International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

World's Semiconductor Ecosystem: A Secondary Analysis of Challenges, Opportunities, and Strategic Pathways for Global Competitiveness

Divij Garg

Abstract

The semiconductor industry has emerged as a critical foundation of modern economies, technological innovation, national security, and defence capabilities. This study examines the global semiconductor ecosystem with particular emphasis on supply-chain vulnerabilities, geopolitical competition, critical-mineral dependencies, and India's evolving strategic position. Using a secondary research methodology, the study analyses scholarly literature, industry reports, government publications, and policy documents to examine the structure of semiconductor value chains and the roles of major economies. The findings highlight that geographical concentration, dependence on specialised technologies and materials, trade restrictions, geopolitical tensions, and unexpected disruptions can significantly affect global semiconductor supply. The study further examines India's strengths in semiconductor design and engineering, alongside challenges in fabrication, advanced manufacturing, critical materials, infrastructure, and skilled workforce development. It concludes that India should pursue strategic competitiveness rather than complete self-sufficiency through domestic capability-building, supply-chain diversification, international partnerships, technological development, and stronger semiconductor capabilities for strategic sectors.

Keywords: Semiconductors; Global Semiconductor Ecosystem; Semiconductor Supply Chain; Supply-Chain Resilience; Geopolitics; Critical Minerals; Technology Competition; India Semiconductor Mission; National Security; Semiconductor Manufacturing; Global Value Chain; Strategic Technology

Chapter 1: Introduction

1.1 Background of the Study

A semiconductor is a material whose electrical conductivity lies between that of a conductor and an insulator. Unlike conductors, the conductivity of semiconductors can be easily influenced by external factors such as temperature, light exposure, magnetic fields, and the presence of small amounts of impurities. This unique property allows precise control over the flow of electric current.

Semiconductors form the foundation of modern electronic devices because they are reliable, compact, energy-efficient, and cost-effective. They are widely used in integrated circuits, transistors, light-emitting devices, sensors, and power control systems, making them indispensable in contemporary technology. Common semiconductor materials include silicon (Si), germanium (Ge), and gallium arsenide (GaAs). Semiconductor technologies are foundational to all modern digital economies. Since the invention of transistors, semiconductors have revolutionized electronics due to their unique properties, acting as the fundamental building blocks for various devices. Over the past several decades, these technologies have transformed global communication and data processing powers, accelerating innovations in sectors such as electric vehicles, renewable energy, healthcare, and advanced computing.

Semiconductors are indispensable components of modern technology, playing a critical role not only in electronic devices but also in renewable energy systems and numerous industrial applications. Their unique electrical properties enable efficient power conversion and signal modulation, making them essential for the operation of a wide range of technologies. Semiconductors continue to drive advancements in emerging fields such as artificial intelligence (AI), nanotechnology, and quantum computing, offering the potential to significantly enhance the speed, efficiency, and capabilities of future electronic systems. Among the most important semiconductor devices are diodes and transistors, which form the foundation of contemporary electronics. Diodes are widely used for rectification, converting alternating current (AC) into direct current (DC), a process necessary for powering electronic devices. They also play a key role in communication systems by facilitating signal modulation and transmission. Transistors function as switches and amplifiers, serving as the fundamental building blocks of integrated circuits found in smartphones, computers, medical equipment, and countless other electronic devices. Their ability to control and amplify electrical signals has enabled the development of compact, reliable, and high-performance technologies that support modern society. Therefore, semiconductors become indispensable for a country's survival too as without it, a country's technological advancement and manufacturing of existing technology.

The semiconductor industry has a very complex ecosystem depending on nations, companies, different policies, technologies and resources. It is structured around three main process steps: design, wafer fabrication, and assembly, test, and packaging (ATP). It identifies key segments, actors, and inputs, and offers a detailed analysis of how the different components and processes within the value chain interact, as part of the complex interdependencies that characterise the industry. Global Distribution**:** Production processes are distributed worldwide, with East Asia (China, Japan, Korea, Chinese Taipei) accounting for 71% of global semiconductor output. By economies, Japan and the United States take the lead in the market, with Germany, China and the Netherlands also playing significant roles. Furthermore, some chip types are mainly built in an IDM or a foundry business model. Gallium and germanium are crucial elements in semiconductor manufacturing, particularly for wafer fabrication, for example, China produced 69% of global silicon in 2023 and over 98% of gallium. The number of trade dependencies for semiconductors has more than doubled from 2012-14 to 2020-22, with many economies increasingly reliant on China for both finished chips and upstream materials. Policymakers are focused on mitigating vulnerabilities by diversifying supply chains, enhancing international collaboration, and monitoring market developments to manage potential disruptions.

1.2 Research Question

The central research question guiding this study is: How can India strengthen its position in the global semiconductor ecosystem by addressing supply-chain vulnerabilities, geopolitical dependencies, critical-mineral constraints, and strategic technology requirements?

1.3 Research Objectives

This study's main goal is to investigate the worldwide semiconductor ecosystem by means of a secondary analysis of previously published scholarly works, industry papers, official documents, and policy studies. Understanding the semiconductor ecosystem's value chains, supply networks, and key players is the goal of this research. It seeks to analyze the difficulties facing the sector, including supply-chain interruptions, geopolitical unrest, technological rivalry, and vital mineral dependencies. Additionally, the study aims to investigate the strategic significance of semiconductors in national security, defense, economic development, and technical innovation. Furthermore, it explores how nations, businesses, and technological capacities are evolving in the global semiconductor market. The report is to provide a thorough understanding of the elements influencing global semiconductor competitiveness and resilience by analyzing emerging possibilities, future trends, and strategic approaches adopted by various countries.

1.4 Significance of the Study

This study is significant because it contributes to the understanding of the semiconductor industry, which is one of the most important and strategically significant industries in the modern world. Semiconductors serve as the foundation of numerous technologies, including computers, smartphones, communication systems, artificial intelligence, automobiles, medical equipment, and defence systems. As the global economy becomes increasingly dependent on digital technologies, understanding the semiconductor ecosystem has become essential for researchers, policymakers, industry stakeholders, and students. By examining issues such as supply-chain vulnerabilities, technological competitiveness, critical resource dependencies, and global interdependence, this study provides insights into the economic, technological, geopolitical, and strategic dimensions of the semiconductor industry. The findings of the study may contribute to discussions on technological competitiveness, industrial resilience, and long-term sustainability within the global semiconductor ecosystem and enhance understanding of the opportunities and challenges associated with semiconductor development.

Chapter 2: Conceptual Background of the Semiconductor Ecosystem

2.1 Meaning of Semiconductors

Semiconductors are materials whose electrical conductivity lies between that of conductors, such as copper, and insulators, such as glass or rubber. Their conductivity can be controlled by introducing impurities or by changing external conditions such as temperature or voltage, making them ideal for manufacturing electronic components. The most commonly used semiconductor material is silicon because of its abundance, reliability, and ability to support large-scale chip production (Sze & Ng, 2021). Semiconductors are primarily used to manufacture integrated circuits (ICs), commonly known as semiconductor chips or microchips. These chips contain millions or even billions of microscopic transistors that perform logical operations, process information, store data, and control the functioning of electronic systems. Owing to these capabilities, semiconductor chips are often referred to as the "brains" of modern electronic devices. They enable computers to process data, smartphones to perform multiple functions, and communication systems to transmit information efficiently (Sze & Ng, 2021).

Today, semiconductors are indispensable across a wide range of industries. Consumer electronics such as laptops, smartphones, and televisions rely on semiconductor chips for computing and connectivity. The automotive sector uses semiconductors in engine control systems, safety technologies, navigation, and electric vehicles. In healthcare, semiconductor devices are integrated into medical equipment such as MRI scanners, CT scanners, and patient-monitoring systems. They also play an essential role in defence technologies, satellite systems, telecommunications, and industrial automation. As this research focuses on the economic and strategic importance of the semiconductor ecosystem, the technical aspects of semiconductor engineering are not discussed in detail (Organisation for Economic Co-operation and Development [OECD], 2025).

2.2 Importance of Semiconductors in the Global Economy

Semiconductors have become one of the most important drivers of the modern global economy because they support nearly every major industrial sector. Industries such as consumer electronics, automobiles, telecommunications, healthcare, defence, and renewable energy depend on semiconductor chips to perform essential computing, sensing, communication, and control functions. Their widespread application has made semiconductors a critical component of digital transformation and industrial development worldwide (OECD, 2024).

The demand for semiconductor chips has increased significantly over the past decade due to the rapid growth of emerging technologies. Artificial intelligence (AI) requires powerful processors capable of handling complex computations, while cloud computing relies on high-performance data centres equipped with advanced semiconductor devices. Similarly, the expansion of fifth-generation (5G) communication networks, the Internet of Things (IoT), smart devices, and electric vehicles has accelerated global demand for specialised chips that offer greater processing power, connectivity, and energy efficiency. This growing dependence has made semiconductor manufacturing one of the world's most strategically important industries (Semiconductor Industry Association [SIA], 2024).

The global semiconductor shortage experienced during and after the COVID-19 pandemic demonstrated the industry's critical role in economic activity. Disruptions in chip production affected automobile manufacturing, consumer electronics, medical equipment, and telecommunications, leading to production delays and financial losses across multiple industries. These events highlighted the vulnerability of global supply chains and emphasised the importance of building resilient semiconductor ecosystems (Haramboure et al., 2023).

As countries increasingly adopt digital technologies and advanced manufacturing, access to semiconductor chips has become closely linked to economic growth, industrial competitiveness, and technological leadership. Governments around the world are investing heavily in semiconductor research, manufacturing capacity, and supply chain resilience to strengthen national competitiveness and reduce dependence on external suppliers. Consequently, semiconductors are now regarded not only as technological products but also as strategic assets that influence economic development and national security (OECD, 2025).

2.3 Semiconductor Value Chain

The semiconductor value chain refers to the series of interconnected activities involved in developing and delivering semiconductor chips to end users. It begins with research and development (R&D), where new materials, manufacturing techniques, and chip architectures are created. This is followed by chip design, in which engineers develop the blueprint of integrated circuits using specialised software. The next stage is wafer fabrication, where microscopic transistors are manufactured on silicon wafers in advanced fabrication facilities. After fabrication, the chips undergo assembly, testing, and packaging to ensure they function correctly and are protected for integration into electronic products. The final stage involves distributing finished semiconductor chips to manufacturers of computers, smartphones, automobiles, medical devices, and other electronic equipment (Organisation for Economic Co-operation and Development [OECD], 2025).

Each stage of the semiconductor value chain requires significant financial investment, cutting-edge technology, and a highly skilled workforce. Semiconductor fabrication plants are among the most expensive manufacturing facilities in the world, often costing billions of dollars to establish and operate. Companies must also invest continuously in research, specialised equipment, and workforce training to remain technologically competitive. These high entry barriers make the semiconductor industry one of the most capital-intensive sectors globally (Boston Consulting Group [BCG] & Semiconductor Industry Association [SIA], 2021).

Different countries specialise in different stages of the value chain, creating a highly interconnected global ecosystem. The United States leads in semiconductor research and chip design, Taiwan dominates advanced fabrication, South Korea is a global leader in memory chips, Japan supplies essential semiconductor materials and chemicals, and the Netherlands manufactures advanced lithography equipment through ASML. Since no single country controls every stage of production, semiconductor manufacturing depends on international cooperation and efficient global trade. This interdependence makes the ecosystem highly productive but also difficult to replace quickly when disruptions occur, highlighting the importance of resilient and diversified value chains (OECD, 2025).

2.4 Semiconductor Supply Chain

The semiconductor supply chain refers to the movement of raw materials, specialised equipment, semiconductor wafers, integrated circuits, and finished electronic products from suppliers to manufacturers and finally to consumers. Unlike the value chain, which focuses on the stages of production, the supply chain emphasises the flow of materials and components required to manufacture semiconductor chips. Since semiconductor production involves numerous suppliers and manufacturing facilities located across different countries, the supply chain is both extensive and highly interconnected (Haramboure et al., 2023).

Semiconductor manufacturing depends on a wide range of specialised inputs, including ultra-pure silicon wafers, rare minerals, industrial gases, advanced chemicals, precision manufacturing equipment, and sophisticated logistics networks. Equipment such as lithography machines, etching systems, and deposition tools is produced by only a small number of highly specialised companies worldwide. As a result, semiconductor manufacturers rely heavily on timely deliveries of materials and machinery to maintain uninterrupted production (Semiconductor Industry Association [SIA], 2024).

Disruptions in any part of the semiconductor supply chain can have widespread consequences for industries around the world. Delays in the supply of raw materials, transportation bottlenecks, natural disasters, geopolitical tensions, or factory shutdowns can interrupt chip production and reduce the availability of electronic products. The global semiconductor shortage following the COVID-19 pandemic demonstrated how supply chain disruptions affected automobile production, consumer electronics, healthcare equipment, and communication technologies. Consequently, governments and businesses are increasingly focusing on supply-chain resilience by diversifying suppliers, increasing domestic manufacturing capacity, and strengthening international cooperation to reduce future risks (OECD, 2024; Haramboure et al., 2023).

2.5 Global Interdependence in Semiconductors

The semiconductor industry is characterised by a high degree of global interdependence, as no single country possesses the capabilities or resources to control the entire semiconductor ecosystem. The development and production of semiconductor chips involve multiple stages, including research, design, manufacturing, packaging, testing, and distribution, each of which is concentrated in different regions of the world. This international division of labour has enabled countries to specialise in areas where they possess technological expertise and competitive advantages, making semiconductor production one of the most globally integrated industries (Organisation for Economic Co-operation and Development [OECD], 2025).

Different countries play distinct roles within the semiconductor ecosystem. The United States is a global leader in semiconductor research, chip design, electronic design automation (EDA) software, and intellectual property. Taiwan dominates advanced semiconductor fabrication through Taiwan Semiconductor Manufacturing Company (TSMC), while South Korea leads the global memory chip market through companies such as Samsung Electronics and SK Hynix. Japan is recognised for its production of high-purity semiconductor materials, specialty chemicals, and manufacturing equipment, whereas the Netherlands occupies a unique position through ASML, the world's only manufacturer of advanced extreme ultraviolet (EUV) lithography systems required for producing the most sophisticated semiconductor chips (Boston Consulting Group [BCG] & Semiconductor Industry Association [SIA], 2021).

China has significantly increased its investment in the semiconductor sector with the objective of reducing its dependence on foreign technology and strengthening domestic manufacturing capabilities. Through initiatives such as the "Made in China 2025" strategy and substantial government funding, China has expanded its semiconductor manufacturing, packaging, testing, and design capacities. Despite these efforts, the country continues to face challenges in producing the world's most advanced chips due to restrictions on access to cutting-edge manufacturing equipment and advanced semiconductor technologies (OECD, 2025).

India is emerging as an important participant in the global semiconductor ecosystem. Although the country currently has limited semiconductor manufacturing capacity, it has established itself as a major centre for semiconductor design, software development, and engineering talent. Several multinational semiconductor companies operate large design and research centres in India, benefiting from its highly skilled workforce. In addition, government initiatives such as the India Semiconductor Mission are encouraging investments in semiconductor fabrication, assembly, testing, and packaging facilities. These developments position India as a promising future player capable of contributing to global semiconductor manufacturing and strengthening supply-chain resilience. As semiconductor technologies become increasingly important for economic growth and national security, international collaboration among countries will remain essential for maintaining a stable and innovative semiconductor ecosystem (Ministry of Electronics and Information Technology [MeitY], 2023; OECD, 2025).

Chapter 3: Semiconductor Supply-Chain Challenges and Disruptions

3.1 Complexity of Semiconductor Supply Chains

Semiconductor supply chains are among the most complex industrial supply chains because the production of a single chip involves numerous companies, countries, specialised inputs, and highly technical processes. The process extends from the supply of raw materials and manufacturing equipment to chip design, fabrication, assembly, testing, packaging, and distribution. OECD (2025) describes the semiconductor ecosystem as highly interconnected, with production processes distributed across different economies and critical inputs concentrated in particular regions. This means that semiconductor manufacturers often depend on suppliers located thousands of kilometres away.

The complexity is further increased by the specialised resources required for chip manufacturing. Semiconductor fabrication requires advanced machinery, highly controlled clean-room environments, specialised chemicals, ultra-pure materials, and a highly skilled workforce. Some integrated circuits can require hundreds or even more than a thousand individual production processes before they become finished chips. The OECD (2025) notes that semiconductor production can involve more than a thousand processes and may depend on hundreds of specialised chemicals. These requirements make semiconductor production difficult to establish and reproduce in new locations.

Another important characteristic is the long and interconnected nature of production cycles. A disruption affecting one supplier or production stage may not immediately appear as a problem but can eventually delay the availability of finished chips. Research by Haramboure et al. (2023) shows that semiconductor supply disruptions can create significant downstream effects because chips are essential inputs for industries such as electronics, telecommunications, automobiles, and machinery. Similarly, research on semiconductor supply-chain complexity highlights the industry's highly differentiated products, long production cycles, and unpredictable demand as important sources of management difficulty (Wang et al., 2016).

Therefore, the complexity of semiconductor supply chains creates both efficiency and vulnerability. Global specialisation allows countries and companies to focus on areas where they have technological advantages, but it also makes the system difficult to manage and protect from disruptions. A disruption involving a specialised supplier, manufacturing facility, transport route, or critical input can potentially affect production across multiple countries and industries. As a result, understanding this complexity is essential for developing strategies aimed at improving the resilience and security of the global semiconductor ecosystem.

3.2 Causes of Semiconductor Shortages

Semiconductor shortages can arise when demand for chips increases faster than manufacturers are able to expand production. In recent years, the rapid growth of electronics, automobiles, artificial intelligence (AI), and cloud computing has placed additional pressure on semiconductor supply. During the COVID-19 pandemic, demand for computers, networking equipment, and other electronic devices increased as remote work and online activities became more common. OECD (2023) notes that this sudden increase in demand for information and communication technology products contributed to a shortage because semiconductor production could not adjust quickly enough to meet the new level of demand.

The COVID-19 pandemic also created major disruptions on the supply side. Factory shutdowns, restrictions on movement, labour shortages, transportation problems, and delays in international logistics affected semiconductor production and distribution. At the same time, manufacturers had to respond to rapidly changing patterns of consumer demand. Haramboure et al. (2023) explain that these demand and supply shocks created significant imbalances in the semiconductor market, with the automotive industry being particularly affected. Automobile manufacturers had reduced orders for chips during the early stages of the pandemic, but when vehicle demand recovered, semiconductor producers had already allocated capacity to other industries.

The problem was further intensified by the geographical concentration of semiconductor production and increasing trade restrictions. OECD (2024) highlights that the semiconductor value chain is highly concentrated, meaning that disruptions in a small number of important production hubs can have effects across international markets. Trade restrictions, geopolitical tensions, and limitations on access to certain technologies and equipment can therefore make it more difficult for companies to obtain alternative supplies. Because advanced semiconductor manufacturing requires specialised facilities and equipment, production cannot easily be shifted from one location to another in the short term.

The effects of these shortages extended far beyond semiconductor manufacturers themselves. The automobile industry experienced production delays because vehicles require large numbers of semiconductor components, while shortages also affected smartphones, gaming consoles, computers, and other consumer electronics. According to the OECD (2023), semiconductor shortages can generate ripple effects across downstream industries because chips are essential intermediate inputs. The experience of the COVID-19 period therefore demonstrated that semiconductor shortages are not simply a problem for the technology industry; they can disrupt manufacturing activity across the wider global economy. This has encouraged governments and businesses to focus increasingly on supply-chain diversification, domestic production capacity, and greater resilience against future disruptions.

3.3 Impact of Public Health Events

The COVID-19 pandemic demonstrated how public health emergencies can disrupt semiconductor production and expose weaknesses in globally interconnected supply chains. Manufacturing facilities in several countries faced temporary closures or restrictions, while transportation networks experienced delays and reduced capacity. Since semiconductor production involves multiple stages across different locations, disruptions at one point could affect subsequent stages of production. Haramboure et al. (2023) explain that the semiconductor shortages during this period resulted from a combination of supply and demand shocks, which were amplified by the industry's geographically concentrated production structure.
At the same time, the pandemic significantly changed patterns of consumer demand. The expansion of remote work and online education increased the need for laptops, computers, networking equipment, and other digital devices. Digital entertainment also became more important as people spent more time at home, increasing demand for gaming consoles and other electronic products. Research by Azhari et al. (2020) found that increased use of electronic products for work, education, and leisure placed additional pressure on global manufacturing and technology-related supply chains.
A major difficulty for semiconductor companies was predicting how long these changes in demand would continue. At the beginning of the pandemic, many businesses expected economic activity and demand for certain products to decline, leading some manufacturers to reduce or modify their orders for semiconductor components. However, demand for electronics subsequently increased sharply, creating an imbalance between available production capacity and market requirements. The *Global Semiconductor Chip Shortage* study similarly identifies the combination of changing demand patterns and existing weaknesses within the semiconductor supply chain as important factors that intensified shortages (Singh et al., 2022).
The experience of COVID-19 therefore highlighted the need for semiconductor supply chains that are more flexible and resilient. Instead of depending heavily on a limited number of suppliers or production locations, companies and governments have increasingly considered strategies such as supplier diversification, improved supply-chain monitoring, additional production capacity, and stronger international cooperation. OECD (2023) argues that understanding dependencies within global value chains is essential for reducing the economic effects of future disruptions. Public health events can therefore be viewed as an important lesson for building a semiconductor ecosystem capable of responding more effectively to unexpected shocks.

3.4 Security Risks in Semiconductor Supply Chains

Semiconductor supply chains face several security risks because chips are used in systems that are essential to economic activity, communication, and national security. One major risk is the introduction of counterfeit or unauthorised components into supply chains. Counterfeit chips may not meet required quality or reliability standards and can therefore create serious problems when incorporated into critical systems. The Cybersecurity and Infrastructure Security Agency (CISA, 2024) identifies counterfeit components as an important supply-chain security concern, particularly when disruptions make organisations more dependent on unfamiliar or alternative suppliers.

Cyberattacks are another growing concern. Semiconductor companies depend heavily on digital systems for chip design, manufacturing, logistics, and communication with suppliers. A successful cyberattack could disrupt production, compromise sensitive information, or interfere with the operation of critical infrastructure. CISA has highlighted that vulnerabilities within technology supply chains can potentially result in data theft, manipulation, malware distribution, and reliability problems. Technology theft and unauthorised access to intellectual property are also significant concerns because semiconductor companies invest heavily in research and development, and access to advanced designs and manufacturing knowledge can provide major economic and strategic advantages.

The importance of semiconductor security becomes even greater when chips are used in critical sectors such as defence, telecommunications, banking, energy, transportation, and digital infrastructure. A disruption or compromise affecting semiconductor-based systems in these sectors could have consequences beyond individual companies. OECD (2023) notes that semiconductor shortages can create ripple effects across downstream industries because of the widespread dependence on semiconductor products.

Foreign dependence can further increase national security concerns when a country relies heavily on external suppliers for critical chips, manufacturing equipment, or materials. This has encouraged governments to treat semiconductor supply-chain security as a policy priority. The Semiconductor Industry Association (SIA, 2026) emphasises the importance of building secure and diversified semiconductor supply chains, while OECD (2024) argues that resilience requires governments and businesses to identify vulnerabilities and prepare for different types of disruptions. Consequently, semiconductor policy is increasingly focused not only on increasing production but also on protecting the security, reliability, and strategic independence of critical supply chains.

3.5 Need for Supply-Chain Resilience

The disruptions experienced during the COVID-19 pandemic and subsequent geopolitical tensions have encouraged countries to reconsider their dependence on a limited number of suppliers and production locations. High geographical concentration within the semiconductor industry means that disruptions in one important region can affect manufacturers and consumers worldwide. OECD (2025) highlights that identifying critical dependencies within semiconductor value chains is increasingly important for governments seeking to reduce vulnerabilities and maintain access to essential technologies.

One major strategy for improving resilience is to develop greater domestic manufacturing capacity. Countries are providing financial incentives, infrastructure support, and research funding to attract semiconductor production and strengthen local capabilities. However, resilience does not necessarily mean producing every semiconductor component domestically. Instead, countries can combine domestic capacity with trusted international partnerships, allowing them to maintain access to specialised technologies and inputs while reducing excessive dependence on any single supplier or region. The OECD (2024) emphasises that diversification and international cooperation can be more effective than complete economic self-sufficiency.

Another important approach is supply-chain mapping, which allows governments and companies to identify critical suppliers, geographical concentrations, and potential points of failure. Strategic reserves of essential materials and components can also provide temporary protection when unexpected disruptions occur. These measures allow organisations to respond more quickly to supply shortages rather than reacting only after a crisis has already developed.

India has increasingly incorporated supply-chain resilience into its semiconductor policy direction. Through the India Semiconductor Mission and government incentives for semiconductor manufacturing and packaging, India is seeking to develop domestic capabilities while becoming a reliable participant in global supply chains. The Ministry of Electronics and Information Technology (MeitY, 2023) identifies semiconductor manufacturing and related capabilities as important for strengthening India's technological and economic position. India's objective is therefore not complete self-sufficiency, but greater domestic capability combined with participation in diversified global semiconductor networks.

Chapter 4: Geopolitical Competition and the Semiconductor Industry

4.1 Semiconductors as a Strategic Technology

Semiconductors have evolved from being primarily commercial products into technologies with significant economic, political, and national-security importance. Their importance comes from their role as essential components in many advanced technologies, including artificial intelligence (AI), telecommunications, defence systems, cyber infrastructure, and advanced manufacturing. As digital technologies become increasingly integrated into economies and government systems, access to reliable and advanced semiconductor technology has become an important strategic consideration. The OECD (2024) notes that semiconductors are essential to modern economies and that disruptions in their supply can create significant economic risks.

The connection between semiconductors and national security is particularly strong because modern defence systems depend heavily on advanced computing and electronic technologies. Semiconductors are used in communication systems, sensors, navigation technologies, computing platforms, and other defence-related applications. Shivakumar and Wessner (2022) argue that the performance of major defence systems is closely connected to access to advanced microelectronics, making semiconductor capabilities an important component of national defence.

Semiconductors are also central to the development of AI and other emerging technologies. Advanced AI systems require powerful computing infrastructure, which depends on sophisticated semiconductor processors. Consequently, countries that maintain strong capabilities in semiconductor design, manufacturing, and related technologies can gain advantages in technological innovation and economic competitiveness. CSIS (2021) further explains that the limited production capacity of advanced semiconductors can create strategic leverage for countries and companies possessing these capabilities.

As a result, semiconductor leadership is increasingly viewed as a source of national power. Governments are investing in domestic manufacturing, research, talent, and supply-chain security while also introducing policies to protect strategically important technologies. The competition surrounding semiconductors therefore extends beyond commercial markets and reflects a broader contest over technological leadership, economic strength, and national security.

4.2 US-China Technology Competition

The United States and China are engaged in an increasingly important competition for leadership in advanced technologies, with semiconductors at the centre of this rivalry. Semiconductor capabilities are essential for artificial intelligence (AI), advanced computing, telecommunications, defence applications, and other digital technologies. As a result, technological leadership in semiconductor design, manufacturing, and related equipment can provide significant economic and strategic advantages. CSIS (2025) describes the competition as closely connected to the future development of AI and the broader technological balance between the two countries.

The United States has attempted to protect its technological advantage by restricting China's access to certain advanced semiconductor chips, manufacturing equipment, and design technologies. These restrictions began expanding significantly from 2022 and have subsequently been strengthened. OECD (2025) notes that U.S. policies have increasingly focused on limiting China's access to advanced semiconductor technologies while also encouraging greater domestic semiconductor production in the United States.

China, meanwhile, has responded by increasing investment in domestic semiconductor capabilities and attempting to reduce its dependence on foreign technologies. CSIS (2026) reports that U.S. and allied export controls have accelerated China's efforts to localise semiconductor design, manufacturing, equipment, and materials. This demonstrates that both countries are seeking greater technological independence, although neither can easily separate itself from the wider global semiconductor ecosystem. The rivalry has consequently affected global trade, investment, and technology partnerships. Companies operating internationally must increasingly consider export controls, investment restrictions, and geopolitical risks when making decisions about production and technology cooperation. At the same time, countries such as Japan, South Korea, Taiwan, and European economies have become increasingly important to the strategic competition because of their roles in semiconductor manufacturing, equipment, and materials. Therefore, US-China competition is not simply a bilateral technological rivalry; it is influencing the structure and direction of the global semiconductor industry.

4.3 US-China Semiconductor Trade Dispute

The semiconductor trade dispute between the United States and China has developed into a major component of their broader technological rivalry. The United States has increasingly used export controls, investment restrictions, and technology-related measures to limit China's access to advanced semiconductor technologies. These measures are intended particularly to restrict technologies that could support advanced artificial intelligence, high-performance computing, and military capabilities. The Congressional Research Service (2025) notes that U.S. controls have expanded from restrictions on individual companies to broader controls covering advanced chips, semiconductor manufacturing equipment, electronic design automation tools, and related technologies.

The restrictions have significant consequences for semiconductor companies and global supply chains. Companies that operate across multiple countries must comply with changing export regulations and may face limitations on selling certain products, equipment, or technologies to Chinese customers. OECD (2025) explains that restrictions on advanced semiconductor exports have also encouraged governments and companies to reconsider the geographical organisation of semiconductor production. The United States has additionally used the CHIPS and Science Act to support domestic semiconductor manufacturing while placing conditions on certain investments and expansions involving countries considered national-security concerns.

China has responded by increasing investment in domestic semiconductor capabilities and attempting to reduce its reliance on foreign technology. This includes expanding domestic chip design and manufacturing, developing semiconductor equipment and materials, and supporting local companies. According to Shivakumar et al. (2026), U.S. and allied export controls have accelerated China's existing drive toward greater semiconductor self-reliance and increased efforts to develop indigenous alternatives. The dispute therefore extends beyond trade in individual semiconductor products. It is reshaping investment decisions, technology partnerships, and the geographical structure of global supply chains. While the United States seeks to protect its technological advantages and national-security interests, China is attempting to strengthen its domestic capabilities and reduce exposure to external restrictions. This competition has consequently made semiconductor technology an important instrument of economic and geopolitical policy.

4.4 Semiconductor Competition as a New Cold War

The growing rivalry between the United States and China has led some scholars and policy analysts to describe the competition over advanced technology as a "new technological Cold War." Unlike the traditional Cold War, however, the present competition is largely centred on technological capabilities, economic influence, and control over critical supply chains. Semiconductors are at the centre of this rivalry because they provide the technological foundation for artificial intelligence, 5G communications, advanced computing, defence systems, and other emerging technologies. The European Council on Foreign Relations identifies AI, cloud computing, semiconductors, 5G, and quantum technology as major areas of contemporary U.S.–China technological competition.

Semiconductor competition is therefore closely connected with the wider race for technological leadership. Advanced chips enable countries and companies to develop more powerful AI systems, sophisticated communication networks, and increasingly capable computing technologies. The Congressional Research Service (2023) similarly identifies semiconductors as fundamental to AI, autonomous systems, 5G communications, quantum computing, and national-security applications.

This rivalry is also reshaping international alliances and trade policies. Countries are increasingly working with trusted partners to strengthen semiconductor supply chains and reduce dependence on geopolitical rivals. Yoon (2023) discusses the development of the "Fab 4" framework involving the United States, Japan, South Korea, and Taiwan as an example of efforts to strengthen semiconductor supply-chain cooperation. At the same time, countries such as Japan, South Korea, Taiwan, and members of the European Union are attempting to balance cooperation with the United States against their own economic interests and technological autonomy.

Consequently, semiconductor competition is contributing to a gradual restructuring of global technology and trade relationships. Rather than complete separation between countries, the emerging pattern involves selective cooperation, technology restrictions, strategic partnerships, and efforts to diversify supply chains. The semiconductor industry has therefore become an important arena through which countries seek to protect economic interests while strengthening their technological and strategic position

4.5 Implications for India

The growing technological competition between the United States and China creates both risks and opportunities for India. On the risk side, India's continued dependence on imported semiconductor components and manufacturing inputs makes it vulnerable to disruptions in international supply chains. Geopolitical tensions, export restrictions, or shortages in major semiconductor-producing regions could increase costs and make it more difficult for Indian industries to obtain critical chips. OECD (2025) highlights that the concentration of semiconductor production and critical inputs in a limited number of economies creates vulnerabilities for countries that depend on international suppliers.

At the same time, the restructuring of global supply chains provides India with an opportunity to attract investment and become an alternative manufacturing and supply-chain location. The "China Plus One" approach, in which companies diversify production beyond China, can create opportunities for India to attract electronics and semiconductor-related investments. India's large workforce, growing electronics industry, and expanding design capabilities can support this transition. MeitY (2025) states that the

Electronics Component Manufacturing Scheme aims to attract both domestic and global investment while integrating Indian companies with global value chains.

India is also attempting to strengthen its position through the India Semiconductor Mission (ISM). OECD (2026) notes that the mission aims to develop India's semiconductor and display ecosystem while supporting semiconductor design and creating a secure supply chain involving materials, chemicals, gases, and manufacturing equipment. These initiatives indicate that India is seeking to move beyond its traditional strength in semiconductor design and engineering talent toward greater participation in manufacturing, assembly, testing, and packaging.

Therefore, the US-China semiconductor rivalry can provide India with an opportunity to position itself as a reliable and diversified partner in global semiconductor networks. However, achieving this position will require continued investment in infrastructure, skilled talent, research and development, domestic components, and stable policy. India's long-term advantage is likely to come not from complete self-sufficiency, but from becoming an important and trusted participant in a more diversified global semiconductor ecosystem.

5.1 Importance of Critical Minerals in Semiconductor Manufacturing

Semiconductor manufacturing depends on a range of specialised raw materials and minerals that support different stages of production. Although silicon is the most widely recognised material associated with semiconductors, the industry also requires other minerals, metals, gases, and chemical inputs for chip fabrication, packaging, equipment, and electronic components. Materials such as gallium, germanium, tungsten, cobalt, copper, and certain rare earth elements can play important roles in semiconductor-related applications. The U.S. Geological Survey (USGS, 2025) identifies several of these materials as strategically important because they have applications in advanced electronics and are subject to supply risks.

These resources are required not only for manufacturing semiconductor devices but also for producing the specialised equipment used in fabrication. Advanced semiconductor production involves highly precise machinery, materials, and chemicals, meaning that shortages of even a relatively small quantity of a critical input can affect production. The OECD (2025) highlights that semiconductor value chains contain several points of geographical concentration, including the supply of certain specialised materials and inputs. This makes access to reliable mineral supplies an important consideration for countries seeking to expand semiconductor manufacturing.

Mineral availability can therefore directly influence a country's ability to develop semiconductor production capacity. Countries with limited domestic resources may need to rely on imports, long-term supply agreements, or partnerships with mineral-producing economies. Export restrictions or disruptions in major mineral-producing regions can consequently create additional risks for semiconductor manufacturers.

This demonstrates that semiconductor competitiveness is not determined by technological capabilities alone. Access to secure, affordable, and reliable resources is equally important. The International Energy Agency (IEA, 2024) emphasises that increasing demand for clean-energy and advanced technologies is placing greater attention on the security and geographical concentration of critical mineral supplies. For the semiconductor industry, strengthening resource security alongside technological capabilities can therefore contribute to more resilient production and reduce vulnerability to external supply disruptions.

5.2 Key Minerals Used in Semiconductors

Semiconductor manufacturing relies on a diverse range of minerals and specialised materials, with differrent materials serving different technological and industrial purposes. Silicon remains the most important semiconductor material because of its widespread use in integrated circuits and its suitability for large-scale chip manufacturing. However, advanced semiconductor and electronic applications also require materials such as gallium, germanium, indium, tantalum, palladium, cobalt, and arsenic. The U.S. Geological Survey (USGS, 2025) identifies several of these materials as critical to modern technologies because of their importance and potential supply risks.

Gallium and arsenic are particularly important for certain compound semiconductors used in high-frequency communications, radio-frequency applications, and specialised electronics. Germanium can be used in semiconductor and fibre-optic applications, while indium is important in electronic displays and other advanced technologies. Tantalum is used in electronic components such as capacitors, whereas cobalt has applications in electronics and battery technologies. Palladium is also used in electronic components and manufacturing processes. Rare earth elements, meanwhile, have applications across advanced electronics, magnets, displays, and other high-technology products. The International Energy Agency (IEA, 2024) highlights that these materials are increasingly important across a range of advanced technologies, while their supply chains can be highly geographically concentrated.

An important challenge is that many of these materials cannot be easily substituted without affecting cost, performance, or manufacturing processes. Some are also produced as by-products of mining other minerals, which limits the ability to rapidly increase their supply. The OECD (2025) notes that concentration in the production and processing of critical materials can create vulnerabilities for industries that depend on them.

Secure access to these minerals is therefore important for the long-term growth of the semiconductor industry. Countries seeking to expand semiconductor manufacturing must consider not only investment in fabrication facilities and technological capabilities but also the availability of essential raw materials. Developing diversified sources, recycling capabilities, international partnerships, and alternative materials can help reduce these risks and strengthen the resilience of semiconductor supply chains.

5.3 Global Concentration of Critical Mineral Supply

The global supply of critical minerals is highly concentrated, with a relatively small number of countries controlling a significant share of mining, processing, or refining for several important materials. This concentration is particularly important for the semiconductor industry because access to specialised minerals can influence the availability and cost of essential inputs. The International Energy Agency (IEA, 2024) highlights that the supply chains for many critical minerals are more geographically concentrated than those of conventional energy resources, creating potential vulnerabilities for industries that depend on them.

For countries that rely heavily on imports, this concentration creates a significant supply risk. A disruption caused by political instability, natural disasters, trade restrictions, transportation problems, or changes in export policies can reduce the availability of a particular mineral in international markets. The OECD (2025) notes that geographical concentration in critical material supply chains can create dependencies that become particularly problematic when alternative suppliers are limited.

Supply disruptions can also have direct economic consequences. When the availability of a critical mineral falls while demand remains high, prices can increase, raising the cost of production for companies that use the material. If the disruption continues, manufacturers may face difficulties obtaining sufficient inputs, potentially resulting in production delays. For semiconductor manufacturers, such delays can have wider consequences because chips are intermediate inputs used across electronics, automobiles, telecommunications, defence, and other industries.

The concentration of mineral supply can therefore provide producing countries with **strategic** influence over global technology supply chains. Countries that control significant mining or processing capacity may have greater bargaining power in international trade and can influence the availability of important resources through export policies. The IEA (2024) argues that diversification of mineral supply chains is increasingly important because high concentration can expose economies to unexpected disruptions. Consequently, securing multiple sources of critical minerals has become an important part of technological and economic security, alongside investment in semiconductor manufacturing itself.

5.4 China's Role in Critical Minerals

China occupies a particularly important position in the global critical-mineral supply chain, especially in the processing and refining of several minerals and materials used by advanced industries. While mining may take place in different countries, China has developed substantial refining and processing capacity, giving it influence over the availability of processed materials. The International Energy Agency (IEA, 2024) reports that China is the leading refiner for many critical minerals, including rare earth elements, gallium, germanium, and graphite. This makes China's role different from simply being a major mining country; its strength also lies in converting raw materials into forms suitable for industrial use.

This position creates strategic concerns for countries attempting to develop more independent semiconductor ecosystems. Building a semiconductor fabrication facility requires reliable access not only to advanced equipment and technology but also to specialised materials and processed minerals. Consequently, countries may reduce their dependence on foreign semiconductor manufacturing while still remaining dependent on foreign mineral processing. The OECD (2025) highlights that vulnerabilities can exist at different stages of semiconductor and critical-material value chains, meaning that domestic production in one stage does not automatically eliminate external dependencies.

China's control over important processing capabilities has also become a geopolitical concern because export restrictions and supply controls can affect international markets. In recent years, China has introduced export-control measures affecting materials such as gallium and germanium, demonstrating how critical minerals can become connected to broader trade and technology disputes. The U.S. Geological Survey (USGS, 2025) identifies China as a major global supplier of several critical minerals and notes the importance of its role in international mineral markets.

Therefore, dependence on Chinese mineral processing is increasingly viewed through the wider lens of economic and national security. Countries seeking resilient semiconductor ecosystems are exploring strategies such as developing alternative suppliers, increasing domestic processing, recycling critical materials, and establishing partnerships with resource-rich countries. This demonstrates that semiconductor security extends beyond chip factories and technological capabilities; it also depends on securing the upstream mineral resources and processing capacity required to sustain advanced technology industries.

Chapter 6: India's Semiconductor Ecosystem

6.1 Historical Context of India's Semiconductor Industry

India has had considerable scientific and engineering capabilities for several decades, particularly in electronics, information technology, and engineering research. However, these strengths did not translate into the development of a large-scale semiconductor manufacturing industry. India's early semiconductor efforts were largely driven by the government and public-sector institutions, with organisations such as the Semiconductor Complex Limited (SCL) established in Mohali in 1983 to develop domestic semiconductor manufacturing capabilities. These initiatives demonstrated India's interest in developing an indigenous semiconductor base, but their scale remained limited compared with the rapidly expanding semiconductor industries of other countries.

Several factors contributed to India's slower progress. Semiconductor manufacturing requires extremely high capital investment, specialised infrastructure, reliable utilities, advanced equipment, and continuous technological upgrades. India's limited financial resources for large-scale fabrication, infrastructure constraints, and dependence on foreign technology made it difficult to compete with countries that were investing aggressively in semiconductor production. According to the Ministry of Electronics and Information Technology (MeitY, 2022), India's semiconductor ecosystem historically developed more strongly around chip design and engineering services than around large-scale fabrication.

The difference becomes clearer when India is compared with countries such as Taiwan, South Korea, China, and the United States. Taiwan and South Korea developed strong semiconductor industries through sustained government support, large corporate investments, export-oriented strategies, and integration into global supply chains. The United States maintained leadership in semiconductor research, design, and technology, while China increasingly invested in domestic manufacturing to reduce technological dependence. OECD (2025) highlights how countries that successfully developed semiconductor capabilities benefited from specialised industrial ecosystems and long-term investment.

India therefore entered the semiconductor manufacturing race relatively late. Nevertheless, its established pool of engineering talent and experience in semiconductor design provide a foundation for future growth. Recent government initiatives indicate a shift from primarily supporting design capabilities toward developing a broader ecosystem covering fabrication, assembly, testing, packaging, and related manufacturing activities. This historical background is important for understanding both the challenges India faces and the opportunities created by its current semiconductor policy.

6.2 Current State of India’s Semiconductor Ecosystem

India’s semiconductor ecosystem is currently stronger in chip design, engineering services, and related software capabilities than in large-scale semiconductor fabrication. Over the years, India has developed a substantial pool of engineers working in areas such as integrated circuit design, verification, embedded systems, and electronic design automation. Many global semiconductor companies operate design and research centres in India, allowing the country to play an important role in the global semiconductor design ecosystem. The India Semiconductor Mission (ISM) highlights India's skilled workforce and established design capabilities as important strengths for the future development of the sector.

India also benefits from a large technology talent pool, strong software industry, expanding electronics market, and increasing government support. These factors create favourable conditions for developing a broader semiconductor ecosystem. However, manufacturing advanced chips requires capabilities beyond engineering talent, including large investments, specialised infrastructure, reliable supplies of materials and equipment, and highly sophisticated fabrication facilities.

In recent years, India has shown growing interest in developing domestic capabilities across semiconductor manufacturing, assembly, testing, and packaging. Through the Semicon India Programme and the India Semiconductor Mission, the government is encouraging investment in semiconductor fabrication facilities and outsourced semiconductor assembly and test (OSAT) and packaging projects.

MeitY (2024) emphasises that these initiatives are intended to develop a more comprehensive semiconductor and display ecosystem within the country.

Despite this progress, India remains in the relatively early stages of building a complete semiconductor ecosystem. The country is seeking to expand from its traditional strengths in design and engineering into manufacturing and other stages of the value chain. OECD (2025) highlights that a successful semiconductor ecosystem requires coordination across multiple interconnected activities, from design and materials to fabrication, equipment, packaging, and distribution. India's long-term progress will therefore depend on its ability to strengthen these different stages while attracting sustained investment and integrating with global supply chains.

6.3 India’s Strength in Semiconductor Design

India's strongest position within the semiconductor ecosystem currently lies in chip design, engineering, and related software capabilities. Many major global semiconductor companies have established design and research operations in India, benefiting from the country's large pool of engineers and technical professionals. These centres contribute to activities such as integrated-circuit design, verification, validation, embedded systems, and semiconductor-related software development. According to MeitY (2022), India has developed significant capabilities in semiconductor design and has become an important location for global semiconductor design and engineering activities.

India's engineering talent is particularly valuable because semiconductor design requires specialised knowledge in electronics, computer engineering, software, and systems development. Engineers working in India contribute to different stages of the design process, including architecture, circuit design, verification, testing, and the development of embedded software. This existing talent base provides India with an advantage that can be developed without requiring the enormous capital investment associated with constructing advanced fabrication facilities.

A strong design ecosystem can also support the development of fabless semiconductor companies. Fabless companies focus on designing and developing chips while outsourcing their physical manufacturing to specialised foundries. This business model can allow Indian startups to participate in the global semiconductor industry without initially having to establish expensive fabrication plants. The India Semiconductor Mission (ISM) has recognised semiconductor design as an important area and introduced initiatives such as the Design Linked Incentive (DLI) Scheme to encourage domestic semiconductor design companies and intellectual property development.

India's strength in design therefore represents one of its most realistic opportunities for achieving early global competitiveness in semiconductors. While becoming a major advanced-chip manufacturing centre will require significant time, investment, and technological development, expanding India's existing design capabilities can provide a comparatively accessible entry point. By supporting startups, intellectual property creation, research, and industry-academia collaboration, India can strengthen its role in the global semiconductor value chain while gradually developing capabilities in other stages of production.

6.4 Semicon India Programme and Policy Support

The Indian government has increasingly used policy support and financial incentives to accelerate the development of the domestic semiconductor ecosystem. This approach is important because semiconductor manufacturing requires extremely high levels of capital investment, specialised infrastructure, advanced equipment, and long development periods. Under the Semicon India Programme, the government has established financial support mechanisms to encourage investment across different parts of the semiconductor value chain. The Ministry of Electronics and Information Technology (MeitY,

2022) states that the programme was designed to develop a sustainable semiconductor and display ecosystem in India and strengthen the country's position in global electronics manufacturing.

A major component of this policy framework is production-linked and project-based financial support for semiconductor manufacturing and related facilities. Government incentives can reduce the initial financial burden faced by companies establishing fabrication, assembly, testing, and packaging facilities. In addition, the Design Linked Incentive (DLI) Scheme provides support to domestic companies developing semiconductor design and intellectual property. MeitY (2024) identifies design support as an important part of India's strategy to strengthen domestic semiconductor capabilities and encourage the development of semiconductor design companies.

Policy support also plays an important role in attracting foreign and domestic investment. Semiconductor projects require substantial upfront investment, while returns may take several years to materialise. Government incentives can therefore make India more attractive to companies comparing different locations for manufacturing and packaging facilities. The India Semiconductor Mission (ISM) has been established to coordinate these efforts and facilitate investment in semiconductor and display manufacturing.

Public-private partnerships are particularly important because neither the government nor individual companies can easily develop a complete semiconductor ecosystem independently. Government support can provide infrastructure, incentives, and policy stability, while private companies contribute capital, technological expertise, management capabilities, and access to international markets. OECD (2025) highlights that successful semiconductor ecosystems depend on coordination between governments and private-sector participants. For India, continued collaboration between the public and private sectors can therefore help transform policy ambitions into sustainable manufacturing and design capabilities.

6.5 Aatmanirbhar Bharat and Semiconductor Self-Reliance

The development of India's semiconductor industry is closely connected with the broader objective of Aatmanirbhar Bharat, or self-reliant India. Semiconductors are considered strategically important because they are essential for electronics, telecommunications, automobiles, defence systems, artificial intelligence, and other critical technologies. Strengthening domestic semiconductor capabilities can therefore reduce India's vulnerability to disruptions in foreign supply chains and improve its ability to access important technologies. The Government of India (2021) has identified self-reliance in critical sectors and stronger domestic manufacturing capabilities as important components of the Aatmanirbhar Bharat approach.

However, semiconductor self-reliance should not be interpreted as complete independence from international markets. The semiconductor industry is highly specialised, with different countries possessing advantages in areas such as chip design, fabrication, manufacturing equipment, materials, and packaging. OECD (2025) highlights that the global semiconductor value chain is deeply interconnected, making complete national self-sufficiency difficult and economically inefficient. India therefore needs to strengthen domestic capabilities while continuing to participate in global semiconductor networks.

A more practical approach is to develop strategic capability in areas where India can establish competitive advantages while maintaining reliable international partnerships. India's existing strengths in semiconductor design and engineering provide an important foundation, while investments in fabrication, assembly, testing, and packaging can gradually expand domestic capacity. Partnerships with technologically advanced countries and international semiconductor companies can also provide access to technology, investment, expertise, and global markets.

The objective of Aatmanirbhar Bharat in the semiconductor sector should therefore be understood as reducing vulnerability rather than eliminating interdependence. India can become more resilient by developing domestic capabilities in critical stages, diversifying its sources of imported materials and equipment, and establishing trusted partnerships with other economies. Such an approach would allow India to strengthen its technological and economic security while remaining an active participant in the global semiconductor ecosystem.

7.1 India-China Economic and Technological Interdependence

India and China remain closely connected through trade and regional production networks, particularly in electronics, machinery, components, chemicals, telecommunications, and other intermediate goods. India's Ministry of Commerce and Industry notes that a significant portion of India's imports from China consists of raw materials, intermediate goods, and capital goods, including electronic parts and assemblies, mobile-phone components, machinery, and auto components. These inputs are used by Indian industries to produce finished goods, meaning that the relationship extends beyond simple consumer-product imports.

This interdependence is particularly relevant to India's technology sector. India's rapidly expanding electronics, telecommunications, and manufacturing industries have historically relied on imported components because domestic production has not always been sufficient to meet demand. The Ministry of Commerce has identified electronics, telecom, and power among the sectors where imported intermediate and capital goods from China have been important for meeting domestic requirements.

Such dependence can become a vulnerability during periods of political or economic tension. Restrictions on trade, transportation disruptions, changes in export policies, or difficulties in obtaining important components can increase costs and create delays for downstream manufacturers. The broader semiconductor industry is particularly sensitive to these risks because its value chain is highly concentrated and disruptions can affect multiple industries. OECD (2025) notes that semiconductor supply chains involve significant geographical concentration, making diversification and alternative sources important for economic security.

For India, this creates a need to strengthen the security and resilience of its semiconductor and electronics supply chains. The objective does not necessarily require eliminating trade with China; rather, India can reduce excessive dependence by developing domestic manufacturing capabilities, diversifying suppliers, and establishing stronger partnerships with other economies. India's Production Linked Incentive schemes have been designed partly to increase domestic manufacturing, attract investment, integrate Indian companies into global supply chains, and reduce import dependence in strategic sectors.

Thus, India-China economic interdependence presents a balance between economic efficiency and strategic vulnerability. Maintaining access to global supply chains while gradually reducing dependence on concentrated sources will be important for India's long-term semiconductor security.

7.2 The Galwan Clash and Strategic Reassessment

The Galwan Valley clash of June 2020 marked a significant deterioration in India-China relations. The violent face-off occurred on 15 June 2020 in eastern Ladakh during a period of heightened tensions along the Line of Actual Control (LAC). The Government of India stated that the incident followed disagreements over the implementation of an earlier disengagement understanding. The clash became an important turning point because it reinforced concerns in India about national security and the broader strategic relationship with China.

The deterioration in bilateral relations also influenced how India approached economic and technological dependence. Following the clash, greater attention was given to vulnerabilities associated with Chinese technology, investment, and digital platforms. This reflected a broader understanding that national security could extend beyond conventional military issues to include data, digital infrastructure, critical technologies, and supply chains.

One visible response was India's decision to restrict Chinese-linked mobile applications. On 29 June 2020, the Ministry of Electronics and Information Technology (MeitY) announced the blocking of 59 mobile applications, citing concerns relating to sovereignty, national security, defence, and data security. Further applications were subsequently blocked in September 2020 on similar grounds. These measures demonstrated India's increasing willingness to treat digital technology and data security as strategic issues.

The post-Galwan environment consequently contributed to India's greater emphasis on trusted technology systems and resilient supply chains. Rather than relying excessively on a single foreign source, India has increasingly sought to diversify suppliers, strengthen domestic technological capabilities, and develop partnerships with trusted countries. This approach is particularly relevant to semiconductors because chips form the technological foundation of telecommunications, defence, computing, and digital infrastructure. India's later partnerships in critical and emerging technologies, including semiconductors and telecommunications, reflect this broader strategic direction.

7.3 Technology Restrictions and Policy Shifts

The Galwan clash and the deterioration of India-China relations led India to adopt a more cautious approach towards Chinese-linked technology and investment. One of the most visible measures was the restriction of Chinese mobile applications. In June 2020, the Ministry of Electronics and Information Technology (MeitY) blocked 59 mobile applications, citing concerns related to the sovereignty and integrity of India, defence, security of the state, and protection of user data. A further 118 applications were blocked in September 2020 on similar grounds.

India also introduced greater scrutiny of investments from countries sharing a land border with India. In April 2020, the government changed the Foreign Direct Investment (FDI) policy so that investments from such countries would require the **Government route** rather than the automatic route. The policy was introduced partly to prevent opportunistic takeovers during the COVID-19 period, but it also reflected the increasing importance of examining foreign investment from a security perspective.

These measures demonstrate how technology policy has become increasingly connected with strategic and national-security policy. Digital platforms are no longer viewed only as commercial services; concerns about data protection, cybersecurity, critical infrastructure, and technological dependence can influence government decisions. The government's stated justification for the app restrictions specifically connected data security and unauthorised data transmission with sovereignty and national security.

This shift is particularly relevant to semiconductor security. Semiconductors are fundamental components of telecommunications, computers, automobiles, defence systems, and other critical technologies. Excessive dependence on a foreign country for critical components can therefore create vulnerabilities during periods of geopolitical tension. India's semiconductor strategy increasingly focuses on developing domestic capabilities while maintaining diversified international partnerships. In this context, technology restrictions and investment scrutiny can be understood as part of a broader effort to build secure, trusted, and resilient technology supply chains rather than relying excessively on any single external source.

Chapter 8: Semiconductors in Defence, Joint Warfighting, and the Indo-Pacific

8.1 Role of Semiconductors in Modern Defence

Semiconductors have become essential to modern defence systems because they provide the electronic processing, sensing, communication, and control capabilities required by advanced military platforms. Modern defence equipment increasingly depends on microelectronics for functions such as data processing, navigation, communications, sensing, and system control. The U.S. Government Accountability Office (GAO, 2005) notes that advanced microelectronics are an enabling technology for defence systems, including satellites, communications equipment, radar, and other military applications.

Semiconductor-based technologies are used across a wide range of defence applications, including radar systems, satellites, communication networks, surveillance platforms, drones, and precision-guidance systems. More broadly, GAO (2025) notes that microelectronics form part of both commercial and defence products, including satellites and precision-guided military systems. This widespread use means that the performance of modern defence systems is increasingly connected to the availability and quality of advanced microelectronics.

Secure and reliable chips are particularly important because defence systems often operate in demanding environments and require high levels of reliability. Military electronics may need to function under conditions such as extreme temperatures and radiation, particularly in space-based systems. GAO (2005) highlights that defence microelectronics can have requirements that differ from those of ordinary commercial electronics, including greater reliability and specialised performance requirements.

Semiconductors are also important for military communications and information networks. For example, satellite communications support command and control, intelligence, surveillance, reconnaissance, and other defence activities. GAO (2025) describes U.S. Department of Defense satellite communications as supporting these functions and emphasises the importance of secure and resilient communication networks.

Consequently, advanced and trusted microelectronics have become an important component of defence capability. Dependence on vulnerable or uncertain sources of semiconductor supply can create risks for military readiness and technological security. GAO (2025) identifies foreign dependence within the microelectronics supply chain as a national-security concern, particularly because much semiconductor manufacturing and assembly is concentrated overseas. This makes semiconductor capability not merely an economic issue but also an important element of long-term defence and strategic security.

8.2 Semiconductors in Joint Warfighting

Joint warfighting refers to the coordination of military forces across multiple domains, including land, air, naval, space, and cyberspace. Modern military operations increasingly depend on the ability of these different forces to communicate and share information with one another. The U.S. Government Accountability Office (GAO, 2025) explains that Joint All-Domain Command and Control (JADC2) aims to connect military assets across these domains so that information can be shared and used more effectively for decision-making.

Semiconductors provide an important technological foundation for this coordination. They are used in communication equipment, computing systems, sensors, navigation technologies, and other electronic systems that collect and process large amounts of information. In joint operations, these capabilities allow data from different platforms and domains to be processed and communicated through interconnected command-and-control systems. GAO (2023) notes that modern joint command systems are intended to

analyse warfighting data across space, air, land, sea, and cyber domains and enable decision-makers to act more effectively.
Real-time decision-making is particularly important in modern warfare because commanders may need to process large volumes of information within short periods. Semiconductor-based computing and communication systems support the rapid processing, transmission, and analysis of this information. As GAO (2025) observes, effective command and control depends on transforming large amounts of data into actionable information and enabling commanders to make timely decisions.
The availability and reliability of semiconductors therefore have implications for military readiness. Weaknesses in the semiconductor supply chain can create difficulties in obtaining the advanced or trusted microelectronics required for defence systems. GAO has highlighted that dependence on global and foreign sources of microelectronics can create uncertainty regarding access to technologies important for defence capabilities. Consequently, semiconductor security is increasingly connected to the ability of armed forces to maintain reliable communication, information sharing, and coordination across multiple domains.
Overall, semiconductors have become a foundational component of joint warfighting because they support the digital infrastructure through which different military forces communicate, process information, and coordinate their activities. Ensuring reliable access to advanced and trusted semiconductor technologies is therefore important not only for technological development but also for maintaining military readiness and effective joint operations.

8.3 Sensors and Actuators

Sensors and actuators are important components of modern electronic systems. **Sensors** detect or measure information from the surrounding environment, such as temperature, pressure, light, sound, movement, or electromagnetic signals. Actuators, in contrast, allow a system to respond to information by producing a physical action. Together, they form an important link between the physical environment and electronic control systems.
In defence applications, sensors are widely used for surveillance, environmental monitoring, navigation, and the detection of objects or signals. They are incorporated into systems used on aircraft, unmanned platforms, naval systems, and other military equipment. The Defence Research and Development Organisation (DRDO) states that its Electronics and Communication Systems cluster develops electronic and electro-optical sensors used in areas including radars, unmanned aerial vehicles, airborne surveillance systems, missile programmes, and other defence platforms.
The operation of modern sensors and actuators increasingly depends on microchips and other electronic components. Semiconductor devices process the signals collected by sensors, convert information into usable data, and support the control systems that allow equipment to respond. GAO (2026) notes that different semiconductor types are used for functions such as sensing, signal processing, and control, demonstrating the importance of chips in modern electronic systems.
For India, reliable access to such semiconductor components is important for strengthening indigenous defence capabilities. India's semiconductor programme specifically includes support for sensors and MEMS (Micro-Electro-Mechanical Systems) manufacturing, while DRDO is developing a range of indigenous sensor technologies for defence applications. Building a dependable domestic ecosystem for these components can reduce vulnerabilities associated with dependence on external suppliers. As GAO has highlighted, dependence on foreign sources for critical microelectronics can create risks for defence supply chains and national security.

Thus, sensors and actuators demonstrate how semiconductors connect the physical environment with modern defence electronics. Their reliability is important for surveillance, monitoring, navigation, and automated system functions, making dependable semiconductor components an important part of India's broader goal of developing a resilient and self-reliant defence technology ecosystem.

Chapter 9: Strategic Pathways and Conclusion

9.1 Summary of Key Findings

The analysis of the global semiconductor ecosystem shows that semiconductor production is highly interdependent, specialised, and geographically concentrated. Different countries have developed strengths in different stages of the value chain, including chip design, fabrication, packaging, equipment, and materials. The OECD (2025) highlights that no single country currently controls the entire semiconductor value chain, while critical inputs and production capabilities remain concentrated in a limited number of economies. This structure creates strong international interdependence but also makes the industry vulnerable to disruptions in individual countries or regions.

The research also shows that the importance of semiconductors has increased because of supply-chain disruptions, geopolitical tensions, critical mineral dependencies, and national-security requirements. The semiconductor shortages experienced in recent years demonstrated how disruptions can affect industries far beyond electronics, including automobiles, telecommunications, and other technology-dependent sectors. At the same time, geopolitical competition has encouraged countries to strengthen domestic semiconductor capabilities and diversify their supply chains. Dependence on concentrated sources of critical minerals and manufacturing inputs further increases these vulnerabilities.

For India, the study identifies several important strengths and opportunities. India has a large pool of engineering and semiconductor-design talent, a growing domestic electronics market, and increasing government support for semiconductor development. Government sources estimate that India is home to around 20% of the world's semiconductor design engineers, demonstrating the country's established position in the design segment. India's large domestic demand across electronics, automobiles, telecommunications, energy, and defence also provides a significant market for the development of a domestic semiconductor ecosystem.

However, India continues to face significant structural weaknesses and challenges. These include limited large-scale fabrication capabilities, gaps in semiconductor manufacturing infrastructure and equipment, dependence on imported materials and critical minerals, and the need for further development of specialised manufacturing skills. Building a complete ecosystem requires substantial long-term investment in infrastructure, research and development, skilled manpower, reliable energy and water supplies, and advanced manufacturing capabilities. The government's continuing expansion of semiconductor programmes reflects the scale of these challenges and the need to strengthen capabilities across design, fabrication, packaging, and testing.

Overall, the findings indicate that India's semiconductor strategy should not be based solely on achieving complete self-sufficiency. Instead, India needs to combine domestic capability-building with international cooperation, supply-chain diversification, talent development, and strategic investment. Strengthening its existing advantages in design while gradually developing manufacturing, packaging, materials, infrastructure, and research capabilities can help India become a more resilient and strategically important participant in the global semiconductor ecosystem.

9.2 Future Research Recommendations

Future research can expand this study by incorporating primary research alongside secondary sources. Interviews and surveys with semiconductor industry experts, policymakers, engineers, investors, researchers, and defence-technology specialists could provide practical insights into the opportunities and challenges facing India's semiconductor ecosystem. Such research could help identify differences between government objectives, industry expectations, and the realities of semiconductor manufacturing and investment.

Another important area for future research is the long-term effectiveness of the India Semiconductor Mission (ISM). Researchers could examine the progress of approved projects, investment levels, employment generation, technology development, domestic value addition, and the growth of manufacturing and packaging capabilities over time. This would allow researchers to assess whether government incentives are successfully strengthening different parts of the semiconductor value chain. The introduction of ISM 2.0 in 2026, with greater emphasis on equipment, materials, design, research, and skilled workforce development, also provides an opportunity for future studies to compare policy objectives with measurable outcomes.

Comparative research could also examine India's semiconductor strategy alongside those of Taiwan, South Korea, China, Japan, and the United States. Such comparisons could study differences in government support, industrial policy, research and development, talent development, infrastructure, international partnerships, and private-sector participation. Rather than attempting to directly replicate another country's model, comparative research could identify policies and institutional approaches that may be relevant to India's economic and strategic circumstances.

Finally, future studies should examine specific areas that are becoming increasingly important to India's semiconductor strategy, including mature-node fabrication, advanced packaging, critical minerals and materials, and secure semiconductor capabilities for strategic sectors. NITI Aayog's 2026 roadmap specifically identifies mature-node and compound semiconductor manufacturing, advanced packaging, critical materials, and mission-critical manufacturing as important areas for India's future ecosystem. Research in these areas could provide a more detailed understanding of where India can develop competitive advantages while reducing vulnerabilities in its semiconductor supply chain.

Overall, future research should move beyond examining the current structure of India's semiconductor ecosystem and instead evaluate how effectively policies, investments, technological capabilities, and international partnerships are translating into long-term economic and strategic resilience.

9.3 Conclusion

The semiconductor industry has emerged as a central pillar of global competitiveness, economic security, technological development, and national power. The analysis in this study shows that semiconductors are no longer simply components used in electronic products; they are strategic technologies that influence industrial growth, digital infrastructure, defence capabilities, and geopolitical relationships. At the same time, the global semiconductor ecosystem remains highly interconnected and concentrated across a limited number of countries, making it vulnerable to supply-chain disruptions, geopolitical tensions, and restrictions on critical technologies and materials.

For India, this changing global environment presents both significant opportunities and important challenges. India possesses major strengths in semiconductor design, engineering talent, research capabilities, and domestic demand. However, gaps remain in large-scale fabrication, advanced manufacturing infrastructure, technology access, critical minerals and materials, specialised equipment, and the development of a sufficiently skilled workforce. Addressing these limitations will require sustained investment, policy continuity, research and development, and stronger cooperation between government, industry, and research institutions.

The study therefore concludes that India's objective should be strategic competitiveness rather than complete self-sufficiency. Attempting to reproduce the entire semiconductor value chain domestically may be economically inefficient and difficult given the industry's global nature. Instead, India can strengthen areas where it already has advantages while developing critical capabilities in a phased manner and maintaining diversified international partnerships. This approach can improve India's resilience without isolating it from the global semiconductor ecosystem.

India's future semiconductor strategy should consequently focus on leveraging its design and engineering strengths, developing manufacturing capabilities in phases, building trusted international partnerships, improving access to critical minerals and materials, and strengthening defence-linked semiconductor capabilities. A combination of domestic capacity-building and international cooperation can enable India to reduce strategic vulnerabilities while becoming a more competitive and resilient participant in the global semiconductor ecosystem. In this way, semiconductors can become not only an important sector of India's technology industry but also a foundation for its long-term economic security, technological capability, and national strategic strength.

References

1. Haramboure, A., Lalanne, G., Schwellnus, C., & Guilhoto, J. (2023). *Vulnerabilities in the semiconductor supply chain*. OECD Science, Technology and Industry Working Papers, 2023/05. OECD Publishing. https://doi.org/10.1787/6bed616f-en
2. OECD. (2025). *Mapping the semiconductor value chain: Working towards identifying dependencies and vulnerabilities*. OECD Science, Technology and Industry Policy Papers, No. 182. OECD Publishing. https://doi.org/10.1787/4154cdbf-en
3. Mohammad, W., Elomri, A., & Kerbache, L. (2022). The global semiconductor chip shortage: Causes, implications, and potential remedies. *IFAC-PapersOnLine, 55*(10), 476–483. https://doi.org/10.1016/j.ifacol.2022.09.439
4. Yoon, J. (2023). Supply chain security in the age of techno-geopolitics: 'Fab 4' case in the semiconductor industry. *The Korean Journal of International Studies, 21*(1), 27–60. https://doi.org/10.14731/kjis.2023.04.21.1.27
5. Moktadir, M. A., & Ren, J. (2024). Global semiconductor supply chain resilience challenges and mitigation strategies: A novel integrated decomposed fuzzy set Delphi, WINGS and QFD model. *International Journal of Production Economics, 273*, 109280. https://doi.org/10.1016/j.ijpe.2024.109280
6. Liao, Z., Tantai, B., Abdul-Hamid, A.-Q., Mukhtar, D., & Ali, M. H. (2025). Exploring resilience in the downstream supply chain of the semiconductor industry: The mediating roles of risk mitigation, process simplification, and flexibility. *International Journal of Production Economics, 281*, 109530. https://doi.org/10.1016/j.ijpe.2025.109530
7. Kumar, D., Soni, G., Mangla, S. K., Liao, J., Rathore, A. P. S., & Kazancoglu, Y. (2024). Integrating resilience and reliability in semiconductor supply chains during disruptions. *International Journal of Production Economics, 276*, 109376. https://doi.org/10.1016/j.ijpe.2024.109376

8. Yu, Y., Ma, D., & Wang, Y. (2024). Structural resilience evolution and vulnerability assessment of semiconductor materials supply network in the global semiconductor industry. *International Journal of Production Economics*, *270*, 109172. https://doi.org/10.1016/j.ijpe.2024.109172
9. Li, L., Wang, H., Li, Z., & Hu, S. (2025). Analysis of the structure and robustness of the global semiconductor trade network. *PLOS ONE*, *20*(1), e0313162. https://doi.org/10.1371/journal.pone.0313162
10. Grimes, S., & Dub, D. (2024). China's interdependent positioning in the semiconductor global value chain. *Global Networks*, *24*, 591–613. https://doi.org/10.1080/23792949.2024.2397973
11. Malkin, A., & He, T. (2024). The geoeconomics of global semiconductor value chains: Extraterritoriality and the US-China technology rivalry. *Review of International Political Economy*, *31*(2), 674–699. https://doi.org/10.1080/09692290.2023.2245404
12. Wong, C.-Y., Yeung, H. W.-C., Huang, S., Song, J., & Lee, K. (2024). Geopolitics and the changing landscape of global value chains and competition in the global semiconductor industry: Rivalry and catch-up in chip manufacturing in East Asia. *Technological Forecasting and Social Change*, *209*, 123749. https://doi.org/10.1016/j.techfore.2024.123749
13. Aoyama, Y., Song, E., & Wang, S.-Y. (2024). Geopolitics and geospatial strategies: The rise of regulatory supply chain controls for semiconductor GPN in Japan, South Korea and Taiwan. *ZFW – Advances in Economic Geography*, *68*(3–4), 167–181. https://doi.org/10.1515/zfw-2024-0046
14. Fu, W., Jing, S., Liu, Q., & Zhang, H. (2023). Resilient supply chain framework for semiconductor distribution and an empirical study of demand risk inference. *Sustainability*, *15*(9), 7382. https://doi.org/10.3390/su15097382
15. Akhtar, M., Hasan, M. G., Kamal, M. M., Namazi, H., & Lenort, R. (2026). Global semiconductor supply chain risk assessment and mitigation: A novel TSF-AHP-FMEA framework. *International Journal of Computational Intelligence Systems*, *19*, 131. https://doi.org/10.1007/s44196-026-01223-0