THE IMPACT OF GLOBAL VALUE CHAIN PARTICIPATION ON TOTAL FACTOR PRODUCTIVITY OF RENEWABLE ENERGY IN CHINA: THE MODERATING ROLE OF DIGITALIZATION

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UNIVERSITI SAINS MALAYSIA

2025

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by

NING CHENGJIA

Thesis submitted in fulfilment of the requirements
for the degree of
Doctor of Philosophy

September 2025

ACKNOWLEDGEMENT

My PhD journey has been the fastest growing period of my life, with anxiety, confusion, but more happiness and achievement. I have been supported by many people through my PhD journey, this thesis would not have been finished without those help.

First and foremost, I would like to thank my supervisors, Professor Dr. Noorliza Karia and Associate Professor Dr. Haslindar Ibrahim, for their patiently and efficiently guidance, my scientific ability has been improved.

Second, I would like to thank the School of Management for providing me with a good research and learning environment through various academic activities. I would like to thank Ms. Robitah Spian and the examiners, Professor Dr. Fadzlan Sufian, Associate Professor Dr. Khaw Khai Wah and Associate Professor Dr. The Sin Yin for their great support during my PhD journey.

Third, I would like to express my special thanks to my wife and my daughter. It was my wife's support that encouraged me to continue my studies during my resignation, and my daughter spent a shorting 3 months with me in Malaysia. Thanks for their continuous love and support.

Last but not least, I would like to thank my friends and classmates at USM for their guidance, support and help during my PhD journey. Of course, I would also like to thank USM for providing me with the opportunity.

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ABSTRAK

Dengan kedalaman globalisasi ekonomi, tenaga boleh diperbaharui boleh menggalakkan pembangunan mampan masyarakat. Walau bagaimanapun, kesan penyertaan dalam rantaian nilai global (GVC) ke atas jumlah faktor produktiviti tenaga boleh diperbaharui (TFP) telah menghasilkan kepelbagaian. Pendigitalan menyuntik tenaga baharu ke dalam pembangunan perindustrian dan mempercepatkan pengemaskinian teknologi dan produk. Apakah kesan rantaian nilai global terhadap jumlah faktor produktiviti industri tenaga boleh diperbaharui China? Apakah peranan pendigitalan? Untuk menjawab soalan di atas, kajian ini memilih 26 wilayah China pada tahun 2011-2020 sebagai sampel penyelidikan, kebaharuan mencadangkan laluan evolusi "penyertaan dalam GVC - pendigitalan - TFP tenaga boleh diperbaharui", dan buat pertama kalinya menganalisis kesan GVC pada TFP tenaga boleh diperbaharui dari perspektif pendigitalan. Kajian itu turut menganalisis kesan penyederhanaan pendigitalan selanjutnya. Dengan menggunakan analisis model regresi, kesimpulan menunjukkan bahawa: 1) Jumlah factor Produktiviti tenaga boleh diperbaharui di Wilayah China telah meningkat secara beransur-ansur, di mana sumbangan perubahan teknikal adalah lebih tinggi daripada kecekapan teknikal. 2) GVC mempunyai kesan positif yang ketara terhadap TFP tenaga boleh diperbaharui. 3) Pendigitalan memainkan peranan penyederhana yang penting dalam hubungan antara GVC dan TFP tenaga boleh diperbaharui, yang telah diuji untuk mengukuhkan kesan positif yang disebabkan oleh GVC. Berdasarkan dapatan yang dibentangkan, kajian ini

membayangkan bahawa pembangunan tenaga boleh diperbaharui harus mengukuhkan pelaburan penyelidikan dan meningkatkan penyertaan dalam GVC, tambahan pula, pendigitalan perlu dititikberatkan kerana kesan penyederhanaannya. Selanjutnya, batasan penyelidikan telah dibincangkan dan cadangan untuk penyelidikan masa depan telah dibentangkan.

THE IMPACT OF GLOBAL VALUE CHAIN PARTICIPATION ON TOTAL FACTOR PRODUCTIVITY OF RENEWABLE ENERGY IN CHINA: THE MODERATING ROLE OF DIGITALIZATION

ABSTRACT

With the depth of economic globalization, renewable energy can greatly promote the sustainable development of society. However, the impact of participation in global value chain (GVC) on renewable energy total factor productivity (TFP) has produced heterogeneity. Digitalization injects new vitality into industrial development and accelerates the updating of technology and products. What is the impact of global value chain on the total factor productivity of China's renewable energy industry? what is the role of digitalization? To answer the above questions, this study chooses 26 provinces of China in 2011-2020 as the research samples, novelty proposes the evolution path of "participation in GVC – digitalization – renewable energy TFP", and for the first time analyzes the impact of GVC on renewable energy TFP from the perspective of digitalization. The study also analyzes the moderating effect of digitalization. By employing regression model analysis, the conclusions indicate that: 1) China's provincial renewable energy total factor productivity has gradually increased, in which the contribution of technical change is higher than that of technical efficiency. 2) GVC has a significantly positive effect on renewable energy TFP. 3) Digitalization plays a significant moderating role in the relationship between GVC and renewable energy TFP, which has been tested to strengthen the positive effect caused by GVC. Based on the findings tabled, this study implies that renewable energy development should strengthen the research investment and increase the participation in GVC, furthermore, digitalization should be emphasized because of the impact of its

moderating effect. Further, limitations of the research were discussed and recommendations for future research were presented.

CHAPTER 1

INTRODUCTION

1.1 Introduction

A massive increase in renewable power capacity during 2024, reaching 4448 GW. The 585 GW addition last year indicates a 92.5% share of the total capacity expansion, and a record rate of annual growth (IRENA, 2025). However, renewable energy cannot adjust its output in response to fluctuations in power demand, leading to a mismatch between supply and demand. This imbalance can be addressed by digital system (Wang et. al., 2025). Digitalization is a key enabler and accelerator of this transformation, but digitalization serves very different purposes in different regions (IRENA, 2025). Therefore, it is necessary to study renewable energy resources to meet current energy demand and maintain a sustainable development.

Chapter 1 mainly presents the research background, problem statements, research questions, research objectives, research significance, and the organization of this study. First, a thorough examination of the current global energy and environmental situation, with a specific focus on China, this section explains the necessity of the usage of renewable energy. Second, the problem statements, research questions, and research objectives are elaborated. Third, discuss the research significance of this study. Fourth, illustrates the key item of this study. In addition, Chapter 1 provides a detailed account of the structure and arrangement of this study.

1.2 Background

As the global economy advances and the population grows, the energy situation is becoming more and more severe, and the problem of world energy security is becoming increasingly prominent. At present, the world's primary energy sources are still coal and oil, which affect the sustainable development of countries in the future (Bekun et al., 2019). Reducing the use of conventional fossil fuels is essential to safeguarding the stability of the world's energy resources and addressing the problems caused by air pollution and climate change.

First, Renewable energy plays a crucial role in achieving sustainable societal development and can effectively solve the problem of fossil energy depletion (Wang, 2022). Second, incorporating more renewable energy into the energy structure is positive to regional economic development. Finally, the utilization of renewable energy as a replacement for fossil fuels can greatly reduce the discharge of air pollutants and slow the rate of global warming, making the immediate environmental benefits of renewable energy more evident (Chen et al., 2023; Galimova & Breyer, 2022).

Renewable energy can not only replace fossil energy to provide continuous energy power for global economic growth but also can help alleviate the negative consequences of energy utilization on both human civilization and the environment. Developing renewable energy can also promote energy upgrades, ensure energy security, enhance the overall condition of the global environment and, in addition, attain sustainable development in human society.

1.2.1 Background of Energy Consumption

Conventional fossil energy sources such as coal, oil, and natural gas related with significant implications for national security and development. In 2022, according to British Petroleum Amoco (BP), the global reserves of oil are 237.33 billion tons, the global reserves of natural gas are 188.07 trillion cubic meters, and the global reserves of coal are 1,074.11 billion tons (Figure 1.1).

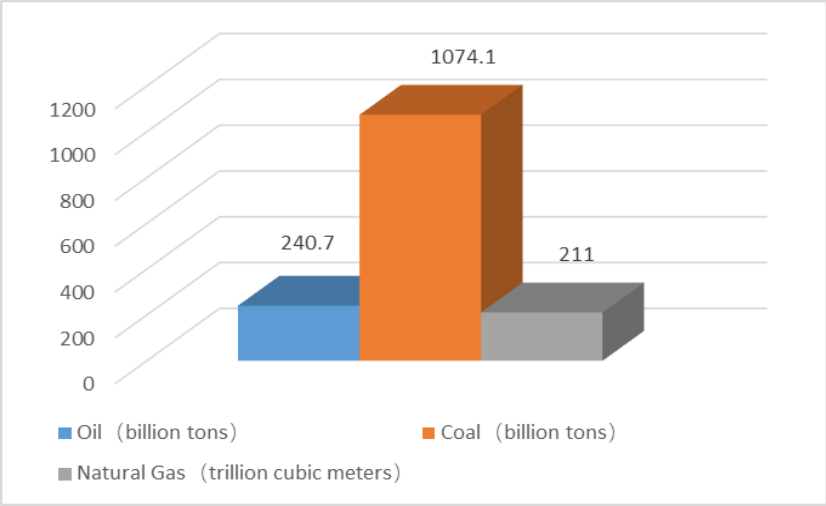

Figure 1. 1 Major Global Energy Reserves in 2022

Source: BP (2023)

The world's oil reserves are mainly distributed throughout Middle East countries. The US and Russia have the greatest coal reserves worldwide, while Russia ranks the top producer of natural gas. Overall, three major energy reserves in Russia are at the forefront of the world (Figure 1.2).

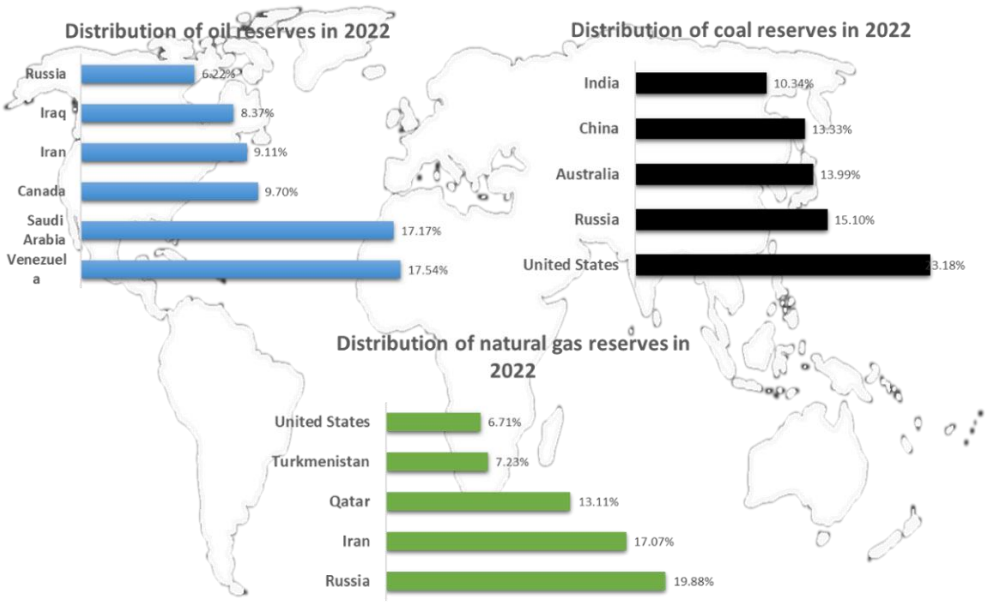

Figure 1. 2 Distribution of Major Global Energy Reserves in 2022

Source: BP (2023)

Before 2019, oil, coal, and natural gas production all showed an upward trend globally. Production of the three main fossil fuels was hampered in 2020 by the COVID-19 pandemic, although traditional energy generation began to recover in 2021. The three main energy-consuming sources accounted for 78.6% of global consumption of energy in 2022, and renewable energy consumption only accounted for 14.7% (Figure 1.3) (BP, 2023). It can be viewed that traditional fossil energy consumption is still the mainstream.

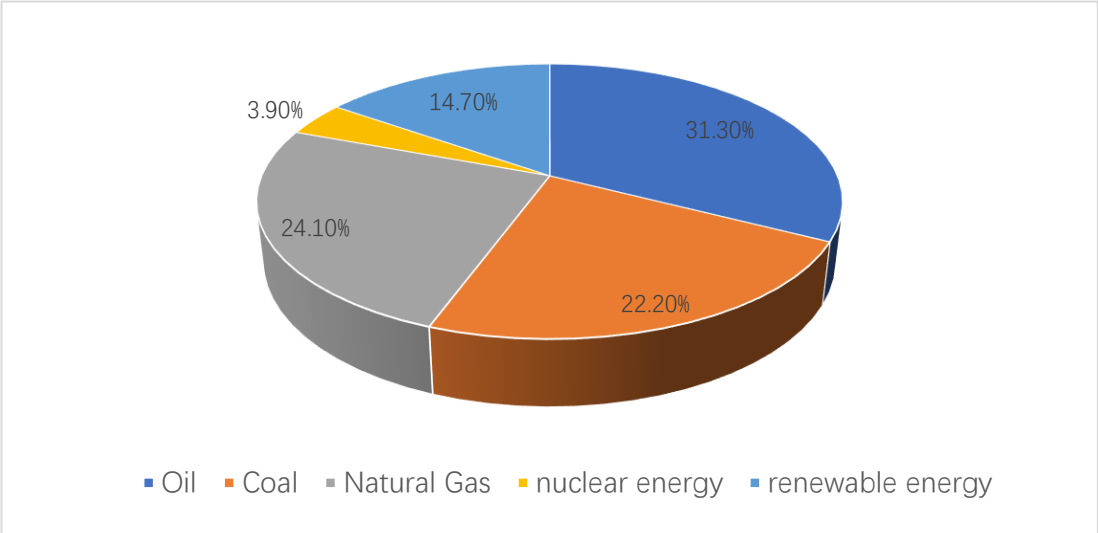

Figure 1. 3 Global Energy Consumption Structure in 2022

Source: BP (2023)

By the Russia-Ukraine conflict in 2022, the shortage of natural gas in Europe is prominent, and since 2021, the energy problem has gained increasing attention as a result of rising global prices for fossil fuels and raw materials, and using renewable energy is now a key component of any response strategy.

The Renewable Energy Policy Network for the 21st Century (REN21) released the Renewables 2022 Worldwide Status Report, 135 countries have set net-zero emissions targets, 84 countries have economic targets for renewable energy, 156 countries have set renewable energy power incentives, 70 countries have renewable energy transport incentives, 26 countries have incentives for renewable energy heating or cooling (REN21, 2023) to realize the transformation of the global energy structure from fossile fuels to renewable energy sources.

Although renewable energy consumption is in a weak position, the rapid expansion of wind and solar power accounts for all or most of the increase global electricity generated. This can be underpinned by their continuing decline in cost and

the increasing ability of energy systems to integrate high concentrations of various energy sources. The average increase in installed capacity in solar and wind is 600-750GW each year in the 2030s and 700-750GW in the 2040s, which two or three times faster than the highest increase seen in the past (BP, 2023).

Compared with fossil energy, renewable energy contributes the least to environmental degradation, so economies have accelerated the development and consumption of renewable energy, the comprehensive application of renewable energy can also greatly alleviate the uneven economic development caused by the uneven distribution of fossil energy (Jithin & Renjith, 2025). At present, the proportion of renewable energy power generation is gradually increasing globally, however, it's relatively rare in construction, industry, agriculture, transportation, and other sectors.

1.2.2 Trends in the Globalization of Renewable Energy

Within the framework of the worldwide effort to combat the COVID-19 pandemic, national trade has been severely curtailed, and it also has a great influence on the energy trade of various countries. The operation of traditional energy value chains has been hindered. It has affected the country's economic development. The advancement and exploitation of renewable energy mostly rely on the unique benefits offered by the resources available in each country. The application of renewable energy can lower energy cost, reduced imports and dependency on fossil energy, as well as alleviate the nation's energy crisis.

The development of global trade and cooperation has led to the international division of labor being the main working mechanism of the worldwide market. When

nations participate in the worldwide division of labor according to their own advantages, the result is the formation of the Global Value Chain. The global value chain gradually differentiates between upstream and downstream based on variations in added value, with upstream countries generally having a financial advantage and focusing on acquiring valuable relationships with significant added value, such as service development and technology research and development (R&D), and with countries downstream generally having the advantage of labor, focusing on the production and manufacturing links, and have low added value.

Developed countries have acquired proficiency in the majority of the fundamental technologies pertaining to renewable energy during the progression of the renewable energy sector. and there is a clear gap between developing countries. Europe, Japan, and the United States dominate the current global renewable energy technology innovation patents. From 2000 to 2019, the combined number of patents in the United States, Japan, and Europe constituted almost 75% of the total international patents for low-carbon energy technologies, South Korea and China accounted for 10% and 8% respectively, while other emerging economies and developing countries accounted for a lower proportion (EPO-IEA, 2021).

In the initial GVC of renewable energy, developed economies occupy an advantageous position in the value chain through technical cooperation. The export of related technologies has been tightly regulated, placing developing nations at a disadvantage in the global renewable energy market, developing countries mostly depend on foreign direct investment (FDI) and technology purchases to support the rapid development of their clean energy companies (Yanikkaya & Altun, 2020). By

the empirical evidence from industrial development and scholarly study, renewable energy has a highly reliance on technologies, which developing nations are disadvantage, leads to a low position of renewable energy GVC. How to exchange this situation? investing in talent development, improving technical capabilities, boosting service value, and increasing investment are the effectively path (Qiaoling et al., 2022).

The renewable energy GVC is now in its early stages of growth. In the process of upgrading the energy structure, the existing industrial system still uses fossil energy as the main energy source, utilizing renewable energy raises the enterprise's production costs and demands greater infrastructure investment; what's more, advanced technology is needed for the growth of renewable energy GVC, different countries have different types of renewable energy and different products, thus, it is difficult to form a complete industrial supply chain, what's more, not formed a complete renewable energy GVC yet.

1.2.3 Trends in the Digitalization of Renewable Energy

At present, the importance of digitalization is increasing in many enterprises, as the rapid development of digital technology causes services to be more intelligent, predictable and standardized. The industrial sector is aggressively encouraging businesses to upgrade and undergo digital transformation, particularly in areas like as buildings and power infrastructure. The aim is to ensure the secure, stable, and effective function of goods and machinery. There has been ongoing expansion in several areas, such as consulting, operations and maintenance, and digital services (Duraivelu, 2022).

Digital is not only a relatively independent element of the manufacturing industry but also more effectively combines traditional development element across time and space, giving new formats in the manufacturing industry (Avom et al., 2020), especially in high-tech manufacturing, which leads the manufacturing industry into an era of digitalization (Duraivelu, 2022). Expediting the process of digitizing and enhancing the industrial sector has become crucial in facilitating superior growth in the economy.

By using digital technology to collect more precise statistics on the efficiency of renewable energy utilization, the field of renewable energy can achieve more flexible resource development. Moreover, digitalization can also improve the management efficiency of renewable energy enterprises, especially multinational corporations, which can lower management costs and accelerate the promotion efficiency of new technologies in enterprises (Lin & Huang, 2023).

Although digital globalization offers additional impetus for global economic progress, it also presents new obstacles, such as worries about data safety and the growing digital divide, which require further strengthening of data management (CAICT, 2022). The combination of renewable energy and information technology may not only promote technical upgrading but also increase costs, which could result in a decrease in utilization of energy. Therefore, the relationship between digitalization and energy consumption needs further argumentation (Bano et al., 2022).

Due to the strong integration of the current energy system with industrial output, the adoption of renewable energy is hindered by its higher prices. Digitalization as a new economic factor, can bring higher productivity for enterprises, promote the

expedited advancement and implementation of renewable energy technologies, causing the price of using renewable energy to steadily decline (Wang et al., 2023). The digital transformation of social production methods has been facilitated by the emergence of the Internet, artificial intelligence, and big data collections (Lange et al., 2020), and digitalization plays a vital role in moderating the shift of energy structure (Shahbaz et al., 2022).

1.2.4 China's Energy Status

China's economy has experienced tremendous development since the implementation of the "Economic Reform and Open-up" policy in 1978, but with the economy having made remarkable progress, it has caused huge energy consumption due to high consumption and high investment. China surpassed all other countries in 2006 to become the world's biggest emitter of carbon emissions (Yang et al., 2020). Recently, the Chinese government set lofty goals to reach carbon neutrality by 2060 and peak carbon emissions by 2030, following an average annual increase in carbon emissions of more than 11% between 2000 and 2016. (Xiang et al., 2023). There is huge energy demand and most of the energy depends on imports, which is also a huge challenge for energy security.

As the basic industrial sector of the national economy, China's energy sector faces major problems such as industry structural adjustment and the transformation of economic growth. In China's current energy structure, fossil energy dominates, and the dependence on oil imports has exceeded 50% since 2009 (Zhao et al., 2023).

Energy security in China mainly focuses on three aspects: First, supply security. The dependence on oil and natural gas imports is high, which leads to a great threat to energy security. In an emergency, it is easy to fall into an energy crisis. Second, price security. The fluctuation of international oil prices is greatly affected by political, financial, and other factors, especially after major political events in petrol-power and gas-rich countries. The fluctuation of oil prices may cause an economic crisis. Third, transportation channel security. China's oil transportation relies on the Malacca Strait and other economic channels, which pose political and security risks (Lee & Wang, 2022; Xie et al., 2022; Yang et al., 2022; Zhu et al., 2022).

As China's economy grows rapidly, there is a notable increase in the imbalance between the availability and demand for high-quality energy. This, in turn, puts enormous strain on raw materials and the environment, highlighting the shortcomings of traditional energy sources. China, being the second largest economy globally, mostly relies on coal as its conventional energy source, which is inefficient in energy utilization and has also brought about huge ecological disasters (Zhao et al., 2023). China has integrated into the world economy, and the consumption of coal resources and other conventional energy sources can no longer satisfy the criteria for long-term economic development and sustainable environmental improvement. The only way to do this is to replace traditional energy with clean energy, vigorously promote the transformation of energy consumption structure, improve energy self-sufficiency, alleviate the energy crisis, and improve ecology (Wang, 2021).

To alleviate the national energy security crisis, achieve the goals of *The Paris Agreement*, and accelerate the upgrading of the energy structure (Wu & Lin, 2018),

China needs to develop the renewable energy industry as an important countermeasure to the energy crisis. China has made significant progress in improving its energy consumption structure in recent years. Data from the National Energy Administration of China (NEA) indicates that in 2022, renewable energy consumption accounted for 17.5%, an increase of 5.5% over 2015 (NEA, 2023) (as shown in Figure 1.4), however, a sizable portion of traditional fuels were still used. Further optimization of the energy consuming structure is required.

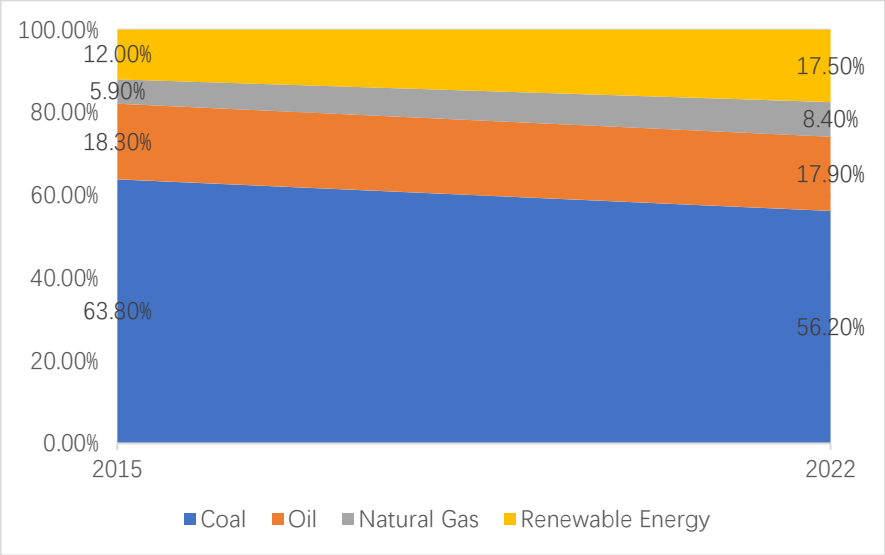

Figure 1. 4 Changes in China's Energy Consumption Structure

Source: NEA (2023)

Electricity is the primary kind of energy and serves as an indicator of progress in society and the economy. To some degree, it demonstrates the velocity and impetus of progress in several domains. As the manufacturing sector continues to undergo the process of continual development, electricity demand is also increasing rapidly, resulting in higher energy consumption. simultaneously, due to China's overall energy constraint, the supply of power resources has surpassed the demand. Industrial power

rationing has grown increasingly prevalent, particularly since 2020. It is analyzed that the main reason is that China's coal power accounts for more than 70% (Figure 1.5), but due to the limitation of mining and import, coal power cannot meet the needs of economic development, and it has seriously restricted industrial development.

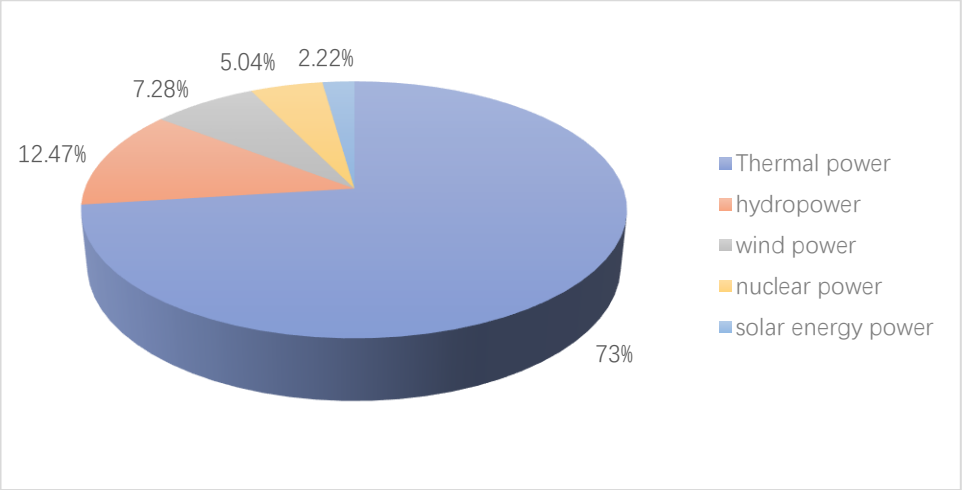

Figure 1. 5 Composition of China's Power Generation in 2021

Source: NEA (2022)

China possesses a wide geographical area that is rich in renewable resources such as hydropower, wind and solar power, and other types of alternate energy. Improving the power generation capacity of renewable energies can significantly alleviate situation of China's power shortage and bring about the modernization and reform of China's energy system.

China relies heavily on imports of natural gas and petroleum. The advancement of renewable energy is essential not just for ensuring energy security but also for fulfilling obligations to reduce carbon emissions. In addition to endorsing the development of new and renewable energy sources and ensuring national energy security, China proposed that the revolution in energy production and consumption be

advanced in the future. (NEA, 2022). Due to the advantages of less environmental pollution, relatively abundant raw materials, renewable energy, and the capacity to stimulate the advancement of the industrial supply chain, energy from renewable sources has emerged as a pivotal focus in the advancement of the energy sector.

China's role in renewable energy has grown, and it is progressively taking the lead in assisting in the transformation of the world's energy system. China holds the distinction of being the global leader in renewable energy, with the greatest installed generation of renewable energy sources worldwide, encompassing both solar and wind energy utilization (BP, 2023). China's energy consumption is rapidly shifting to a low-carbon model, owing to a number of measures that encourage the growth of renewable energy (as shown in Table 1.1).

Changes have occurred in the global value chain of renewable energy as a result of the growth of the renewable energy sector in various countries. In particular, throughout the past many years, the international division of production has been moving towards vertical specialization, and the economic integration and international division of production have been continuously refined, causing the upgrading of the renewable energy industry and global allocation of resources, China has rapidly expanded the scale of its renewable energy industry and actively participated in the global value chain with its advantages in labor, resources, and economy (Ge et al., 2018).

Table 1. 1 Statistics on China's Renewable Energy Policy

Year	Name of Policy	Information
2005	Renewable Energy Law	Legislation regarding the advancement and utilization of sustainable energy sources in China
2006	Interim Measures for the Management of Special Funds for Renewable Energy Development	Create a dedicated fund for the advancement of renewable energy, aimed at providing financial assistance for the research and development of renewable energy technology
2012	Interim Measures for the Administration of Additional Subsidy Funds for Renewable Energy Electricity Prices	Enhance the level of financial support for the generation of power from renewable energy sources.
2017	Energy Production and Consumption Revolution Strategy	Accelerate the development of solar power generation technology and equipment manufacturing, research and develop renewable energy large-scale consumption technology, and study the new generation of ocean energy and biomass energy utilization technologies
2021	Carbon Peak Action Plan by 2030	Advocating comprehensive and superior advancement of renewable energy, adhering to both centralized and decentralized methods, exploring the utilization technologies of various renewable energies, further improving the guaranteed technology of renewable energy power consumption, and keeping up the promotion of raising the installed capacity of renewable energy overall
2021	Guiding Opinions of the State Council on Accelerating the Establishment and Improvement of a Green, Low-Carbon, and Circular Development Economic System	encouraging the energy system to become greener and lower in carbon emissions, boosting the share of renewable energy use, and actively supporting the growth of the wind and solar power industries
2022	Rural Construction Action Implementation Plan	Execute clean energy building initiatives in rural areas, cultivate renewable energy sources such as solar, wind, hydro, geothermal, and biomass, and form a regional renewable energy utilization system
2022	Implementation Plan for Promoting the High-Quality Development of New Energy in the New Era	Support enterprises to deploy decentralized renewable energy power generation projects, encourage the building sector to fully integrate renewable energy sources like geothermal, solar, and other energy sources, and to accelerate the development of innovative energy storage technologies

Source: Shenzhen Electronic Chamber of Commerce (SECC, 2022).

The upgrading of energy structures has become the trend of global energy development. The global value chain of renewable energy will progressively emerge and improve, and countries will face new energy rivalry. Within this framework, each nation's Total Factor Productivity for renewable energy will take on significant importance as an indicator.

The China Academy of Information and Communication Technology (CAICT) reported significant growth in the digital service trade within Asia Pacific region between 2005 and 2020, accounting for 17% -24% of the global share, making it the most dynamic region in the global digital economy. Due to the swift advancement of mobile telephone technology 5G and artificial intelligence (AI), digitalization is leading international cutting-edge technological cooperation more diversely (CAICT, 2022).

The digital economy in China is impeded by the comparatively low total implementation of digital technology (He et al., 2022), thereby affecting energy productivity. China has strong capabilities in digital infrastructure construction. The industrial industry in China had a 48.7% digitization rate as of June of 2020. However, the contribution of digitalization to technology is relatively low, the quality of digitalization needs to be improved (Cheng et al., 2023).

China participates in the GVC, which altered the structure of China's renewable energy industry and input factors. However, China has no obvious advantages in renewable energy technology, it faces "low-end lock" risk in the GVC of renewable energy (Hu et al., 2021). Regarding the numerous challenges that arise from China's participation in the GVC, digitalization can expedite the development of renewable

energy technologies, reduce the expense of utilizing renewable energy, and enhance the frequency of exchanging renewable energy information.

However, how does GVC impact the TFP in China's renewable energy industry? What role does digitalization play in China's renewable energy industry's integration into the global value chain? What is the impact path?

Explaining the above problems effectively can provide theoretical support and practical direction for China's renewable energy sector to engage in the GVC. Furthermore, it serves as a guide for other emerging economies to participate in the global value chain of renewable energy.

1.3 Problem statement

According to the tabled above, China has achieved significant advancements in renewable energy, yet, it is still in the developmental phase. To address the questions raised above, this section examines the current problem statement in China from three aspects: Renewable energy Total Factor Productivity, participation in Global Value Chain, and Digitalization.

1.3.1 Statement of Renewable Energy Total Factor Productivity

Heavy environment cost. The Chinese economy has expanded quickly since the "Economic Reform and Opening-up," however at an incurred heavy environmental cost (Jiang et al., 2020). Restructuring its energy infrastructure and increasing the usage of power from renewable energies could help China significantly reduce carbon dioxide emissions. However, the advancement of renewable energy generation in

China is currently in its growing phase, and there are still disadvantages in terms of utilization, digitalization, and market expansion, which lead to a low development efficiency of renewable energy (Xin et al., 2022).

Strictly CO2 reduction. China has comparatively little oil and natural gas reserves, but enormous coal deposits, resulting in China's energy consumption relying mainly on coal and generating greater carbon dioxide emissions (Wen & Jia, 2022). To achieve net zero emissions, China has made significant efforts in terms of energy consumption structure (Xu & Ge, 2020). Some studies argued that China might upgrade its energy consumption by lowering total coal consumption through regulatory measures, thereby, improving energy total factor productivity (Peng et al., 2021). From the standpoint of sustainable development, renewable energy production can assist in resolving the conflict between economic progress and environmental restrictions.

China's energy transition remains inefficient due to the low TFP of renewable energy, thereby constraining the release of new drivers of economic growth. The low efficiency of energy utilization leads to increased production costs and heightened operational pressures on enterprises, subsequently undermining their capacity to expand investment and generate employment opportunities (Xin et al., 2022). Moreover, the insufficient supply of renewable energy inhibits the expansion of green consumption demand, thereby slowing the optimization and upgrading of the consumption structure. The deceleration of the energy transition process has further exacerbated interregional development disparities and restricted the potential

expansion of domestic demand, ultimately exerting a negative impact on real economic growth, job creation, and consumption expansion.

Imbalance development of renewable energy in different provinces. During the development of renewable energy in China, it has been an uneven development: (1) Higher investment in hydro, solar and wind energy, but lower investment in other renewable energy sources (Jianda et al., 2023); (2) In comparison to inland provinces, the growth of renewable energy is occurring more quickly in coastal provinces (Zhang, 2019); (3) It is still early in the process of changing the structure of energy consumption (Wang et al., 2023). These lead to relatively low level of renewable energy TFP (as shown in Figure 1.6).

In renewable energy sector, China has a rapidly development, however, high environment cost, strictly CO2 reduction and Uneven development leads to a complex situation, which should conduct a appreciate model to measure the renewable energy TFP of China.

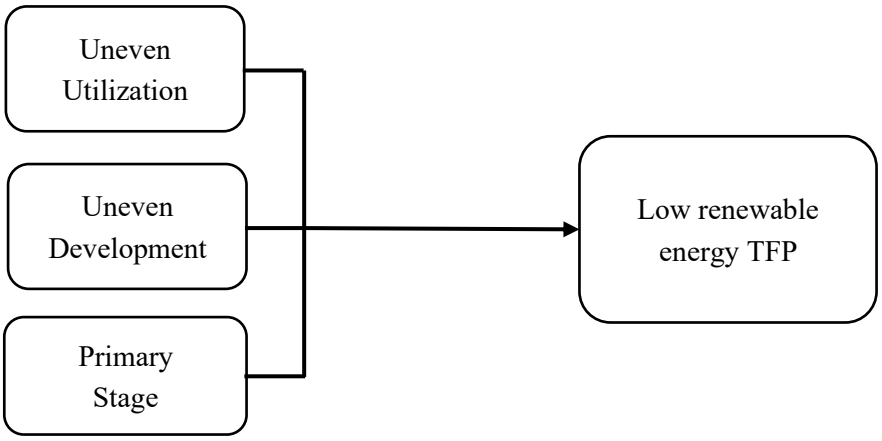

Figure 1. 6 Statement of Renewable Energy TFP in China

Source: Xin et al. (2022), Zhang (2019), Jianda et al. (2023)

1.3.2 Statement of Relationship Between Global Value Chain and Renewable Energy Total Factor Productivity

In the context of economic globalization, the international flow of production factors promotes the continuing development of industries. Studies already conducted have demonstrated that engaging in the global division of labor, absorbing FDI, undertaking OFDI, and acquiring intermediate products can boost the total factor productivity of the host country through technological spillover effects (Ho et al., 2018). However, there may be a large technical gap between technology exporters and importing countries, which results in a technology crowding-out effect, hindering the improvement of the TFP of the host country (Qiaoling et al., 2022).

Furthermore, GVC participation has resulted in significant environmental cost for undeveloped economics (Fei et al., 2020). China belongs to the downstream countries and improving GVC participation can attain a significantly positive influence on renewable energy TFP (Qu et al., 2020).

In the renewable energy sector, China primarily occupies a downstream position in the GVC, characterized by weak technology, which in turn hampers the development of high value-added industries and slows the upgrading of the industrial structure (Ge et al., 2018). This disadvantage constrains the capacity of domestic enterprises to enhance innovation and international competitiveness, thereby inhibiting the development of economic growth. Employment generated through participation in low-end segments is predominantly concentrated in low-skill sectors, offering limited wage growth and career development prospects, thus impeding improvements in household income and the upgrading of consumption patterns. In the long term, the

persistent inability to move up the GVC is likely to constitute a significant barrier to the high-quality development of the economy.

Given these developments, participation in GVC by one industry can lead to changes in the TFP (Ge et al., 2018). It is significant to the influence of GVC on TFP in China (as shown in Figure 1.7).

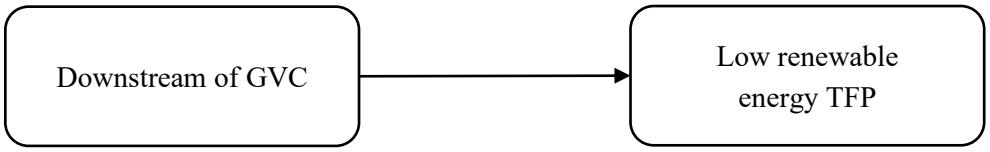

Figure 1. 7 Statement of Relationship Between GVC and Renewable Energy TFP

References: Ge et al. (2018), Fei et al. (2020), Qu et al. (2020), Qiaoling et al. (2022)

1.3.3 Statement of Digitalization

Importance of technology innovation. To date, most of the previous studies on TFP and GVC have provided extensive methodologies and findings. Improving China's renewable energy TFP result in less input or more output, which is significantly contributes to the advancement of China's energy consumption structures. Researches confirmed that the main factor advancing China's efforts to increase its renewable energy TFP is technological innovation (Egli et al., 2018). Additionally, policies, investments, and subsidies all have a positive influence. (Li & Yao, 2020).

Advantage of digitalization. As information and communications technology (ICT) has advanced, Digitalization has accelerated the pace and efficiency of technical innovation. Industrial digitalization reduces communication costs, mitigates geographical hazards, and increases value chain flexibility (Ballestar et al., 2020). In

terms of enterprise, Sasidaran (2022) asserted that the level of digitalization in enterprises deepens the degree of involvement in GVC, this result is not only relevant to large companies but also has a significant impact on SMEs (Gopalan et al., 2022).

To clarify the impact, Sestino et al. (2020) stated that ICT can expedite energy technology innovation while decreasing conventional energy consumption. He and Xie (2022) stated that digital technology is a new component of production, it can reduce resource consumption. Alhasnawi et al. (2024) confirmed that digital technologies can reduce the cost of growth of renewable energy decentralization and improve the reliability and flexibility of renewable energy microgrids.

As digitalization continues to advance, the synergies between digitalization and renewable energy can help economies transition to a low-carbon economy (Zuo & Ren, 2025). However, China's digitalization needs improvement, due to insufficient digital infrastructure and low connectivity (Lange & Santarius, 2020; Wang et al., 2023).

However, other academics contended that as industry digitizes, there would be significant construction expenses, which can also create resource waste and hinder the improvement of enterprise economic efficiency (Heavin & Power, 2018), Therefore, some scholars argued that during the initial phases of digitization, the TFP of the industry can decrease (Cheng et al., 2023). subsequently, China still needs significant investment in digital infrastructure.

Although digital transformation plays a critical role in enhancing technological capabilities and improving resource allocation efficiency within the energy industry, the digital infrastructure in China's renewable energy sector remains underdeveloped,

and the degree of informatization varies significantly across regions and enterprises (Wei et al., 2020). These deficiencies lead to elevated production costs and insufficient resource mobility, thereby limiting the diffusion of technological innovation and diminishing the efficiency of industrial chain coordination, with adverse implications for economic growth. Furthermore, the shortage of digital skills results in delayed labor market adjustments, exacerbating structural unemployment and undermining employment stability. In addition, the restricted development of the digital economy hampers the expansion of emerging consumption patterns such as smart consumption and green consumption, thus inhibiting the release of residents' consumption potential and ultimately constraining the domestic economic growth.

This study confirms that due to China's insufficient technological innovation capability, incomplete digital infrastructure, and low industrial agglomeration, digitalization has made an insignificant contribution to renewable energy TFP (Wei et al., 2020) (as shown in Figure 1.8).

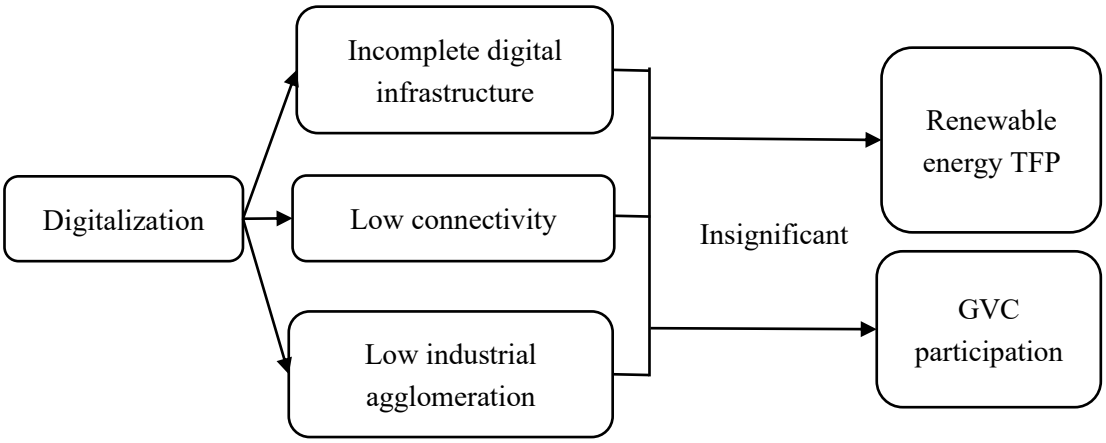

Figure 1. 8 Statement of Digitalization

Source: Gopalan et al. (2022), Lange and Santarius (2020), Wang et al. (2023), Wei et al. (2020).

Hence, based on the discussions tabled in this section, the main issue addressed in this study is “Due to low GVC and lack of utilization in digitalization, China’s renewable energy TFP at a relatively low situation”.

1.4 Research Questions

To resolve the main problem statement “Due to low GVC and lack of utilization in digitalization, China’s renewable energy TFP at a relatively low situation”. The following questions are put forth by this study:

(1) Are there any main drivers to improve renewable energy TFP in China?

(2) Is there any relationship between GVC and renewable energy TFP?

(3) Is there a moderating effect of digitalization on the relationship between GVC and renewable energy TFP?

1.5 Research Objectives

Finding out how participation in global value chains (GVC) affects China's renewable energy industry's total factor productivity (TFP) is the main goal of this study, as well as to analyze the mechanism by which digitalization affects this relationship. Corresponding to the research questions, the objectives of this study are as below:

(1) To measure the renewable energy TFP in China and observe the core driver.