The Analysis and Strategy in Developing National Resilience in Semiconductor Supply Chains in Indonesia

Permata Nur Miftahur Rizki[1], Rokhmat Febrianto[2], and Purba Purnama[3,4*]

[1]Department of Software Engineering, School of Science, Technology, Engineering, and Mathematics, Universitas Prasetiya Mulya, Tangerang, Indonesia 15339
[2]Department of Computer Systems Engineering, School of Science, Technology, Engineering, and Mathematics, Universitas Prasetiya Mulya, Tangerang, Indonesia 15339
[3]Department of Food Business Technology, School of Science, Technology, Engineering, and Mathematics, Universitas Prasetiya Mulya, Tangerang, Indonesia 15339
[4]Department of Technical Support, Vanadia Utama Science and Technology, Jakarta, Indonesia 14470

[1]permata.nmr@prasetiyamulya.ac.id; [2]rokhmat.febrianto@prasetiyamulya.ac.id; [3]purba.purnama@prasetiyamulya.ac.id
*Corresponding author

How to Cite: Rizki, P. N. M., Febrianto, R., & Purnama, P. (2026). The analysis and strategy in developing national resilience in semiconductor supply chains in Indonesia. *Journal of ASEAN Studies, 14*(1), 227-250. https://doi.org/10.21512/jas.v14i1.15589

Abstract

Semiconductors have become essential components across diverse industries, yet their global supply chains remain highly vulnerable to public health crises and geopolitical tensions, such as the COVID-19 pandemic and the US–China rivalry. Although Indonesia possesses significant critical mineral resources for semiconductor components, including silica, nickel, gallium, and germanium, its semiconductor sector lags behind Southeast Asian neighbors such as Singapore, Malaysia, and Vietnam and remains deeply dependent on overseas supply, as reflected in a persistent semiconductor trade deficit since 2019. This research combined a systematic literature review, document analysis, and thematic analysis of focus group discussions and expert interviews with researchers, industry stakeholders, and government officials to evaluate Indonesia's national capabilities in research, technological innovation, and talent development, in line with the Golden Indonesia 2045 vision. The findings show that Indonesia has a large domestic market but a limited number of semiconductor researchers, highly skilled engineers, and research facilities, with research capacity concentrated in IC design and layout. Building national resilience in the semiconductor supply chain therefore requires technological advancement, a state-directed workforce, targeted industrial policies, and integration into global value chains rather than complete self-sufficiency. Key recommendations include utilizing domestic resources through downstreaming policies, providing government incentives to attract

P-ISSN 2338-1361/ E-ISSN 2338-1353
Received: 16th March 2026/ Revised: 03rd July 2026/ Accepted: 14th July 2026

foreign investment, and prioritizing the fabless business model as a realistic entry point to bridge the technological gap and ensure economic security. Indonesia can also complement ASEAN's existing strengths in back-end manufacturing and research and development (R&D) to strengthen regional supply chain resilience.

Keywords: semiconductor supply chain, national resilience, fabless industry, critical minerals, ASEAN

Introduction

Technological innovation has driven changes in human lifestyles. Many consumer products have changed to simplify human needs and comfort, such as household appliances, smartphones, automobiles, aerospace, consumer electronics, and utility systems. In these applications, semiconductors or integrated circuits (ICs) are the essential components in those products' manufacturing which correlate with the economic growth of the country (Xiong et al., 2025). Semiconductor supply chains are critical, and each country should prepare a mitigation plan to minimize disruptions.

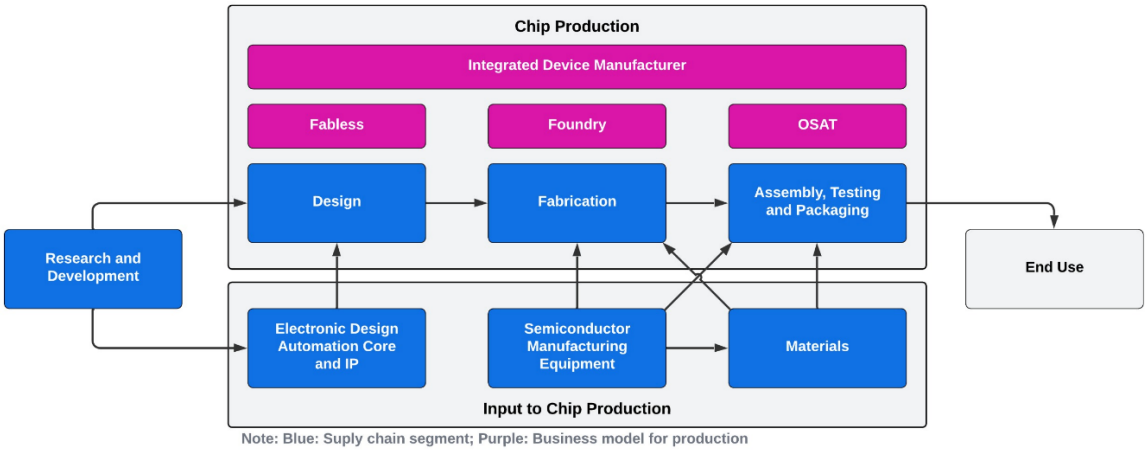


Figure 1. Semiconductor supply chains (Khan et al., 2021).

Figure 1 shows that the semiconductor supply chain is a complex process with advanced technology and highly integrated segments (Khan et al., 2021). The global semiconductor production network is an extraordinarily complex system where a single computer chip often requires more than 1,000 process steps and crosses international borders 70 or more times before reaching an end customer (Alam et al., 2020). The network is structured around four primary stages: research and development (R&D), which advances all other segments; chip design; wafer fabrication (front-end manufacturing); and assembly, testing, and packaging (ATP) (back-end manufacturing) (Khan et al., 2021). In other words, the production business model of semiconductors includes fabless, foundry, and Outsourced Semiconductor Assembly and Test (OSAT). Over the last three decades, the industry has transitioned from a vertically integrated device manufacturer (IDM) model to a geographically fragmented

fabless-foundry model driven by the fabless revolution (Yeung et al., 2023). In this network, the United States leads in high-value, R&D-intensive upstream segments such as electronic design automation (EDA) software, core IP, and logic chip design, accounting for roughly 39% of the total supply chain value (Khan et al., 2021). Conversely, physical manufacturing is heavily concentrated in East Asia with Taiwan and South Korea dominating advanced logic and memory wafer fabrication. At the same time, Mainland China and Southeast Asian nations like Malaysia and Vietnam serve as critical hubs for labor-intensive ATP processes (Semiconductor Industry Association, 2022). This specialized global network requires massive capital, as a single state-of-the-art fabrication facility ("fab") can cost between $5 billion and over $20 billion (Yeung et al., 2023).

The geopolitics of the semiconductor supply chain has transitioned from a cost-driven globalized model to a landscape defined by techno-nationalism and intense strategic rivalry, particularly between the United States and China (Reich, 1987; Yeung et al., 2023; VerWey, 2019; Capri, 2020). This shift is characterized by the weaponization of supply chain chokepoints, where the U.S. uses complex export controls on essential inputs like EDA software and manufacturing equipment to restrict rivals' access to advanced logic chips (Bown, 2025). To mitigate the vulnerabilities caused by the high geographic concentration of advanced fabrication in East Asia, major powers are implementing aggressive industrial policies, such as the United States' Creating Helpful Incentives to Produce Semiconductors (CHIPS) Act and the European Chips Act, which provide billions in subsidies to reshore manufacturing and secure domestic capacity (Yeung et al., 2023; Semiconductor Industry Association & Boston Consulting Group, 2024). Industrial policies are serving as a global catalyst for semiconductor supply chain resilience by providing massive financial incentives, such as the US CHIPS Act and the European Chips Act, to diversify manufacturing geographically and reshore critical fabrication capacity (Semiconductor Industry Association & Boston Consulting Group, 2024).

In parallel, technological upgrading is being pursued through sustained investment in foundational R&D, the adoption of Industry 4.0 tools like digital twins for proactive disruption management, and the development of advanced packaging techniques such as chiplets to enable higher-cost regions to remain competitive (Ivanov et al., 2019; MacCarthy & Ivanov, 2022; Hosokawa, 2022; Shivakumar et al., 2023) For emerging players like Indonesia, this strategy integrates mineral downstreaming policies with targeted workforce development to transition from a nascent assembly base toward more sophisticated roles in the global value chain (Guild, 2026; Haedar, 2023). Ultimately, while full technological sovereignty is widely considered unrealistic because of the industry's extreme capital demands and specialization, these combined efforts help create distributed cooperative networks that are more adaptable to systemic shocks. Furthermore, the conflict has expanded into the control of critical minerals, where China's dominance in materials like gallium and germanium has been utilized for retaliatory export bans, underscoring the urgency for nations to build resilient, distributed cooperative networks through geostrategic partnerships with resource-rich countries like Indonesia and Australia (Lv & Munroe, 2024; Young, 2024; The White House, 2025; Guild, 2026).

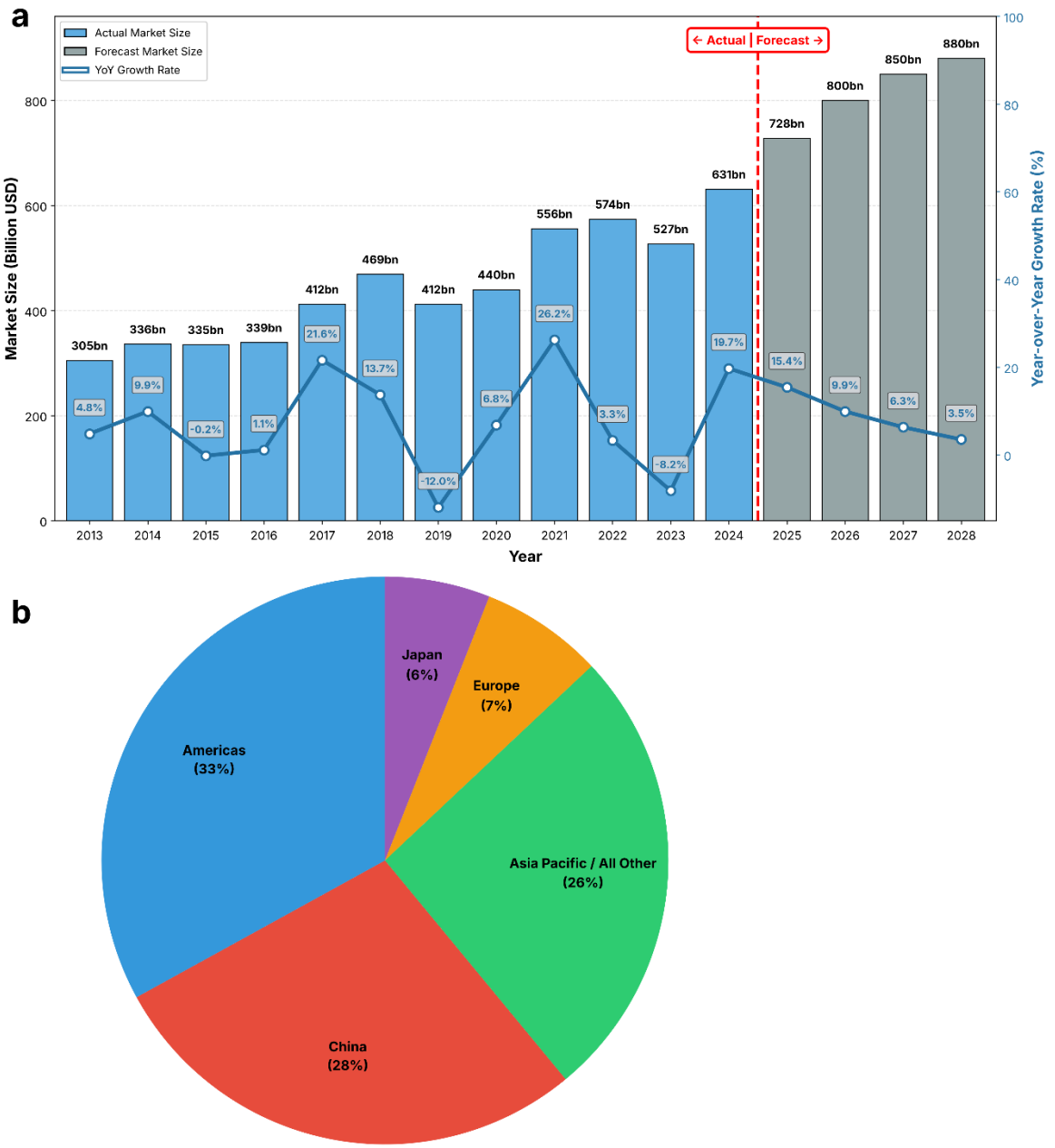


Figure 2. Annual global semiconductor market (actual and forecast) in billion US$ and year-over-year market growth (percentage) (a) (World Semiconductor Trade Statistics, 2025) and Semiconductor market size from January to August 2025 (b) (LaRocca, 2025; Semiconductor Industry Association, 2025)

According to World Semiconductor Trade Statistics (WTST), the semiconductor market is experiencing robust expansion, with a projected growth of 15.4% in 2025 and a market value of approximately US $728 billion, as illustrated in Figure 2 (World Semiconductor Trade Statistics, 2025). Based on the Semiconductor Industry Association (SIA), US-headquartered firms currently hold a dominant 50.4% of the global market share in 2024 (Semiconductor Industry Association, 2025), followed by South Korea, Europe, Japan, Taiwan, and China-headquartered companies with sales contribution of 21.1%, 9.2%, 8.1%, 6.5%, and 4.5%,

respectively (LaRocca, 2025). Up to August 2025 (Figure 2b), America and China dominated the market, accounting for more than 61% of global market size, followed by Europe and Japan, and another available potential market size from Asia Pacific and other regions of about 26% of global market size, which increase by up to 43.1% year-to-year sales (Semiconductor Industry Association, 2025). Southeast Asia has become a critical hub for specialized operations; Malaysia leads the global Assembly, Testing, and Packaging (ATP) market with a 13% share, Singapore excels in R&D and advanced manufacturing, and Vietnam and the Philippines are emerging as vital players in assembly and back-end processes (Wang et al., 2024).

Semiconductors play a critical role in many industries, including information technology, communications, healthcare, energy, and electronics. Disruptions in semiconductor supply chains will have multiple effects on these industries and the global economy. Geopolitical tensions and public health events are critical disruptions that directly affect the semiconductor supply chains (Xiong et al., 2025; Ramirez & Le, 2025; Mohammad et al., 2022). The COVID-19 pandemic, as an unexpected disruption, caused a shortage of semiconductor supply due to manufacturing shutdowns, labor health issues, sudden consumer demand fluctuations, and logistics delays (Feizabadi et al., 2023; Ivanov & Dolgui, 2022; Prabheesh & Vidya, 2024; Chen et al., 2023). In Southeast Asia, it significantly affects on their trade flows and connectivity (Chorzempa, 2023). On other hand, geopolitical tensions such as the Rusia–Ukraine conflict and the US–China trade war affect distribution delays, trade policies, lead times, production, and procurement processes (Brown & Linden, 2009), including uncertainty (Mukherjee et al., 2024). These situations create opportunities to expand the Association of Southeast Asia Nations (ASEAN) Network's contribution to semiconductor supply chains by maintaining a neutral position, as their economies are strongly interconnected with China, the US, Europe, and Asia.

Semiconductor supply chain resilience is increasingly defined as the geographic diversification of manufacturing and design activities to mitigate vulnerabilities arising from high regional concentration, which is catalyzed by aggressive industrial policy (SIA, 2024). Crucially, resilience is not synonymous with self-sufficiency. Rather, it depends on distributed cooperative networks and geostrategic partnerships that ensure access to essential critical materials (Guild, 2026). Ultimately, achieving national resilience requires a transition toward agile, decentralized network structures that prioritize viability and the capacity to survive extreme shocks, while maintaining open trade and aligned international standards.

Indonesia's semiconductor sector is currently characterized by a deep dependency on overseas supply chains, representing the country's third-largest import category after oil and gas (Observatory of Economic Complexity, n.d.). In 2021, semiconductor imports reached US$ 4.87 billion, nearly double the US$ 2.33 billion recorded in 2020 (Santoso, 2026). In contrast, Indonesia has abundant natural resources for semiconductor products, such as silica, nickel, and other essential minerals (Guild, 2026; U.S. Geological Survey, 2025). Silica (quartz) sand resources in Indonesia are estimated at 25 billion to 27 billion tonnes, distributed approximately 330 million to 340 million tonnes across 23 provinces (InCorp Editorial Team, n.d.; Hanan, 2026; Galuh, n.d.). In 2024, Indonesia dominated nickel production, accounting

for approximately 59% of global nickel production (U.S. Geological Survey, 2025). Gallium and germanium are critical components in semiconductor production. Gallium is a byproduct of bauxite and zinc processing, while germanium is extracted from coal ash (Guild, 2026). Converting critical minerals into semiconductor raw materials requires technology transfer and high-skilled engineers. It also related to the substantial environmental and social costs. This reliance makes the domestic semiconductor supply chains highly vulnerable to global disruptions.

Therefore, the research question focuses on suitable strategies for developing national resilience in semiconductor supply chains. Moreover, Indonesia lacks a centralized semiconductor R&D hub, and domestic innovation has been hampered by a heavy reliance on foreign licensing and technology. In line with the National Vision Golden Indonesia 2045, Indonesia must prioritize strenghthening semiconductor supply chain resilience through strategic reconfigurations based on national capabilities. This requires supporting the development of semiconductor industries, utilizing government incentives for domestic production, and developing an adaptive and innovative supply chains design to ensure long-term viability and mitigate unexpected future crisis.

Furthermore, no research has examined Indonesia's national resilience in semiconductor supply chains. This research applies systematic literature and thematic analysis of semiconductor supply chain resilience to evaluate the current state of semiconductor supply chains in Indonesia and the urgency of developing their resilience. The research aims to address current conditions in technology advancements, research and development, human resources in semiconductors, and the gap with neighboring countries. Moreover, this research provides an in-depth evaluation of research and national capabilities and suitable strategies in the semiconductor industry to achieve national resilience and develop adaptive, innovative semiconductor supply chains.

Analytical Framework

Dependant supply of semiconductor products shows the vulnerability of semiconductor supply chains. As a large country with the huge population, the Indonesian Government must prepare to secure semiconductor supply chains by considering all of the strengths and weaknesses. A comprehensive evaluation of the current condition and global situation is important to determine the strategic plan for national semiconductor supply chains. The discussion starts with the strengths of Indonesia in the global semiconductor networks, followed by many aspects related to semiconductor ecosystem. Then, it summarizes the current status and suitable strategies for national resilience in semiconductor supply chains.

Indonesia, with abundant mineral resources, has the potential to become a semiconductor hub in the Southeast Asia region. For battery and semiconductor materials, Indonesia plays a central role in the mineral supply chains. However, many mining and extraction industries are stilll in the evelopment stage, supported by foreign investors, such

as China and South Korea (Guild, 2026). Nevertheless, many challenges to realize these potencies and foreign investments in Indonesia, such as high-cost economy (Subiyanto & Rini, 2020; Amin et al., 2024; Bahagia et al., 2013), oligarchy intervention (Sahab et al., 2025; Hadiz & Robison, 2013; Kim, 2021, 2022; Pramono et al., 2026), corruption (Kennedy, 2018; Kartikasari & Suyanto, 2022; Damayanti & Mukhlis, 2024; Triatmanto & Bawono, 2023), law and regulation uncertainty (Sukamto et al., 2025; Kim, 2023) and others (Winanti & Diprose, 2020; Khalil & Broughel, 2025). Despite this, this research shifts the debate to the technological conditions, workforce, supply chain structure, and strategic policies needed to build national resilience in semiconductor supply chains. Indonesia's semiconductor product trading determines the position of Indonesia in the semiconductor supply chains. The semiconductor trade balance will determine the dependence of critical semiconductor supplies placed Indonesia into vulnerable conditions (Sharma et al., 2023; Yu et al., 2024). Big demand of semiconductor for domestic industries shows that Indonesia has big potential market to be fulfilled.

From research and innovation perspectives, semiconductor sectors requiretechnological advancement in materials and manufacturing processes, aligned with the needs of highly skilled engineers (Rumage, 2024). Currently, Indonesia has few researchers and institutions specializing in semiconductor field, which contributes to limited research development and a low number of high-skilled semiconductor engineers. Limited research facilities also limit the national capabilities in research and development which required government support. No country has successfully developed a semiconductor ecosystem without government intervention. Government commitment and intervention are a crucial part in developing semiconductor ecosystem in Indonesia. Legal protection, overlapping regulations, and non-transparent bureaucracy influence foreign investment in Indonesia (Sukamto et al., 2025; Le, 2025) Directional technological upgrading in semiconductors is critical to stimulate stakeholders in semiconductor research and development, as well as fabrication activities (Varas et al., 2020). Indonesia's science, technology and innovation policy must focus on providing infrastructure for semiconductor technology. Strengthening research institutes will increase innovation in semiconductor technology and align with increasing publication and research talent in semiconductors.

The abundance of critical minerals and high demand of domestic market are good capital for building domestic semiconductor ecosystems. However, limited workforce, limited research facilities, and current government initiatives keep Indonesia far behind from other neighboring countries such as Singapore, Malaysia, and Vietnam. After revieweing the current conditions, it is important to determine suitable strategies to achieve national resilience in semiconductor supply chains. Determining fabless, fabrications, and OSAT industries are related to capital, value add, human resources, research, and technology. Following the evaluation of current conditions, analyzing achievable and suitable strategies is important to develop semiconductor supply chain resilience.

Methodology

The research applies a systematic literature review and qualitative approach, adopting an interpretative framework to understand the current situation in Indonesia's semiconductor supply chains and industries. A systematic literature review allows to synthesize prior research and integrate the findings to gain an understanding of the semiconductor supply chain, especially research, technological advancement, human resources, and government intervention (Perry & Hammond, 2002). Qualitative research involves collecting and utilizing empirical materials related to semiconductor industries and supply chains, including case histories, observations, personal experiences, and interviews (Guba & Lincoln, 2005; Lincoln et al., 2011). Document analysis is also conducted by gathering various literature and official documents from government related to the policy on developing national resilience in semiconductor supply chains and industries.

The literature analysis is based on objective criteria related to semiconductor supply chains. Also, this research gathers some information from official websites of national, regional, and global agencies to obtain deeper information on national strategies in the semiconductor industry. The inclusion criteria for data collection are articles focusing on semiconductor technology and supply chains, data from official institutions (national, regional, global), and regulations from Indonesian government.

Furthermore, some information is gathered from researchers, stakeholders, and experts in semiconductor technology advancements from universities, research institutes, and government institutions through focus group discussions and interviews with a minimum of 25 participants for each discussion. Respondents have at least minimum 5 years of experience in research in semiconductor fields and/or technology industries, or are key person from government institutions involved in industrial or research policy. The semiconductor experts interviewed are researchers with doctoral degrees and more than 10 years of research experiences, or high-level officials from related government institutions. With the support of related government representatives and the Indoonesia Chip Design Collaborative Center, researchers and experts are gathered to support the discussion on the semiconductor supply chains and resilience. The group discussion covers research and workforce development in the semiconductor industry, current conditions, and a more critical discussion of national strategies for semiconductor resilience. All data are collected through group discussions and expert interviews using thematic analysis approaches which focus on semiconductor supply chains (Clarke & Braun, 2017). A systematic literature review combined with information gathered from stakeholders, group discussions, and interviews allows to integrate findings to gain a new understanding of semiconductor supply chains, particularly the current status of supply chains of semiconductor industry and suitable steps to start semiconductor industries and prepare national resilience.

The research focuses on the understanding of the importance of national resilience in semiconductor supply chains, evaluating the current condition, and then developing strategies to establish semiconductor industries based on national capabilities. A systematic literature review is performed to identify the theoretical background and insights from the

domestic context. Any discrepancies in the findings are discussed and resolved through deliberation.

Discussions

The global semiconductor market has grown significantly over the last decade and plays a crucial role in the technology-driven world. Indonesia, as a country with a large population, is a big market for various products, including semiconductor-based products. High demand for semiconductor-based products must be fulfilled by domestic manufacturers or supplied by other countries. Badan Pusat Statistik (2025) reported that semiconductor-based product trade in Indonesia has shown a deficit since 2019, with significant increase import values for the last 5 consecutive years, as shown in Figure 3. These findings suggest that the domestic market for semiconductor-based products has grown significantly, driven by changes in customer behavior after COVID-19. This growth aligns with the global semiconductor market, which grew by approximately 25.6% in 2025 and is projected to reach US$ 1 trillion in 2026 (World Semiconductor Trade Statistics, 2025). Depending on different point of views, the large semiconductor market in Indonesia may be a good opportunity or a serious threat.

This market value will become a good chance as an available domestic market for semiconductors in Indonesia. This domestic market can be fulfilled if Indonesia can build semiconductor ecosystem. Connecting producers and consumers of semiconductors will be easier with lower transportation costs. The abundance of essential minerals for semiconductor components can be absorbed domestically. Then, economic benefit will be retained domestically. The critical question is how Indonesia can expedite the development of its semiconductor ecosystem to take part in the global semiconductor supply chains.

On the other hand, the deficit gap of import-export trade in semiconductors is a critical problem due to deep reliance on overseas supply, which leaves Indonesia vulnerable in semiconductor supply chain (Sharma et al., 2023; Yu et al., 2024). Indonesia has only a few of semiconductor companies, such as Infineon, Xirka Silicon Technology, Versatile Silicon Technology, and others. Indonesia is relatively a small player in ATP capacity (less than 1%) (LaRocca, 2025; Semiconductor Industry Association, 2025). Considering big semiconductor market and existing small contribution in semiconductor supply chains, domestic demand must be met by overseas producers. Indonesia's current position in semiconductor supply chains is highly sensitive. Therefore, disruptions will directly affect Indonesia's semiconductor supply chain.

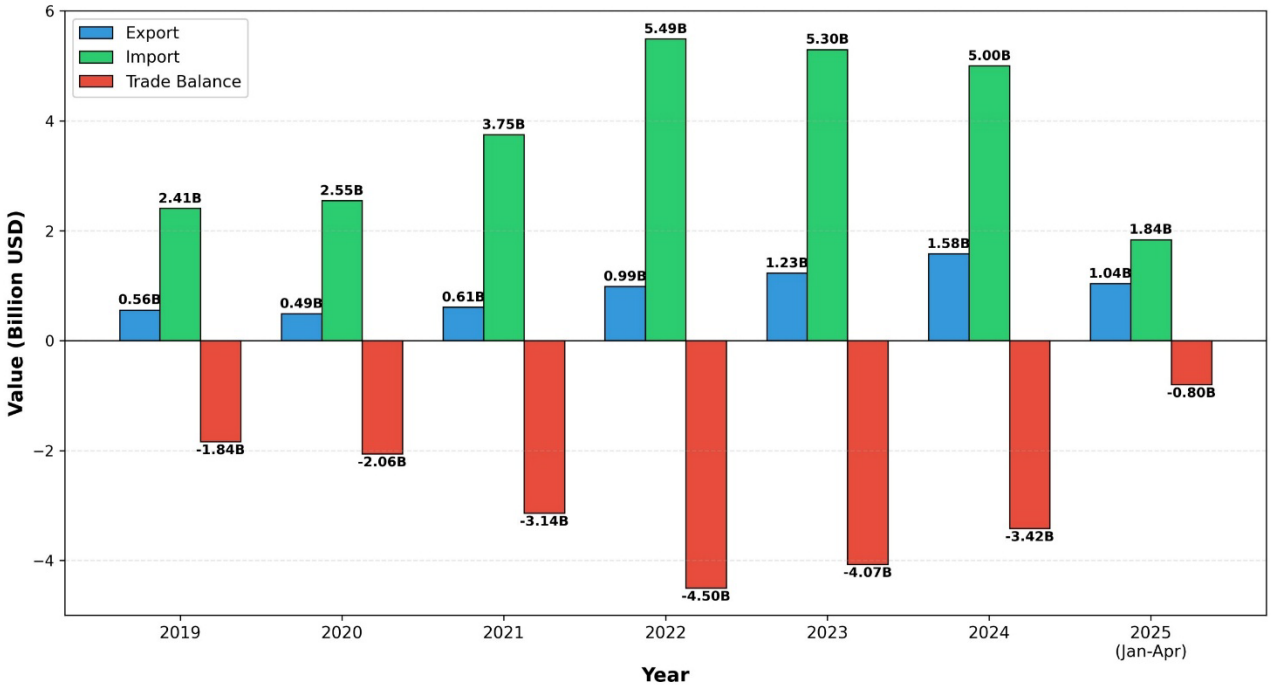


Figure 3. The semiconductor product trading in Indonesia.

Source: Badan Pusat Statistik, 2025.

The semiconductor supply chains viability and resilience have been tested various disruptions during last recent years. In 2019, it was affected by the COVID-19 pandemic which caused labor shortages and a lack of logistic and transportation, including factory closures (Xiong et al., 2025; Zlady, 2021). During the COVID-19 pandemic, the demand for semiconductor products for communication increased caused by behaviour change that minimized direct human interaction because of health concern. This concern also affected many companies and created ripple effects, including the low production of materials (material shortages), limited logistics flow, energy supply constraints, reduce capital circulation, and higher logistic cost (Zlady, 2021). Geopolitical disruptions came from regional tensions and trade conflicts have also created uncertainty in trade policies and activities, including production, procurement, and shipment (Chen et al., 2023). Ukraine-Russia and Taiwan-China tensions affect the stability of semiconductor supply chains (Xiong et al., 2025). The US-China trade war prompted China's ambition of semiconductor self-sufficiency (VerWey, 2019; Grimes & Du, 2020). These pandemic effects and geopolitical situations cause product shortages and significantly increases price.

The vulnerability in semiconductor supply chains must be used as a consideration to mitigate and anticipate any risk from disruptions in the future, such as pandemics (Haren & Simchi-Levi, 2020; Feizabadi et al., 2023; Wang & Yao, 2023) and geopolitical conflicts (Bown, 2020; Lincicome, 2021; Chen et al., 2023). Consequently, Indonesia with its deep reliance on semiconductor supply chain must develop innovations and strategies to face any future unexpected disruptions. Although developing national resilience in the semiconductor

supply chain is mandatory and very urgent, a comprehensive evaluation of various conditions related to semiconductor industries is required. It is because the semiconductor sector requires advanced technology and innovation, high-quality talent, proper infrastructure, regulatory support, and government intervention.

The fulfilment of semiconductor domestic demand can be achieved by developing domestic semiconductor industries. Preparing semiconductor industries can reduce the deficit gap and, in parallel, can reduce dependence on overseas supply. In semiconductor supply chains, Indonesia has many essential minerals and the Indonesian government is working to secure a resilience supply of critical minerals through downstreaming policy (Guild, 2026). Following this policy, the government offers some incentives to foreign companies that invest in critical mineral downstream industries, such as tax holidays and duty exemptions (ASEAN Briefing, n.d.). Since January 2020, the Indonesian Ministry of Energy and Mineral Resources has limited the export of raw minerals and increased the added value of minerals through domestic processing (Indonesia, Pemerintah Pusat, 2020; Kementerian Energi dan Sumber Daya Mineral Republik Indonesia, 2019). The downstreaming policy will improve long-term value for Indonesia through technology transfer and upskilling, including retaining more economic value domestically. The resilience of critical minerals supply chain becomes a high priority to maintain a competitive edge in global semiconductor supply chains.

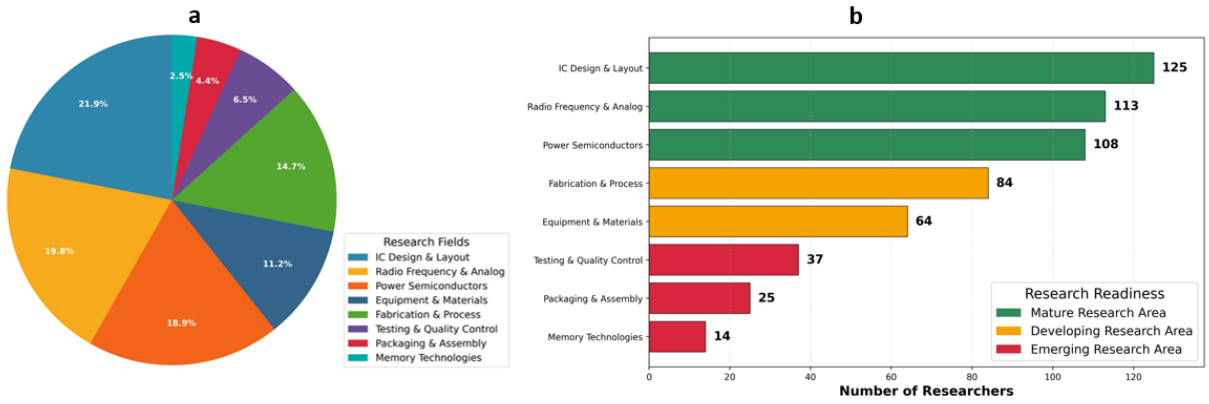


Figure 4. Distribution of researchers by research field in semiconductor sector (a) and Readiness level of semiconductor research in Indonesia (b)

Note. Data retrieved from OpenAlex (n.d.)

Developing domestic semiconductor industries requires strong research and development. In semiconductor research and innovation, there is a limited number of Indonesian semiconductor researchers from universities or institutes in Indonesia across various semiconductor categories, as shown in Figure 4 (OpenAlex, n.d.). By research area, more than 30% of research focuses on IC design and layout, followed by radio frequency (RF) and analog (17%) and power semiconductors (13.2%). It is also aligned with the technological

readiness level of each research field, where IC design and layout at the highest readiness level and in a growth position. Based on the data, IC design and layout is a suitable choice to start semiconductor supply chains in Indonesia, as many researchers focus on this field and there is a good chance to overcome technological backwardness through collaboration with overseas researchers. Other research areas mostly relate to material development, which requires advanced technological processing and facilities. With limited researchers in those areas, overtaking the technological gap may require more time compared to the IC design and layout. Instead focusing only on IC design and layout research area, strengthening other research areas is also important, such as materials processing where Indonesia has abundant critical minerals for semiconductors. Semiconductor research and development in Indonesia must be driven by customer needs and supported by government policy. High-level of semiconductor research will attract industries to collaborate with researchers to solve their customer needs in semiconductor products.

The development of technology and innovation in semiconductors also requires researchers and high-skilled engineers. Indonesia has many industries, but it has a limited number of high-skilled engineers and researchers in the semiconductor field. Compared to Singapore and Malaysia, Indonesia has around 345,000 engineers in the electronic industry, but only a few highly skilled engineers and researchers in the semiconductor industry. Indonesia's ratio of engineers per million inhabitants is about 2,671, while Malaysia's is 3,333 and Vietnam's is 9,037 with their rapid growth of semiconductor industries (Kurniawan, 2024). In Southeast Asia, Singapore and Malaysia show better contribution in the global semiconductor supply chain compare to Indonesia (Wang et al., 2024). Based on educational background, around 12,000 researchers directly support the global semiconductor industry in Singapore such as GlobalFoundries, Micron Technology, STMicroelectronics, Applied Materials, and AMD, and serve as backbone of research and development and technological innovation in manufacturing processes (Rumage, 2024).

Singapore's semiconductor industries have around 35,000 highly skilled engineers, with about 30% involved in the R&D activities. It contributes around 7% of their national GDP (Medina, 2024). Then, Malaysia's semiconductor industries have around 100,000 highly skilled engineers, with 30% in packaging and assembly and 22% in testing and quality control. This workforce has positioned Malaysia as a leading contributor in back-end industries (ATP) (Medina, 2025). With their current contributions and future ambitions in global semiconductor market share, Singapore and Malaysia are estimated to require about 34,000 and 60,000 highly skilled engineers, respectively (Rumage, 2024; Medina, 2025). To increase Indonesia's contribution in semiconductor supply chain, strengthening research and development and increasing the number of researchers and highly skilled engineers in semiconductor field must be prepare to minimize the gap with Singapore and Malaysia. There are many options to increase the number of researchers and highly skilled engineers for semiconductors, such as supporting domestic semiconductor research, collaborating domestically with overseas researchers, and attracting global talent to Indonesia. China, the US, South Korea, Japan, the European Union, and Taiwan provide big grant for research in semiconductors (LaRocca, 2025; Blevins et al, 2023). Clear government direction in

semiconductor research and development is mandatory to increase the research level, including the number of researchers and highly skilled engineers.

Preparing semiconductor industry requires government intervention through regulation and infrastructure. The government must make substantial policy change to support the development of semiconductor supply chains. Government policies is required to accommodate foreign investment, technological protection, transfer and advancement, including attracting global talent. Policies must be attractive to encourage foreign investment in Indonesia. Corruption (Kennedy, 2018; Kartikasari & Suyanto, 2022; Damayanti & Mukhlis, 2024; Triatmanto & Bawono, 2023), oligarchy intervention (Sahab et al., 2025; Hadiz & Robison, 2013; Kim, 2021, 2022; Pramono et al, 2026), and regulation uncertainty uncertainty (Sukamto et al., 2025; Kim, 2023) are some factors that hamper investment, which requires real action from government to guarantee the investment. Government policy initiatives and incentives are also required to boost semiconductor growth in Indonesia. Protecting mineral resources is one of the key policies to secure future materials for semiconductors and advanced materials (Indonesia, Pemerintah Pusat, 2020). This policy will secure the availability of critical minerals for the future and retain more economic benefits domestically.

Government policy initiatives and incentives are also required to boost semiconductor growth in Indonesia. Many countries support their semiconductor industries by giving incentives and competitive taxes. The SIA reports that US national policies will focus on supporting US chipmaking and investment through advanced incentives, competitive taxes, developing semiconductor talent, export controls, and environmental regulation (LaRocca, 2025). The SIA also compares the government incentive strategies of semiconductor key players. The US aims to achieve semiconductor resilience through the CHIPS and Science Act with key incentives including ~$39B in manufacturing grants and ~$13B in R&D funding (Blevins et al, 2023). China with its semiconductor self-sufficiency ambition provides at least $200B subsidies for chip R&D through the national IC outline policy. Moreover, the China government provides substantial financing instrument to address weaknesses in materials and equipment (Fu et al., 2025). Taiwan in US-China-Taiwan triangle provides ~16B in tax incentives through the Angstrom Semiconductor Initiative to achieve breakthrough 1 nm in 2030. South Korea with the K-Semiconductor Belt strategy provides ~55B in tax incentives through the K-Chip Act to strengthen fab leadership. Japan is trying to regain semiconductor contribution through its strategy for semiconductors and the digital industry with ~17.5 in grants to achieve ~112B in targeted sales by 2030. Then, the European Union provides ~47B in grants and loans through the EU Chip Act, with a 20% global share target by 2030. The Asian countries support bigger incentive than US resulted in cost advantage to attract manufacturing partnership for semiconductor facilities (Varas et al., 2020).

The policy relates to human resources, which also becomes important for supporting the development of semiconductor industry and aligns with national development plans to achieve Golden Indonesia 2045. Presidential Regulation No. 12/2025 states the national priority program on national resilience based on the digital economy and industrial development driven by high qualified manpower, technological innovation, and export orientation (Indonesia, Pemerintah Pusat, 2025). Following this regulation, developing

national resilience in semiconductor supply chains is a national program priority. As stated by Indonesian Coordinating Minister for Economic Affairs, Mr. Airlangga Hartanto, Indonesia is taking steps to build its own semiconductor ecosystem. This policy is expected to accelerate growth in research and innovation, researchers, and highly skilled engineers.

After evaluating current conditions, Indonesia, with big domestic semiconductor market and abundant mineral resources faces semiconductor supply chain vulnerability due to some limitations. Research and innovation in semiconductors are in critical condition, with a limited number of researchers, highly skilled engineers, and research facilities. This condition creates barriers between researchers and semiconductor industries because of a large gap in technological development. Government intervention is still limited in the area of downstreaming critical minerals, but there has been improvement in developing human resources. However, a clear gap in technological innovation of semiconductor remains, and it can be solved through collaboration between researchers and industries, supported by government.

Indonesian government must prepare strategies to achieve national resilience in the semiconductor supply chain based on existing conditions related to the research and innovation, human resources, and a suitable starting point for developing the domestic semiconductor industry. Based on the literature and input from researchers and stakeholders, there are some key points required to develop national resilience in semiconductor supply chains that require collaboration among government, industry, and academia.

In strategic policy and investment, the government plays a vital role as a policy maker. This focus includes government incentives and subsidies, R&D funding, policy for the semiconductor industry, IP protection and security, and support for international collaboration for trade and research in semiconductors. Incentives, subsidies, and clear policies and regulation in the semiconductor industry will attract foreign investors to Indonesia's semiconductor industries. R&D funding and support for international collaboration will accelerate research and innovation in the semiconductor sectors, including the development of researchers and highly skilled engineers as a backbone of the semiconductor industry. IP protection and security will boost the knowledge transfer from mature semiconductor industries into Indonesian semiconductor industries. Moreover, strategic collaboration will increase competitive advantage and resilience (Anumula, 2026). Policies should take targeted approaches that strengthen resilience rather than pursue complete self-sufficiency (Xiong et al., 2025). Strengthening resilience in semiconductor supply chains will help Indonesia adapt to unexpected disruptions in the future. It is more important focus on resilience rather than on complete self-sufficiency as semiconductor supply chains are a complex multinational network. Thus, the government must give clear direction and support to realize and accelerate this goal.

In supply chain structure and design, it must consider the manufacturer diversification, domestic production, decentralized networks, and agility of supply chains model. Manufacturer diversification and sourcing locations in semiconductor supply chains are important to minimize dependence on a single source or country (Lima et al., 2021; Shin et al.,

2019). Domestic production is part of strategies to reduce reliance on foreign technology and retain more benefits for the domestic economy. Designing decentralized supply chain networks is required to facilitate multiple pathways for supply chain operations and reduce any potential risk of a single supply failure in the future (Koh et al., 2020). Thus, collaboration among government, domestic industries, and researchers is required to build an agile semiconductor supply chain. The agility of supply chain's structure or dynamically adaptive model based on viability must be considered because of the many possibilities of potential disruption in the future.

Technology and digitalization are important for preparing and securing semiconductor supply chains as advanced tools to improve monitoring, planning, and response capabilities (Ivanov et al., 2019; MacCarthy & Ivanov, 2022). Moreover, semiconductor requires high level research and advanced technological processes. R&D is the backbone of all semiconductor processes. Advanced technology supports efficient and effective industrial processes. Digitalization supports for monitoring, traceability, and mitigating potential risks or disruptions.

Given the need for innovative and sustainable operations in semiconductor supply chains, human capital development is mandatory (Fu & Chien, 2019). Considering the current state of semiconductor research and researchers, preparing a skilled workforce is important to strengthening semiconductor supply chain resilience. From a regulatory perspective, this direction aligns with the vision of Golden Indonesia 2045. The government needs to initiate policies to address talent shortage in research and development and prepare for semiconductor workforce development. This may include some policies to attract global talent, foster innovation through upstream policy priorities, and promote R&D based on changing technological demand.

As semiconductor supply chains include three types of production business model, determining an appropriate model to enhance resilience requires considering several factors. Based on extensive discussion with researchers, government representatives, industry stakeholders, Table 1 summarizes the current state of semiconductor production business models.

Table 1. Indonesia's current state in supply chain of semiconductor industry.

Business Model	Value adds	Capital	Human Resources	Technology Readiness	Research Gap
Fabless	High	Low	Grow Level	Ready	Low
Fabrication	High	High	Early stage	Early stage	High
OSAT	Low	High	Early stage	Early stage	High

Generally, semiconductor industries are complex process with capital intensive and sophisticated technology (Chen & Chien, 2018; Hong et al., 2023; Lu et al., 2013). As shown in Table 1, fabless and fabrication add more value than OSAT, while the fabless industry requires

lower capital expense than the others. Establishing fabrication and OSAT industries requires advanced technological facilities and huge capital investment, whereas fabless operation requires less investment due to low-cost equipment. As semiconductor industries rely on R&D as its backbone, technology readiness and high-quality human resources are key factors in determining suitable semiconductor industries. Indonesia's high domestic semiconductor market and abundant mineral resources can be considered to initiate semiconductor industries. However, semiconductor products require material development with sophisticated technologies, advanced production facilities, and high-cost investment. So, Indonesia needs considerable time to achieve this level regarding technological readiness and human resource availability.

On the other hand, developing national resilience in semiconductor supply chains must also consider the end-users of semiconductor products. Indonesia has many domestic end-users as represented by deficit in the export-import trade balance. The domestic semiconductor market always starts their process with IC design and layout before mass production. Connecting domestic end-users with IC design and layout researchers is more realistic than starting other semiconductor industries. Technological readiness and IC design and layout researcher are more advanced than in other research fields. Fabless industries, especially design services, will directly relate to end-user requirements. So, connecting domestic fabless industries and end-user will be the best strategy as a starting point to develop national resilience in semiconductor supply chains, while supply chain gaps in fabrication and OSAT may be solved by cooperation with existing key players. This strategy must be supported by government policy to strengthen resilience, rather than complete self-sufficiency at the initial stage.

Conclusions

This research concludes that achieving national resilience in the semiconductor supply chain is a mandatory priority, in line with the Golden Indonesia 2045 vision. Indonesia should prioritize the fabless (chip design) industry as strategic entry point for semiconductor supply chain resilience. The fabless business model offers high value-add with relatively low capital expenditure and aligns with the existing concentration of Indonesian researchers in IC design and layout.

Indonesia has significant potential to leverage its abundant mineral resources and growing domestic market to transition from a consumer to a strategic player in the global semiconductor supply chains. To realize this potential, strong, coherent government initiatives are needed to provide targeted incentives, subsidies, and legal protections for foreign investors. Government should serve as the primary catalyst for developing semiconductor industries. National resilience in the semiconductor supply chain depends on systematic talent development and fostering deep collaboration between universities, research institutes, and private firms to increase the number of researchers and highly skilled engineers. A state-directed workforce is required to lead the talent development and the R&D pipeline. Ultimately, by integrating domestic end-user demand with local fabless industry

and chip design capabilities, along with international partnerships, Indonesia can mitigate the ripple effects of global disruption and anchor its status as a competitive, resilient node in the global semiconductor supply chain.

These findings also carry implications for ASEAN. Rather than competing with neighboring countries in segments where they are already established, Indonesia can position its fabless capabilities and critical mineral resources as complements to ASEAN's existing strengths, namely Malaysia's leadership in assembly, testing, and packaging, Singapore's R&D and advanced manufacturing, and the emerging back-end capacity of Vietnam and the Philippines. Such a division of roles would allow chips designed in Indonesia to be fabricated, assembled, and tested within the region, thereby building a more diversified and resilient Southeast Asian semiconductor network. As ASEAN economies are closely interconnected with China, the United States, Europe, and other Asian partners, a coordinated regional approach would also reinforce ASEAN's neutral position amid the US–China rivalry and reduce the region's exposure to geopolitical disruptions. To realize this potential, ASEAN member states need deeper cooperation in critical mineral supply, joint research and talent mobility, alignment of technical standards, and better-coordinated investment incentives to avoid costly subsidy competition within the region. Ultimately, strengthening Indonesia's national resilience can contribute to ASEAN's collective resilience in the global semiconductor supply chain.

Future research directions for strengthening Indonesia's semiconductor supply chain resilience should focus on moving beyond the initial fabless entry point into more complex segments of the supply chain. First, future research should assess feasible technology nodes and product segments suitable for Indonesia's current capabilities through techno-economic analyses, including comparison of the viability of greenfield fabs against partnership or joint-venture models with established global players. Second, research is needed to design a competitive national roadmap that attracts high-capital investment while minimizing any risks. The focus areas include designing specific industrial policies, governance models, and risk-sharing arrangements to de-risk massive private investment. It should also evaluate the physical and ecosystem requirements needed to support advanced manufacturing facilities as part of infrastructure readiness. Third, the research should prioritize detailed skill mapping to identify specific technical gaps and create clear training pathways for specialized fab operations. Finally, research on technology transfer mechanisms, regional integration within ASEAN, and strategies to ensure environmental sustainability and supply chain resilience will be essential to design a realistic and competitive national roadmap.

Acknowledgement

We would like to express our sincere gratitude to the editor and reviewers for their insightful comments and constructive feedback, which have significantly improved the quality of this article. This research was supported by the Ministry of Education, Culture, Research, and Technology, as well as the Indonesia Endowment Fund for Education (LPDP) through the PRPB Funding Program, based on Decree Number 1106/E5/DT.05.00/2024and

Agreement/Contract Letter Number 057/E5/PG.02.00/PRPB.PRN/2024. We gratefully acknowledge their financial support, which made this work possible.

About The Authors

Permata Nur Miftahur Rizki, Ph.D. is a computer scientist and digital transformation practitioner with experience across academia, government, and industry, focusing on machine learning, mobile web applications, and cloud computing for SMEs and public sector initiatives in Indonesia and South Korea. He holds a Ph.D. in Computer Science from Ajou University, South Korea, and serves in leadership roles at the Faculty of STEM, Universitas Prasetiya Mulya, while actively advancing cloud-based innovation in education and industry.

Rokhmat Febrianto, S.Tr.T., M.T. is a lecturer in AI & Robotics at the Faculty of STEM, Universitas Prasetiya Mulya, Indonesia. He received his bachelor's degree in Mechatronics Engineering from Politeknik Elektronika Negeri Surabaya (PENS) and his master's degree in Electrical Engineering with a specialization in Multimedia Intelligent Network from Institut Teknologi Sepuluh Nopember (ITS). His research interests lie in robotics, machine learning, and computer vision, particularly focusing on intelligent robotic systems, autonomous platforms, and the integration of artificial intelligence in engineering applications. He is actively involved in developing educational robotics systems, robotic manipulators, and AI-enabled embedded systems, while mentoring students in interdisciplinary technology projects.

Purba Purnama, Ph.D. is an associate professor, material scientist and practitioner with experience across academia, government, and industry, focusing on material development, chemical analysist and characterization. He holds a Ph.D. in Biomaterial Science from Korea Institute of Science and Technology and Biomolecular Science from University of Science and Technology, South Korea, and serves as faculty member at the Faculty of STEM, Universitas Prasetiya Mulya.

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