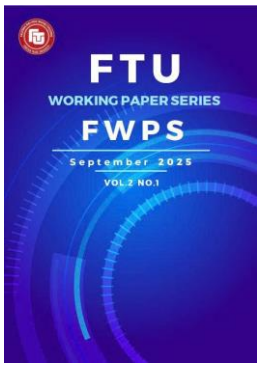

Working Paper 2025.2.1.4

- Vol. 2, No. 1

TÌNH HÌNH LAO ĐỘNG Ở ĐÔNG NAM Á TRONG BỐI CẢNH CÔNG NGHIỆP 4.0

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Tóm tắt:

Cuộc cách mạng công nghiệp lần thứ tư (Công nghiệp 4.0) đang định hình lại lực lượng lao động toàn cầu, đặc biệt là ở Đông Nam Á (SA), nơi bối cảnh kinh tế đa dạng và mức độ áp dụng công nghệ khác nhau đặt ra những thách thức riêng. Nghiên cứu này xem xét tình hình lực lượng lao động và những thay đổi gần đây của nó trong bối cảnh cuộc cách mạng công nghiệp lần thứ tư tại

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SA. Sử dụng phương pháp tiếp cận định tính, nghiên cứu phân tích xu hướng thị trường lao động, khoảng cách kỹ năng và nhu cầu về năng lực mới trong các lĩnh vực khác nhau kết hợp với phương pháp thống kê mô tả để cung cấp hiểu biết toàn diện về khả năng thích ứng của lực lượng lao động đối với những điều này. Nghiên cứu cho thấy có sự không ăn khớp đáng kể giữa các kỹ năng của lực lượng lao động hiện tại và nhu cầu của doanh nghiệp đang thay đổi do Công nghiệp 4.0, đặc biệt là về kiến thức số và kỹ năng về các kỹ thuật tiên tiến. Nghiên cứu cũng xác định nhu cầu về các chương trình giáo dục và đào tạo có mục tiêu và cải cách chính sách để hỗ trợ phát triển lực lượng lao động. Kết quả nghiên cứu nhấn mạnh tầm quan trọng của sự hợp tác khu vực và lập kế hoạch chiến lược để nâng cao khả năng cạnh tranh của lực lượng lao động Đông Nam Á trên thị trường toàn cầu. Bài viết đóng góp vào các tài liệu hiện có bằng cách giải quyết khoảng cách trong nghiên cứu về sự chuẩn bị của thị trường lao động Đông Nam Á cho Công nghiệp 4.0, cung cấp thông tin chi tiết cho các nhà hoạch định chính sách và các bên liên quan để cải thiện tình hình.

THE SITUATION OF WORKFORCE IN SOUTHEAST ASIA IN THE CONTEXT OF INDUSTRY 4.0

Abstract

The Fourth Industrial Revolution (Industry 4.0) is reshaping global workforce dynamics, particularly in Southeast Asia (SA), where diverse economic contexts and varying levels of technological adoption present unique challenges. This study examines the workforce situation and its recent changes in the context of the fourth industrial revolution in SA. Employing a qualitative methods approach, the research analyzes labor market trends, skill gaps, and the demand for new competencies across different sectors combined with a small amount of quantitative data, and descriptive statistics to provide a comprehensive understanding of the workforce's adaptability to these. The findings reveal a significant misalignment between current workforce skills and the evolving demands of Industry 4.0, particularly in digital literacy and advanced technical skills. The study also identifies the need for targeted education and training programs and policy reforms to support workforce development. Our results emphasize the importance of regional collaboration and strategic planning to enhance the competitiveness of Southeast Asia's workforce in the global market. This paper contributes to the existing literature by addressing the gap in research on the preparedness of Southeast Asian labor markets for Industry 4.0, providing insights for policymakers and stakeholders to enhance the situation.

Keywords: Industry 4.0, workforce, Southeast Asia

1. Introduction

The onset of the Fourth Industrial Revolution (I4.0) has initiated a wave of technological advancements that are fundamentally altering the fabric of industries worldwide. This new technological frontier is transforming the way businesses create value, how individuals perform their work, and the manner in which people connect and communicate with each other. I4.0 has

significantly transformed job roles and the skill profiles required of workers (Ghislieri et al., 2018, 2018). These technologies are the cornerstones of changing industrial processes to substantially enhance productivity. In Southeast Asia, these changes are particularly evident, as countries strive to integrate new technologies such as robotics, artificial intelligence, and the Internet of Things (IoT) into their economic frameworks (Miah et al., 2024). This transformation is creating both opportunities and challenges. Countries in the region are at various stages of adopting these technologies, influenced by differing levels of economic development, digital infrastructure, and educational capabilities. Understanding the regional impact of Industry 4.0 is essential to developing strategies that can harness these technologies for economic growth while mitigating potential workforce disruptions.

Previous studies have explored the implications of Industry 4.0 on global labor markets, highlighting the benefits of technological innovation alongside the risks of job displacement due to automation (Weerasekara et al., 2022; Perez Perales et al., 2018). There is a significant gap in research focusing on the impacts of Industry 4.0 on the workforce of Southeast Asia. While much of the existing literature focuses on developed economies (Kadir et al., 2019; Bolbot et al., 2022; Echchakoui et al. 2020), little is known about how diverse economic structures, levels of digital infrastructure, and varied technological adoption rates in Southeast Asian countries affect their ability to adapt to Industry 4.0. This study aims to fill this gap by examining the challenges and opportunities these countries face, specifically addressing how disparities in technological readiness and workforce skills impact the region's employment landscape and economic growth in the context of Industry 4.0.

To achieve these aims, the research employs a qualitative methods approach. We analyze quantitative data from national labor statistics, industry reports, and workforce surveys to identify trends in employment and skill demand. This approach allows for a comprehensive analysis of current workforce capabilities and the identification of critical skill gaps that need to be addressed.

The findings reveal that while there is significant potential for economic growth through the adoption of Industry 4.0 technologies, there is also a need for comprehensive workforce development strategies. The 4.0 revolution has created more jobs, but the rate at which jobs are being created is still slower than the rate at which workers are losing jobs. Furthermore, disparities among SA countries also lead to disparities in workforce readiness, the ability of workers to meet competency requirements. These gaps must be addressed through targeted education reforms, continuous professional development, and regional collaboration to ensure that the workforce is equipped to thrive in an Industry 4.0 environment.

Following the introduction, the remainder of this paper is structured as follows: Section 2 reviews the relevant literature on Industry 4.0 and workforce dynamics, particularly in Southeast Asia. Section 3 outlines the methodology used in this study. Section 4 presents the findings and discusses their implications for policymakers and stakeholders. Finally, Section 5 concludes with recommendations for future research and strategic initiatives to support regional workforce development.

By addressing the identified research gap and providing actionable insights, this study contributes to the ongoing discourse on workforce readiness in the age of Industry 4.0, particularly within Southeast Asia, offering valuable contributions to academic and policy discussions.

2. Theoretical Basis and Literature Review

Industry 4.0

Industry 4.0 concept was coined in 2011 by a German public-private initiative to acknowledge the industrial challenges in this new age and propose a strategic program to develop advanced production systems for German companies (Kagermann et al., 2022). Klaus Schwab defines the Fourth Industrial Revolution (4.0 Revolution) as a new era of technological innovation that fundamentally changed how we live, work, and interact. Unlike previous industrial revolutions, which were driven by advances in mechanization, electricity, and digital technologies, the Fourth Industrial Revolution is characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological worlds (Schwab, 2017). Agreeing with this view, Rupp et al. (2021) emphasized in contrast with previous industrial revolutions which were driven by single technology inventions such as the steam engine (1.0), electricity (2.0) and computers (3.0), the ongoing fourth industrial revolution is driven by existing technological developments and the ability to process large amounts of data.

This perspective is reinforced by Ghobakhloo and Fathi (2021), who argue that Industry 4.0 represents not just technological advancement but a socio-technical transformation. Their comprehensive framework identifies nine foundational technologies and six design principles that collectively enable smart manufacturing systems. The researchers emphasize that unlike previous industrial transitions, Industry 4.0 is characterized by its exponential rather than linear pace of change, creating unprecedented challenges for workforce adaptation (Ghobakhloo & Fathi, 2021). Recently, the main components of Industry 4.0 included: Virtual Reality Systems (CPS), Internet of Things (IoT), Big data, Augmented Reality (AR), Autonomous Robots, Additive Manufacturing (3D Printing), Cloud Computing (CP), Simulation, Artificial Intelligence (AI), Internet of Energy (IOE) and Blockchain (Ing Tay et al., 2018; Stankovic et al., 2017). The report of UNIDO emphasizes that Industry 4.0 is breaking down barriers by combining industries (e.g., information, communication, and entertainment), combining disciplines (e.g., genomics, nanotechnology, and robotics), and combining biology with physics and the virtual world (e.g., cyber-physical systems (CPS) (Stankovic et al., 2017). Muhamad et al (2023) expanded this list to include emerging technologies such as digital twins, edge computing, and 5G connectivity, which are now considered essential enablers of the Industry 4.0 ecosystem. Their critical review highlights how these technologies are increasingly converging to create more sophisticated cyber-physical systems that offer unprecedented levels of automation, predictive capabilities, and system autonomy.

In summary, Industry 4.0 is the future of global manufacturing which aggregates existing ideas into a new value chain that plays a crucial role in transforming whole value chains of life cycle of

goods (Tay et al., 2018) and reshaping economies, workforces, and societies by driving efficiency, innovation, and new business opportunities. As Ojra (2019) defined, Industry 4.0 is advanced digitized manufacturing. Therefore, this revolution represents a groundbreaking advancement in manufacturing and business technologies, profoundly impacting all aspects of life .

Workforce

According to Cambridge dictionary, workforce is the total number of people who are employed or available for work in a particular area, industry, or company. It's often used to describe the people who work for a specific organization, but it can also refer to the entire labor pool in a region or nation (Cambridge Dictionary). In the context of Industry 4.0, the workforce is evolving rapidly, with new skills and competencies becoming increasingly essential.

Several factors can significantly impact a workforce's productivity, morale, and overall success. These factors include economic conditions, technological advancements, demographic shifts, and globalization. Economic downturns can lead to job losses and reduced hours, while economic growth can create new opportunities and increase demand for the labor economy. Technological advancements can automate tasks, leading to job displacement in some areas but creating new roles in others. Demographic changes, such as aging populations and declining birth rates, can affect the availability and composition of the workforce. Globalization can lead to increased competition for jobs and outsourcing of work to lower-cost regions. Understanding these factors is essential for businesses to adapt and thrive in a rapidly changing labor market (The Future of Jobs Report, 2023).

The workforce is a critical factor in the success of Industry 4.0 initiatives. A skilled and adaptable workforce is essential for implementing new technologies, developing innovative products and services, and driving economic growth. However, a skill gap between the skills required for Industry 4.0 jobs and the skills possessed by the current workforce can hinder the adoption and implementation of new technologies (McKinsey Global Institute, 2018). On the other hand, increased automation and robotics can lead to job displacement in certain sectors while creating new opportunities in others (McKinsey Global Institute)

This skills gap has been quantified by recent research from Deloitte and the Manufacturing Institute (2023), which estimates that up to 2.1 million manufacturing jobs could remain unfilled by 2030 due to a shortage of qualified workers. Their survey of over 800 manufacturing executives identified specific skill deficiencies, with 78% reporting difficulties finding workers with the necessary digital skills and 65% struggling to find employees capable of working with automated systems. The report suggests that as manufacturing becomes increasingly digitized, the skills gap could cost the industry up to $454 billion in unproduced GDP during this period.

Literature review about the impact of Industry 4.0 on workforce:

Industry 4.0 leads to "Technological Unemployment"

The economist John Maynard Keynes coined the term "technological unemployment" to describe job losses caused by technological advancements. Keynes recognized that while

technology can displace workers, it can also lead to the creation of new industries and jobs. However, this theory also says that technological advancements will replace human jobs faster than we can create new ones because technologies provide more advanced, more affordable solutions for companies (Szabó-Szentgróti et al., 2021a). The acquisition of robots and machines will replace the unqualified workforce, character and qualifications of the labor force as well as the number of workers in a given industry set to change dramatically (Kurt, 2019). According to Gábor Szabó-Szentgróti et al, today, 50% of all work-related tasks can be automated with 4.0 technologies while only a few jobs (less than 5%) that consist of tasks that cannot be automated at all; meanwhile, in 60% of jobs, one-third of the tasks can be replaced by technology (Szabó-Szentgróti et al., 2021a). In the cells consisting of 54 occupational fields and 63 economic sectors 490,000 jobs will be lost while in other areas 430,000 jobs will be newly created within ten years beyond the baseline scenario (Weber et al., 2016). This requires the employees to have many sets of skills to not be replaced.

Recent studies also indicate that the automation risk is not evenly distributed across job categories. Lower-skilled jobs in repetitive and routine-based industries, such as manufacturing and retail, face the highest risk of displacement. However, the rise of new technology-driven industries is expected to generate employment in emerging fields like cybersecurity, AI development, and data analysis (World Economic Forum, 2023). Furthermore, initiatives focused on upskilling workers to transition into these roles are becoming a critical policy priority (OECD, 2024).

Contemporary economists have refined Keynes' concept to account for the unique characteristics of Industry 4.0 technologies. Acemoglu and Restrepo (2022) introduce the distinction between "enabling" and "replacing" technologies, arguing that previous industrial revolutions primarily deployed technologies that complemented human capabilities, whereas many Industry 4.0 technologies directly substitute for human labor. Their economic models suggest that the displacement effect occurs more rapidly than the complementary effect, leading to temporary but potentially extended periods of employment disruption. They estimate that the adaptation period for labor markets may extend to 8-15 years—significantly longer than with previous technological transitions.

Industry 4.0 leads to new skills and training requirements

As mentioned above, to not be replaced by 4.0 technologies, the labor requires more skill sets and upskilling. Zofia Grodek-Szostak et al pointed out that, employees in the context of the 4.0 industry are required to have the know-how and technological skills, values social and personal skills, critical thinking, analytical skills, emotional intelligence or cognitive flexibility (Grodek-Szostak et al., 2020)… while the study of Puhovichová et al. (2022) shows that entrepreneurial thinking, conflict resolution, creativity, problem-solving, decision making, research skills, analytical skills, efficiency orientation are skills that meet the requirements of Industry 4.0 . Additionally, this study also adds that new jobs related to those skills such as growth hackers, data scientists, customer specialists, artificial intelligence specialists, wind turbine service technicians,

social media assistants, landfill biogas systems technicians, green marketers… are increasingly appearing on the job market (Puhovichová et al., 2022). Agreeing with the above view, Gormus (2019) highlighted that new jobs with higher skills created by Industry 4.0 will require new qualifications and new skill sets. Creativity and decision-making skills and technical and information and communication technologies (ICT) expertise will be capabilities that play an important role.

Industry 4.0 increase workforce productivity and efficiency

Every industrial revolution has brought efficiency and productivity gains (Puhovichová et al., 2022). Industry 4.0 will lead to a significant increase in productivity and efficiency. Because of the disappearance of some jobs, the level of collaboration among people and technologies will increase drastically. It will also provide new opportunities for the integration of people with physical disabilities. The labor productivity gains of technology adoption are not limited to robotics; instead, they are distributed across several Industry 4.0-type technologies (i.e., robotics, laser cutting, big data, and cloud (Puhovichová et al., 2022).

There are 3 main mechanisms by which Industry 4.0 technologies affect firm labor productivity: speeding up production processes, improving the use of inputs and materials, lowering (unexpected) costs as well as waste, innovating production processes and products and facilitating integration and communication among production stages. Moreover, "The adoption of Industry 4.0 technologies has a positive and economically relevant impact on MSME labor productivity, with an estimated 7.4% increase in labor productivity associated with the adoption of new technologies". However, this impact diminishes over time, with the peak gains occurring 2 years after adoption (Bettiol et al., 2024).

Digitalization increases productivity and, in addition, makes work more enjoyable, while promoting interaction with colleagues and supervisors. A happy employee is a productive employee, which means that employees who are satisfied with their jobs and feel happy in their jobs are then more engaged, more productive, and less likely to leave (Salvadorinho et al., 2023)

Industry 4.0 affects women workforce

Women are most vulnerable to technological displacement especially women in low- to middle-income jobs are disproportionately crowded in jobs that will be technologically displaced (Maisiri, 2024). The research of the International Monetary Fund indicates that the trend toward greater automation will be especially challenging for women. According to this study, automation could put women at risk of losing their jobs by up to 11%, while the rate for men is only 9%. Moreover, it's estimated that in the next 20 years, 26 million women's jobs in 30 countries are at high risk of being displaced by technology (Brussevich et al., 2018). Conversely, the research of Martina Porubčinová argues that women appear to face lower risks in replacing them by a machine compared to men's workforce (Porubčinová et al., 2020). Based on the fourth revolution, the new manufacturing environment offers more occupational opportunities for women, such as data scientist, analyst, programmer and software engineer… These positions center on cognitive

abilities instead of physical ones (Ilyana Janisa et al., 2020). Given that the Industry 4.0 technology provides "the cleanliness of production, hi-tech equipment and simplified production layout"(Janisa et al., 2020), the increased use of technology can help to automate routine tasks, freeing up women's time for higher-value work and offer opportunities for more equal participation of women in the labor market, in financial markets and business (Porubčinová et al., 2020).

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Research Methodology

To gain better insight into the situation of the workforce in Southeast Asia in the context of Industry 4.0, this paper will use the qualitative method. In order to achieve this research goal, we sought answers to the following research questions:

RQ1: "What has changed in the Southeast Asia workforce structure in the context of 4.0?"

RQ2: "Does the ASEAN workforce meet the skills of Industry 4.0?"

The research was based on a literature analysis of studies published in the context of Industry 4.0 and Southeast Asia workforce. As a first step, keywords and bibliographic databases were identified. The articles were selected based on the keywords "Fourth Industrial Revolution," as well as the abbreviations of "4IR", "4th IR", and "IR 4.0", followed by "Labor force" or "Workforce" and "Southeast Asia" or "ASEAN". Google Scholar and ScienceDirect were selected for their comprehensive coverage of academic literature across various disciplines. They index a wide array of scholarly works, including peer-reviewed articles, theses, books, and conference papers, making it an essential tool for conducting bibliometric data analysis. In addition, some ASEAN reports from ASEAN Secretariat, Asean Stat also selected to have a deeper insight into the real workforce structure in Southeast Asia. In the following step, theme analysis will be used

to provide further investigation about the way Industry 4.0 impacts Southeast Asia's workforce. This approach involves identifying and categorizing recurring themes or patterns within the data. The following key themes will be explored:

First, the adoption level will be investigated. This includes examining the extent to which Southeast Asian countries have adopted Industry 4.0 technologies and practices. Second, the potential job displacement resulting from Industry 4.0 will be analyzed, as well as the emergence of new job roles. Third, the Readiness of the Workforce for 4IR will be examined. From the secondary data, we will investigate the preparedness of the Southeast Asian workforce to meet the challenges and opportunities of Industry 4.0. Finally, the Female Engagement of Industry 4.0 in the Southeast Asian region will be considered.

By systematically analyzing these themes, this research aims to provide a comprehensive understanding of the evolving dynamics between Industry 4.0 and the Southeast Asian workforce.

3. Research results and discussion:

Current State of Industry 4.0 Adoption in Southeast Asia

Before Industry 4.0, ASEAN economies were primarily focused on traditional manufacturing, agriculture, and low to mid-level service industries. The region's economic growth was largely driven by labor-intensive industries. Vietnam, Thailand, and the Philippines became key players in the global supply chain for electronics, garments, and automotive parts due to their competitive labor costs (United Nations Industrial Development Organization, 2023). The digital economy was still in its infancy, with limited integration of digital technologies into business operations and government services, as evidenced by the low ICT adoption rates in many ASEAN countries during this period. Automation and advanced manufacturing technologies were not widespread; instead, the emphasis was on cost-competitive labor rather than technological innovation. Economic disparities between countries were pronounced, with higher-income nations like Singapore leading in technology adoption, while lower-income countries like Cambodia and Myanmar remained heavily reliant on agriculture, contributing over 20% to their GDPs in 2010.

The mid-2010s marked the period when most SEA countries started seriously engaging with Industry 4.0, with government policies and strategic roadmaps setting the stage for digital transformation across various sectors. According to the ASEAN Employment Outlook which applied the Gross Domestic Product (GDP) per capita as a measurement, one can categorize these countries into three main groups (ASEAN Secretariat). The categories are used to evaluate the 4IR adoption level of SEA countries.

Higher-income countries like Brunei Darussalam, Malaysia, Singapore, and Thailand are leading the way in innovation and digital transformation. Singapore has been a leader in embracing Industry 4.0, starting around 2014 with the launch of initiatives like the Smart Nation strategy, which aimed to integrate digital innovation, data analytics, and AI into various sectors. The ASEAN Employment Outlook highlighted that Singapore is the most advanced in various digital indicators. It is included in the top 10 countries in digital innovation, security, transformation, and trade, and

also included in the top 20 countries in digital government, skills and inclusion, and connectivity (ASEAN Secretariat). Meanwhile, Thailand's engagement with Industry 4.0 began in 2016 with the introduction of the Thailand 4.0 economic model which initiative marked a significant shift towards advanced manufacturing and digital transformation. Thinking Asean Issue 26 pointed out that the use of automation and robotics in Thailand's food and processing industry has been on the rise in recent years. Malaysia is currently focusing on the production of complex and high-value products, or also known as frontier products (Chan, 2017). In 2019, Brunei started to adopt Industrial Revolution 4.0 and transform Brunei into a Smart Nation. Brunei is actively implementing the development of digital technologies, namely: cybersecurity, big data, Internet of Things, AI and 5G.

Middle-income countries like Indonesia, the Philippines, Lao PDR, and Vietnam are also making strides, though at a different pace. The Philippines has overtaken India as a major hub for the IT industry and business process outsourcing. In Indonesia, robotics are becoming increasingly prevalent in industries such as automotive, rubber, and plastics. Vietnam's engagement with Industry 4.0 gained momentum around 2017, with various government initiatives promoting digital transformation. Resolution No. 52-NQ/TW, issued in 2019, solidified the commitment to Industry 4.0 with specific goals set for digital transformation by 2030. Recently, Vietnam, recognized as a leading emerging market, has experienced rapid growth in e-commerce, with revenues projected to reach $5 billion by 2020, making it the fastest-growing e-commerce market globally.

Engagement with Industry 4.0 in Cambodia and Myanmar has been more limited and started later, around 2019-2020. These countries are progressing, particularly in the trade of services, as they gradually shift away from agriculture between 2016 and 2019.

Table 1: Indices for Measuring the Readiness of Industry 4.0

ASEAN Member States	Change Readiness Index (2019)		Digital Readiness Index (DRI)		GCI 4.0: Global Competitiveness Index 4.0	
	Rank out of 140 countries	Rank in ASEAN	Rank out of 146 countries	Rank in ASEAN	Rank out of 140 countries	Rank in ASEAN
Brunei Darussalam	-	-	-	-	56	5
Cambodia	107	8	92	7	106	8
Indonesia	41	3	73	5	50	4
Lao PDR	116	9	115	9	113	9
Malaysia	24	2	42	2	27	2
Myanmar	99	7	110	8	-	-
Philippines	44	4	87	6	64	6
Singapore	2	1	1	1	1	1
Thailand	66	5	51	3	40	3
Viet Nam	83	6	57	4	67	7

Notes: *"-" means data is not available at the time of publication.*

Sources: *KPMG, Cisco, World bank*

Table 1 provides insights into ASEAN countries' performance based on three significant indicators: the Change Readiness Index (CRI), the Digital Readiness Index (DRI), and the Global Competitiveness Index 4.0 (GCI 4.0). These indices evaluate a country's ability to adapt to technological changes, the extent of digital infrastructure and capabilities, and overall economic competitiveness in the Fourth Industrial Revolution (4IR).

Singapore leads ASEAN in all three indices, ranking 1st regionally and within the top 10 globally, demonstrating its robust digital ecosystem, government-led innovation policies, and strong investment in Industry 4.0. Malaysia, Thailand, and Vietnam follow, with relatively high rankings in digital readiness and competitiveness, driven by their respective national strategies for technological advancement. Middle-income nations like Indonesia and the Philippines show moderate readiness levels, particularly in digital infrastructure and industrial automation, though challenges remain in workforce upskilling and regulatory frameworks. Meanwhile, Cambodia, Myanmar, and Lao PDR rank lower, reflecting slower adoption of digital transformation initiatives, weaker infrastructure, and reliance on traditional industries. These disparities highlight the uneven pace of Industry 4.0 adoption across ASEAN, with more developed economies spearheading innovation while lower-income nations face structural and economic challenges in fully integrating into the digital era.

With recent analysis, it is obvious that: i) ASEAN's transformation is not occurring evenly across the region. Higher-income countries, with well-developed technological infrastructures and advanced digital economies, have effectively leveraged technology adoption to drive GDP growth. Meanwhile, other countries considered as middle-income and lower-income countries recently

faced considerable challenges due to limitations in technological infrastructure, a lack of skilled workforce, and an overall readiness gap in embracing digital transformation. ii) A major challenge in ASEAN is that enterprises are often followers rather than innovators in technology adoption. The WEF's Networked Readiness Index 2023 reflects this, with only Singapore in the top 5 globally and the rest were ranked below.

The differences in Industry 4.0 adoption levels across Southeast Asian countries have directly influenced the structure and skill composition of their labor forces. In nations with high Industry 4.0 adoption, such as Singapore, Malaysia, and Thailand, the demand for digitally skilled workers has increased significantly. Singapore's advanced digital infrastructure and government-driven investments in AI and IoT have led to a workforce highly proficient in digital technologies. Similarly, Malaysia's "Industry 4WRD" initiative has encouraged SMEs to adopt automation, driving a growing need for AI and data analytics specialists. Thailand, with its "Thailand 4.0" strategy, has been shifting from low-cost labor-intensive industries to innovation-driven sectors, reducing reliance on manual labor while increasing demand for engineers and IT professionals.

Conversely, countries with lower levels of Industry 4.0 adoption, such as Vietnam, Indonesia, and the Philippines, still rely heavily on traditional labor-intensive industries. While automation and digital transformation are gradually increasing, the workforce in these countries remains largely composed of low-skilled or semi-skilled workers, with a smaller proportion trained in AI, big data, or robotics. For instance, Vietnam has great potential for digital transformation, but its low adoption rate of industrial robots (14%) indicates that much of its labor force is still engaged in manual production processes. In the Philippines, where only 35% of the workforce possesses digital skills, the slow transition to Industry 4.0 limits opportunities for higher-skilled employment.

In developing nations such as Cambodia, Laos, and Myanmar, the minimal adoption of digital technologies (below 10%) has resulted in a labor market that remains predominantly manual and low-skilled. The lack of digital infrastructure and government policies supporting Industry 4.0 further delays the development of a digitally competent workforce. Moreover, low internet penetration rates in these countries hinder access to digital education and skill training, restricting workers' ability to transition into technology-driven industries.

Current State of Workforce Changes in Industry 4.0 in Southeast Asia

In the context of Industry 4.0, the workforce in Southeast Asia is undergoing profound changes due to the rapid development of technology and automation. These changes are not occurring uniformly across countries and industries, creating a diverse picture of the impact of Industry 4.0 on the labor force in the region.

Regarding ASEAN's total labor force in the era of Industry 4.0

From 2013 to 2022, labor force participation rates in ASEAN countries have shown diverse trends. While participation rates have fluctuated across nations, Southeast Asia as a whole has maintained a relatively stable level in this regard. Before the pandemic, Southeast Asia was experiencing steady workforce growth, driven by population increases and economic expansion.

ASEAN countries had a combined labor force of around 350 million people in 2019, with annual growth rates of about 1-2% (*ASEAN Key Figures, 2020*). A young population and rural-to-urban migration contributed to the expanding workforce, with countries like Indonesia and the Philippines seeing significant increases in their working-age population. The onset of COVID-19 in 2020 led to a sharp decline in workforce participation across Southeast Asia. In Indonesia, the unemployment rate spiked from 5.3% in 2019 to 7.1% in 2020. As the region emerged from the pandemic, the workforce began to recover, but not uniformly across all countries. Vietnam saw a quicker return to near pre-pandemic employment levels due to its effective early control of the virus, while countries like the Philippines experienced a more prolonged recovery period. The pandemic accelerated shifts towards automation and digital work, which has permanently altered the workforce composition, with some sectors recovering more slowly than others.

With the onset of Industry 4.0, some countries, such as Indonesia, Malaysia, and Singapore, have recorded slight but steady increases in labor force participation rates, indicating improvements in mobilizing and sustaining the workforce over this period. The rise in labor force participation rates can be attributed to their rapid adoption of new technologies in the economy. Technology has created new industries requiring a more skilled workforce, thereby increasing labor demand and driving up participation rates. However, other countries like Brunei Darussalam and the Philippines experienced more significant fluctuations, with slight declines in some years followed by gradual recoveries. Notably, the Philippines underwent a continuous decline from 63.9% in 2013 to 59.5% in 2020 before rebounding to 64.7% in 2022. Vietnam, one of the countries with the highest workforce participation rates, saw a decline from 77.6% in 2013 to 68.5% in 2022. The decline in participation rates in some countries may be related to technology replacing manual labor and low-skilled jobs. Automation has led to job losses in traditional industries, pushing some workers out of the labor force due to a lack of appropriate skills to transition to new, higher-skilled jobs (refer to Table 2).

Table 2. Labour Force Participation Rate in ASEAN, 2013-2022 (in percent)

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Brunei Darussalam	-	65.6	-	-	62.7	65.4	64.3	65.5	63.8	62.7
Cambodia	83	82.6	82.7	62.5	84.3	-	87.4	-	83.7	83.7
Indonesia	66.8	66.6	65.8	66.3	66.7	67.3	67.5	67.8	67.8	68.6
Lao PDR	-	-	68	-	40.8	-	-	-	-	47.1
Malaysia	67.3	67.6	67.9	67.7	68	68.3	68.7	68.4	68.6	69.3
Myanmar	66.9	67	64.7	-	61.2	61.5	59.4	-	-	-
Philippines	63.9	64.4	63.6	63.5	61.2	60.9	61.3	59.5	63.3	64.7
Singapore	66.7	67	68.3	68	67.7	67.7	68	68.1	70.5	70
Thailand	71.1	70.3	69.8	68.8	68.1	68.3	67.5	67.8	67.8	68.1

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Viet Nam	77.6	77.5	77.8	77.3	76.7	76.8	76.8	74.4	67.8	68.5

Notes: "-" means data is not available at the time of publication.

Source: ASEAN Secretariat

The adoption of Industry 4.0 (I4.0) technologies has had mixed effects on labor force participation in Southeast Asia. In the Philippines, a rebound in participation from 2020 to 2022 can be linked to gradual I4.0 integration, particularly in the outsourcing and IT sectors, where digital platforms and upskilling initiatives created new job opportunities. Conversely, Vietnam, despite being proactive in adopting I4.0 in manufacturing, saw a decline in participation due to the displacement of low-skilled workers unable to transition to more tech-driven roles. This suggests that while I4.0 can drive labor force participation when supported by adequate reskilling and policy initiatives, it can also hinder participation if workers are left behind in the technological transition.

Regarding Proportion of Employment in ASEAN by Economic Activity

According to OECD Local Economic and Employment Development (LEED) Papers 2010/01, most Southeast Asia countries still base their economies on primary industries except Singapore where the service sector is strong. Countries where the highest numbers of people are employed in the agriculture, fishery and forestry sectors are Cambodia, Indonesia, Myanmar, the Philippines and Thailand. Wholesale and retail trade, restaurants and hotels employ the highest number of people in Brunei Darussalam and Malaysia. (Martinez-Fernandez et al., 2009).

During the boom of 4IR, as shown in ASEAN statistical yearbook 2023, there has been a noticeable shift in the labor force from traditional sectors to industries. This trend highlights the region's economic development, industrialization, and urbanization across many countries. As the focus moves towards more industrial and service-oriented sectors, the labor market is evolving to meet the demands of these growing industries, reflecting broader changes in the region's economic landscape (refer to Table 2). As Industry 4.0 introduces advanced technologies such as automation, artificial intelligence, and the Internet of Things (IoT), the region's economies are adapting by shifting their focus toward industries that can leverage these innovations. There is a growing demand for a workforce equipped with new skills, such as digital literacy, advanced manufacturing techniques, data analysis, and technical expertise.

Table 3. Proportion of Employment in ASEAN by Economic Activity (in percent)

Country	Year	Traditional sector (Agriculture, Fishery & Forestry,Construction)	Manufacturing	Wholesales & Retail Trade, Restaurants, & Hotels	Transportation, Storage, Information and Communication	Finance, Insurance, Real Estate and Business Services	Public Services	Others (Mining & Quarrying, Electricity, Gas & Water, Unknown)	Total
Brunei	2020	13.5	4.3	22.7	5.1	8.9	32.5	13	100
	2021	10.6	9.1	21.6	5.1	9.4	31.9	12.2	100
	2022	10.4	6.5	22.8	5.2	10.7	32.2	12.1	100
Cambodia	2011	61.2	9.2	11.3	2.9	0.4	2.6	12.4	100
	2012	53.7	11.8	15.3	4	0.4	2.9	11.9	100
	2019	43.1	16.7	20.2	5	2.5	5.9	6.7	100
Indonesia	2020	36.1	13.6	25.9	5.1	2.9	9.8	6.7	100
	2021	34.6	14.3	26.6	4.9	3	10.3	6.2	100
	2022	34.9	14.2	26.5	5	3.2	10.1	6.2	100
Lao PDR	2015	82.2	3.9	5.8	0.9	0.4	7	-	100
	2017	52.2	11.5	27.1	3.2	0.9	2	3	100
	2022	62.4	4.7	14.3	2.6	4	8.9	3.2	100
Malaysia	2020	18.3	16.7	28.8	6.1	10.9	14.9	4.2	100

	2021	18	16.6	29	6.2	11.1	14.8	4.3	100
	2022	17.6	16.8	29.1	6.2	11.1	14.9	4.3	100
Myanmar	2017	54.8	10.5	17.3	4.8	2.3	4.2	6.1	100
	2018	53.4	11.1	18.3	5.3	2	3.8	6.1	100
	2019	54.5	10.4	20	5.8	2.1	3.3	3.9	100
Philippines	2020	33.7	8.2	24.4	8.4	6.6	11.1	7.5	100
	2021	34	7.8	25.3	7.7	6.7	10.9	7.4	100
	2022	32.4	8	26	8	7.3	10.6	7.7	100
Singapore	2020	4.4	9.6	20.9	14.7	25.5	24	1	100
	2021	4.3	9.3	20.3	14	25.9	25.1	1	100
	2022	4.2	9.6	20.4	14.5	26.1	24.4	0.9	100
Thailand	2020	37.3	15.9	24.3	4.1	4.5	9.4	4.5	100
	2021	37.8	15.7	23.9	4.1	4.5	9.5	4.6	100
	2022	36	16	24.6	4.3	4.9	9.6	4.6	100
Viet Nam	2020	41.9	21.1	18.7	4.3	2.8	7.6	3.8	100
	2021	38.4	22.8	19.8	4.4	2.9	7.8	4	100
	2022	36.7	23.3	20.9	4.4	1.7	8.9	4.2	100

Notes: a. Data for Singapore refer to residents only b. Data for Agriculture, Fishery & Forestry of Singapore are subsumed under "Others (Mining & Quarrying, Electricity, Gas & Water,Unknown)" '-' not available at the time of publication

Source: *ASEAN Secretariat*

Regarding Skill Levels of SEA's Workforce in the context of 4IR-Skills vital for 4IR

Before the rise of Industry 4.0, workforce skills were largely focused on manual labor, routine tasks, and industry-specific expertise.

Digitalization and the use of industrial robots are widespread; however, opinions are divided on their mass appearance and the extent of their effects on employees and jobs. Most analyses report huge changes affecting up to hundreds of millions of jobs worldwide. According to the International Federation of Robotics (IFR) forecast, by 2022, nearly 4 million industrial robots may be present in various work processes, and this number might grow by up to 13% per year (Szabó-Szentgróti et al., 2021b). The characteristics of essential workers in the 4IR will therefore be determined less by the level of training, knowledge, and expertise required to do the job, and more by whether humans hold a comparative advantage over machines in doing the work. Based on current and expected technological advancements, this will mean workers with skills in communications, problem-solving, empathy, moral values, and complicated manual dexterity will have the advantage (Gentile, 2019).

Readiness of the ASEAN Community for the 4th Industrial Revolution in terms of skill level

With the acquisition of robots and machines that will replace the unqualified workforce, the character and qualifications of the labor force as well as the number of workers in a given industry are set to change dramatically. With Industry 4.0 advancing, employers are looking for a greater mix of skills in their future employees, including an amalgamation of both procedural, vocational and soft skills, with a strong capacity for creative thoughts and actions (Adnan et al., 2021). However, the SEA region is facing a shortage of talent capable of optimally utilizing technology while unemployment is still on the rise. These problems can be explained by a gap where the quality of the workforce has not kept pace with the demands of Industry 4.0.

Thinking ASEAN highlighted in Issue 26 that 89% of about 600,000 workers in call centers in the Philippines could face a high risk of automation. According to the Ministry of Labour, Invalids and Social Affairs of VietNam, 41% of the 6.6 million surplus workers lack the IT skills required for new job positions (Ministry of Labour, 2018). Moreover, nearly 30% of workers are missing "interpersonal skills" necessary for future job roles, such as negotiation, persuasion, and customer service. Just over 25% lack "basic skills" like literacy and numeracy. The quality of the labor force, such as technical expertise, is still low (with only over 20% of the workforce having technical skills), and labor productivity is lower compared to many other ASEAN countries. Vietnam is among the countries that are not yet prepared for Industry 4.0, ranking 70th out of 100 in terms of human resources and 81st out of 100 in terms of skilled labor. Only 13% of ASEAN countries are ready in terms of technological infrastructure, policy, and human resource to welcome Industry 4.0.

As analyzed, the SEA's countries are facing certain problems related to the readiness of the workforce for 4IR, which includes: skill gap, increasing unemployment due to automation, and labor productivity.

Regarding SEA's Female Workforce Participation

In the countries where employment has recently shifted out of agriculture from 2011 to 2015, such as the Philippines, Thailand, and Viet Nam, the share of females was greater than males in the services sector. From 2016-2019, as the employment share of the service sector increased, the same countries had a greater share of females employed in services. This points to the relevance of the service sector in providing jobs to women and other vulnerable groups. The table 4 below shows the rate of ASEAN female participation in the overall labor force (ASEAN Secretariat).

Table 4. Labour Force Participation Rate in ASEAN by Sex, 2013-2022 (in percent)

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Male										
Brunei Darussalam	-	72.4	-	-	68.9	72.7	72.5	74.3	71.6	71.5
Cambodia	88.7	87.9	88.5	89.4	88.8	-	91	-	88.7	88.7
Indonesia	83.4	83.1	82.7	82	82.5	82.8	83.3	82.4	82.3	83.9
Lao PDR	-	-	62	-	45.2	-	-	-	-	52.6
Malaysia	81	80.6	80.6	80.2	80.1	80.4	80.8	80.6	80.9	81.9
Myanmar	83.5	85.2	80.2	-	77.3	77	75.4	-	-	-
Philippines	78.1	78.5	77.3	77.6	76.2	75.1	74.8	73	75.4	75.8
Singapore[1)]	75.8	75.9	76.7	76.2	76	75.6	75.4	75.4	77.2	77
Thailand	79.5	79.3	78.6	77.6	76.9	77.1	76.2	76.4	76.3	76.6
Viet Nam	82.1	82.1	83	82.4	81.9	82.3	81.9	79.9	74.3	74.9
Female										
Brunei Darussalam	-	58.3	-	-	56.5	57.3	54.8	55.4	54.9	52.8
Cambodia	77.8	77.5	72.2	78.9	80.1	-	84.1	-	78.9	78.9
Indonesia	50.3	50.2	48.9	50.8	50.9	51.8	51.8	53.1	53.3	53.4
Lao PDR	-	-	69	-	36.5	-	-	-	-	41.9
Malaysia	52.6	53.7	54.1	54.3	54.7	55.2	55.6	55.3	55.5	55.8
Myanmar	50.7	50.5	51.6	-	47.7	48.5	46.1	-	-	-
Philippines	49.9	50.5	50	49.3	46.2	46.6	47.6	45.8	51.2	53.5
Singapore[1)]	58.1	58.6	60.4	60.4	59.8	60.2	61.1	61.2	64.2	63.4
Thailand	63.1	62	61.6	60.6	59.8	60.1	59.4	59.8	59.9	60.3

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Viet Nam	73.3	73.2	72.6	72.5	71.9	71.6	71.8	69	61.6	62.4

Notes: 1) Data for Singapore refer to resident only '-' not available at the time of publication

Source: ASEAN Secretariat.

The table 4 highlights an increase in the number of ASEAN females involved in the labor force. In most ASEAN countries, except for a few like Viet Nam and Brunei Darussalam, there was an increase in female labor force participation over the years. Female labor force participation in Indonesia rose from 50.3% in 2013 to 53.4% in 2022, showing steady progress over the decade. While the rate of Malaysia increased from 52.6% in 2013 to 55.8% in 2022, indicating a gradual but consistent upward trend. The most significant increases were observed in Cambodia, Indonesia, and Singapore, indicating more women entering the workforce in these countries. Female participation in Cambodia jumped from 77.8% in 2013 to a peak of 84.1% in 2019, before stabilizing at 78.9% by 2021 and 2022.

Despite some increases, the overall female labor force participation remains lower than that of males in all countries. This reflects ongoing gender disparities in the labor market, where women might face more barriers to entering and remaining in the workforce.

Data shown by ASEAN statistical yearbook 2023 highlights that in many ASEAN countries, female unemployment rates tend to be higher than male rates. Also, the COVID-19 pandemic had a significant impact on female unemployment rates, with noticeable spikes in 2020 across several countries, such as the Philippines (9.7%), Brunei Darussalam (8.8%), and Indonesia (6.5%). This reflects the disproportionate effect of the pandemic on sectors where women are more likely to work, such as retail, hospitality, and service industries. Due to ASEAN Employment Outlook, female workers in any age group seem to have a higher unemployment rate than their male counterparts. Traditionally, women, however, look for temporary and irregular jobs (ASEAN Secretariat).

4. Conclusions

This study sheds light on the impact of Industry 4.0 (4IR) on the labor market in Southeast Asia, highlighting both the opportunities and challenges it presents. The findings indicate that while Industry 4.0 creates new job opportunities through the emergence of advanced technologies, the pace of job creation remains slower than the pace of job loss due to automation and other technological advances. This leads to increased unemployment, especially for workers lacking the appropriate skills, and requires workers to upskill and reskill to remain competitive.

In addition, the study also points out significant disparities among countries in the region in their readiness to engage in Industry 4.0. Countries such as Singapore and Malaysia are better prepared with a highly skilled workforce and developed digital infrastructure, while Laos,

Cambodia, and Myanmar still face many skills and infrastructure constraints. Employment rates also vary widely, from low-skilled jobs to high-skilled positions, reflecting the diversity of skills and needs of each country.

In terms of the skill level of Southeast Asia's workforce in the context of the 4IR, much still needs to be improved. The ASEAN Community's readiness for the 4th Industrial Revolution in terms of skills levels remains limited, with an urgent need to improve the quality of education and skills training for the current and future workforce. In particular, women's labor force participation in the region is limited by cultural and social barriers, requiring policies that support and encourage women to participate more actively in the technology and engineering sectors.

Overall, this study highlights the need to develop comprehensive and flexible strategies to prepare Southeast Asia's workforce for the changes by Industry 4.0, while promoting diverse and inclusive participation in the rapidly evolving digital economy.

This study provides a comprehensive analysis of the impact of Industry 4.0 on the workforce in Southeast Asia, yet it has several limitations that highlight opportunities for future research. One of the primary limitations is the scope of the study, which focuses on data primarily from secondary sources such as governmental and international organization reports, excluding peer-reviewed articles and empirical studies. This approach might limit the depth of understanding regarding specific country-level challenges and opportunities in the region.

Moreover, the study does not fully explore the long-term effects of Industry 4.0 technologies on different sectors beyond the manufacturing and service industries. Future research should consider examining other sectors, such as agriculture and healthcare, where the impacts of 4IR technologies could differ significantly and where unique challenges and skill demands may arise.

Another limitation lies in the generalization of the findings across Southeast Asia. The study identifies a significant disparity in readiness and adaptation levels among countries in the region, suggesting a need for more localized studies that focus on individual countries' specific socio-economic contexts, labor market dynamics, and educational systems. This would provide a more nuanced understanding of how Industry 4.0 affects the workforce in each country, considering the diverse economic development stages and labor market structures.

To build upon the findings of this research, future studies should include longitudinal analyses to track the evolution of skill demands and employment patterns over time as Industry 4.0 technologies become more embedded in the workforce. There is also a need for empirical research that employs mixed-method approaches, combining quantitative data with qualitative insights, to provide a holistic understanding of the multifaceted impacts of Industry 4.0 on the workforce. Exploring these areas will not only fill the existing gaps but also provide deeper insights into the policy interventions needed to foster a resilient and inclusive labor market in the era of digital transformation.

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