium-ion batteries with diverse uses including powering smartphones. The DRC is also a significant producer of copper, which is used in semiconductor packaging.

16 Gan, C.L., Chung, M.H., Zou, Y.S., Huang, C.Y. and Takiar, H., 2023. Technological Sustainable Materials and Enabling in Semiconductor Memory Industry: A Review. *e-Prime-Advances in Electrical Engineering, Electronics and Energy*, p.100245.

17 Mullen, E. and Morris, M.A., 2021. Green nanofabrication opportunities in the semiconductor industry: A life cycle perspective. *Nanomaterials, 11*(5), p.1085.

18 Chen, H.W., 2006. Gallium, indium, and arsenic pollution of groundwater from a semiconductor manufacturing area of Taiwan. *Bulletin of Environmental Contamination & Toxicology, 77*(2).

19 Garelick, H., Jones, H., Dybowska, A. and Valsami-Jones, E., 2008. Arsenic pollution sources. *Reviews of environmental contamination volume 197: International perspectives on arsenic pollution and remediation*, pp.17-60.

20 San Yoo, C., 2008. *Semiconductor manufacturing technology* (Vol. 13). World Scientific.

Other countries in the Global South that produce materials used in semiconductors are Bolivia (lithium), Brazil (niobium), Indonesia (tin), Peru (zinc) and the Philippines (nickel). Determining how many materials are used to manufacture semiconductors from the Global South is complicated because this information is not always readily available. One study estimates that the Global South produces approximately 60% of the world's basic semiconductor materials. Given this staggering contribution by the Global South, the benefits of semiconductors should also be shared with the Global South. However, this is not the case.

Although the Global South produces a significant quantity of the semiconductor industry's raw materials, as this paper has demonstrated, most semiconductors are manufactured in the Global North. This is because the semiconductor industry requires substantial research and development (R&D) investments and a qualified labor force.

In recent years, efforts to develop semiconductor manufacturing capabilities in the Global South have increased, as outlined above. This is motivated by a desire to reduce reliance on imported semiconductors, as well as to generate employment and stimulate economic development. However, several obstacles must be overcome, including a lack of investment and skilled labor.

Semiconductors in the Global South

There are several reasons why semiconductor processors are essential in the Global South. Semiconductor processors are utilized in numerous industries, including manufacturing, agriculture, and healthcare, contributing to economic growth. By developing and manufacturing semiconductor chips, countries in the Global South can stimulate their economies and generate new employment.

Semiconductor circuits are indispensable to technological progress. By investing in semiconductor R&D, countries in the Global South can develop new technologies to enhance the lives of their growing population and leapfrog ahead, or bypass traditional stages of development.

Semiconductor processors can be used to develop various sustainable technologies, such as renewable energy systems and energy-efficient appliances, for sustainable development. Countries in the Global South can reduce their environmental impact and construct a more sustainable future by developing and utilizing semiconductor chips. We cannot tackle climate change if we leave most people in the Global South behind.

There are already some tangible semiconductor developments in the Global South. In Africa, semiconductor chips are being utilized to create new agricultural technologies that can assist producers in producing more food with less water and land. Kenyan farmers, for instance, employ drones equipped with semiconductor processors to monitor their crops and detect pests and diseases early on.[21]

In Latin America, semiconductor chips are used to develop novel healthcare technologies that can enhance healthcare quality for all individuals. For instance, Brazilian physicians use semiconductor-based microscopes to diagnose illnesses.[22]

In Asia, semiconductor processors are being utilized to develop new renewable energy technologies that can assist nations in decreasing their reliance on fossil fuels. For instance, Indian engineers are producing solar panels based on more cost-effective and efficient semiconductors than conventional solar panels.[23]

Semiconductor chips play a crucial role in the Global South's development. By developing and employing semiconductor processors, countries in the Global South can strengthen their economies, advance their technological capacity, and construct a more sustainable future.

Recommendations Concerning Public Policy

In order to leverage the capabilities of chips in the attainment of sustainable development, governments must invest in the research, development and transfer of more energy-efficient and sustainable semiconductor technologies; promote the diversification of the global semiconductor supply chain; promote equitable and fair commerce in semiconductors; act to link-up and reduce centralization and dependency of scientific and technological hubs associated with the sector; and work to diminish the semiconductor industry's environmental impact.

In this regard, these are the recommendations for policymakers to consider:

1. Improve Resource Productivity and Waste Minimization
It is imperative to encourage industries to adopt circular economy principles in order to reduce waste and reuse

21 https://www.businessdailyafrica.com/bd/corporate/enterprise/engineer-uses-drones-to-tap-data-driven-farming-demand-4278880

22 Moreau, A.L., Janissen, R., Santos, C.A., Peroni, L.A., Stach-Machado, D.R., de Souza, A.A., de Souza, A.P. and Cotta, M.A., 2012. Highly-sensitive and label-free indium phosphide biosensor for early phytopathogen diagnosis. Biosensors and bioelectronics, 36(1), pp.62-68.

23 Devabhaktuni, V., Alam, M., Depuru, S.S.S.R., Green II, R.C., Nims, D. and Near, C., 2013. Solar energy: Trends and enabling technologies. Renewable and Sustainable Energy Reviews, 19, pp.555-564.

resources in the semiconductor manufacturing process.[24, 25] Additionally, there should be more focused R&D in material efficiency. This includes funding R&D of resource-efficient semiconductor manufacturing materials.

2. Implement Sustainable Semiconductor Manufacturing Methods

Policies should facilitate the transition of semiconductor manufacturing facilities to renewable energy sources to reduce greenhouse gas emission.[26] Consideration should be given to tax rebates and grants, which should be used to promote water conservation practices in the semiconductor manufacturing industry.

3. Implement Sustainable Supply Chains

Policy should encourage ethical procurement and emphasize implementing stringent guidelines based on transparency and accountability for the ethical procurement of raw materials. Furthermore, policy should promote the development of local supply chains to reduce the carbon footprint associated with transporting basic materials and finished goods.

4. Digital Accessibility

For equitable systems to emerge, there should be affordable access to technology. Policies should facilitate the availability of chip-based technologies to underserved communities, thereby fostering digital inclusion and reducing the digital divide, encompassed not only be access but also by knowledge. Policymakers should launch educational initiatives to promote digital literacy and global exchange (North-South and South-South), focusing on driving the potential of semiconductor technologies towards advancing sustainable development objectives.

5. Transfer Semiconductor Technology that Facilitates Sustainable Development to the Global South

Based on the assumption that the semiconductor industry is essential to tackle global challenges such as poverty, migration, and climate change, it is important that semiconductor technology focused on sustainability is also transferred to the Global South.[27, 28] This can be pursued through a multifaceted approach based on joint ventures between the Global North and Global South; foreign direct investment (FDI); technology licencing; education and training through university programmes, technical workshops, seminars, and online courses; and focused R&D that fosters local talent and capabilities. Additionally, establishing technology clusters dedicated to semiconductor innovation can facilitate technology transfer through shared resources and a supportive ecosystem. There is scope for both North-South partnerships and South-South partnerships to emerge in response to calls for technological transfer and investment.

Policymakers in the Global South also have a role to play in strengthening intellectual property protection laws and enforcement mechanisms. Similarly, negotiating trade agreements facilitating the exchange of semiconductor technology and components between developed and developing regions is essential. Ultimately, this must be based on sustainable practices and requires the buy-in of the government and other crucial stakeholders.

Governments in the Global South can also foster the transfer of semiconductor technology to their countries by providing foreign semiconductor companies with financial incentives to invest in their countries; developing a regulatory environment favourable to the semiconductor industry; and investing in semiconductor industry training and education programs and contributing to semiconductor R&D in partnerships with Global North.

6. Develop Sustainably Targeted Application-Specific Integrated Circuits (ASICs) Industries

ASICs are computer processors designed for a particular purpose.[29] They are generally more efficient and quicker than general-purpose chips like CPUs and GPUs at specific tasks. ASICs can have a multitude of functions. For example, ASICs are used in routers, switches, and other networking equipment to process data efficiently and rapidly. They are utilized to process voice and data traffic in base stations and other telecommunications equipment. ASICs are used in smartphones, tablets, and other consumer electronics devices to execute image processing, video encoding, and audio decoding, among other tasks. Other uses for ASICs

24 Ishak, S., Shaharudin, M.R., Salim, N.A.M., Zainoddin, A.I. and Deng, Z., 2023. The effect of supply chain adaptive strategies during the COVID-19 pandemic on firm performance in Malaysia's semiconductor industries. *Global Journal of Flexible Systems Management*, pp.1-20.

25 Lu, W.M., Lo, S.F., Hung, S.W. and Yo, J., Semiconductor industry supply chain productivity changes: Incorporating corporate green performances. *Managerial and Decision Economics*.

26 He, Q.R. and Chen, P.K., 2023. Developing a green supplier evaluation system for the Chinese semiconductor manufacturing industry based on supplier willingness. *Operations Management Research, 16*(1), pp.227-244.

27 Sharma, A., 2023. Assessing Core-monopolization and the Possibilities for the Semi-periphery in the World-system Today: A Case Study of the Semiconductors Industry. *Journal of World-Systems Research, 29*(2), pp.480-504.

28 Thorbecke, W., 2023. The East Asian Electronics Sector: The Roles of Exchange Rates, Technology Transfer, and Global Value Chains. *Cambridge Elements in International Economics*.

29 Liu, J., Zhou, H., Chen, F. and Yu, J., 2022. The coevolution of innovation ecosystems and the strategic growth paths of knowledge-intensive enterprises: The case of China's integrated circuit design industry. *Journal of Business Research, 144*, pp.428-439.

include regulating engine functions, brake systems, and other critical systems in automobiles and other vehicles. ASICs are also used in industrial automation systems, robotics, and for other industrial applications. Given the wide use and potential applications of ASICs, they must be developed in a sustainability-targeted manner.

Designing and producing ASICs is typically more expensive than designing and producing general-purpose processors, as they are customized to specific tasks or applications. However, the gains in performance based on their optimization and efficiency based on their precision can mitigate the increased expense. ASICs have numerous other benefits, including reduced latency, their often-compact size, customization opportunities, and their long-term durability and reliability. Thus, the benefits of using ASICs justify the initial investment for applications where speed, energy efficiency, and specialized functionality are critical, particularly in pursuing sustainable development. Civilian and humanitarian demands, such as smart technologies for cities, agricultural and other health-food production, as well as climate monitoring pursuits, can be considered as good starting points.

7. Collaborate and Partner to Inclusively Develop Semiconductor Industry

There are various partnerships envisioned to facilitate this process.[30] For example, policies should promote partnerships between governments, businesses, communities, and academic institutions to promote research and innovation in sustainable semiconductor technologies. Moreover, policies should promote international collaboration to facilitate knowledge exchange and collaborative initiatives in advancing chip technologies for sustainable development.

8. Ensure Access to Semiconductor Technology

There are several methods to improve access to semiconductor technology. Investing in R&D to develop more affordable and accessible semiconductor manufacturing technologies is one approach. Creating government programs to support the semiconductor industry's growth in developing nations is another. It is also essential to promote international semiconductor technology cooperation. This may involve exchanging information and resources or collaborating on R&D initiatives.

9. Develop Mechanisms and Incentives to Promote Sustainable Semiconductor Industries

Whilst there are several implementation techniques to consider for adoption in policy frameworks, it is recommended that policymakers focus their efforts on developing legal and tax frameworks for implementing sustainability measures in the semiconductor manufacturing industry. Amongst the incentives, policymakers should prioritize financial incentives to businesses that adhere to environmentally responsible manufacturing practices. A focus on communication is essential, and policymakers should create public awareness campaigns and encourage engagement in chip-related sustainable development initiatives with communities. Finally, policymakers should implement monitoring and evaluation mechanisms to ensure policies' efficacy and impact while guaranteeing their ongoing adaptation and improvement.

Conclusion

Chips are indispensable for a vast array of technologies necessary for sustainable development. Governments can ensure that chips are used to foster a more sustainable future by taking the appropriate policy steps. In addition to the policy recommendations outlined above, governments can prioritize measures to promote a long-term plan for responsible and sustainable chip production. This includes the development of policy frameworks that enable chip factories to utilize clean energy, recycle waste materials, and safeguard the rights of their employees. By adopting the policy measures outlined in this brief, governments can ensure that chips are manufactured without harming the environment or people. Countries, regional bodies, industries, and sectors must explore the appropriacy of policy frameworks to ensure alignment with legal and regulatory systems. It is recommended that policies be adopted holistically, coherently, and integrated to have reasonable and acceptable impact.

30 Elia, G., Petruzzelli, A.M. and Urbinati, A., 2020. Implementing open innovation through virtual brand communities: A case study analysis in the semiconductor industry. *Technological forecasting and social change, 155*, p.119994.

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