ENERGY ECONOMICS, FINANCE, AND MANAGEMENT IN DEVELOPING AND EMERGING ECONOMIES

Edited by

Hooi Hooi Lean and Jin Hooi Chan

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He was trained at the University of Cambridge in sustainable development and energy policy and industrial structure, with full scholarships from Shell-Chevening and the ESRC-Cambridge Commonwealth Trust Dorothy Hodgkin Award. His research in sustainable development and climate change encompasses several subjects (policy analysis, ethical finance and financial innovation, ESG and climate risks and litigation, firm strategies and green transitions, SME and entrepreneurship ecosystem, and social psychology-behavioural change), and ventures into several sectors (renewable energy; fintech, crowdfunding, and e-commerce; tourism and hospitality; eco- and social enterprises; creative industries; and heritage and cultural sector). Prof. Chan is a prolific writer who has published widely in reputable peer-reviewed academic journals and industry outlets, including many top-ranked academic journals, such as *Industrial Marketing Management*, *Transportation Research Part E: Logistics and Transportation Review*, *Journal of Sustainable Tourism*, *International Journal*

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Chan Tze Haw, Senior Lecturer at the Graduate School of Business, Universiti Sains Malaysia (USM), is a recognized expert in International Finance, East Asian Economics, and Applied Econometrics, holding both a PhD and postdoctoral qualification in Financial Economics. He was awarded the prestigious Perdana Post-Doctoral Research Fellowship (2009–12) at USM and founded the Centre for Globalization and Sustainability Research at Multimedia University in 2008. Dr. Chan also contributed as a research member at the International Medical University from 2004 to 2006. He has published over 90 peer-reviewed articles in high-impact journals such as *Transportation Research Part D: Transport and Environment*, *Economic Modelling*, and *Applied Economics*, garnering more than 1000 citations on Google Scholar. He is actively involved in research and consultancy on industry competitiveness and financial economics and has supervised over 40 MBA students and more than 10 PhD candidates to completion.

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Yansong Li is currently a master's student in Western Economics at the School of Economics, Shandong University of Finance and Economics, where he enrolled in 2023. His research interests encompass digital economy, agricultural economics, and international trade. His methodological expertise includes the application of bilateral stochastic frontier models, generalized additive models, and mediation effect models. He has demonstrated significant research productivity by publishing three peer-reviewed papers in *Agriculture-Basel*, a Q1 SCI-indexed journal. His academic engagement includes active participation in multiple agricultural economics conferences and an international online conference focusing on the digital economy. Through his research activities, he has shown a strong commitment to advancing knowledge in both traditional agricultural economics and emerging digital economic frameworks.

Yeap Xiu Wei holds a Master of Social Science in Economics from the School of Social Sciences at Universiti Sains Malaysia. His research has been featured in several prestigious academic journals, including the *International Review of Economics and Finance*, *Emerging Markets Review*, *The North American Journal of Economics and Finance*, and the *International Journal of Emerging Markets*.

Yuan Chang received his PhD from National Chengchi University, Taiwan, R.O.C. He is now a professor at the Department of Finance of the National Changhua University of Education. His work focuses specifically on the empirical research of corporate social responsibility and corporate governance. His recent publications can be found in the *Journal of Business Ethics*, *Contemporary Economic Policy*, *Emerging Markets Finance and Trade*, *International Review of Economics and Finance*, *NTU Management Review*, *Taiwan Economic Review*, *Review of Securities and Futures Markets*, and *Academia Economic Papers*. Recently, his research interests have shifted toward corporate ESG performance, examining how environmental performance (such as carbon emission efficiency) impacts financial consequences, including institutional investor shareholdings and financing costs and choice.

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Introduction

Jin Hooi Chan and Hooi Hooi Lean

Energy is a fundamental driver of economic activity. Access to reliable and affordable energy sources is essential for industrial development, job creation, food security, and improved living standards (Lean & Smyth, 2010). In many regions of the world, limited access to energy or electricity has compromised the population's ability to meet basic needs and, thereby, their fundamental human rights. The study of energy economics and finance and the management and innovation of energy systems in developing and emerging economies has gained traction as it directly impacts the region's economic growth, prosperity, social stability, and environmental sustainability. In many developing economies, for instance, energy investments account for a significant portion of public and private capital investments, underscoring the sector's importance in economic development and infrastructure growth (IEA, 2021).

However, the energy sector is also the primary sector with substantial CO_2 emissions that necessitate a low-carbon transition in the face of global climate change. There is an urgency for the transition to limit global warming to 1.5 degrees in line with the Paris Climate Agreement, including the large-scale deployment of negative emissions technologies (Honegger & Reiner, 2018). This transition remains an eminent challenge for most countries, and the developing/emerging economies are no exception. Nevertheless, transitioning from fossil fuel–based to green energy sources presents significant opportunities (Lee et al., 2024). Effective policies, strategies, and governance structures, coupled with the proper management approaches in green energy, including creating strategic financial investments and opportunities, can foster sustainable economic growth while mitigating the adverse environmental impacts of overdependency on fossil energy (Geels et al., 2017). However, this transition concerns environmental and economic benefits and ensures energy security and resilience against global energy market fluctuations, two critical aspects of energy options (Roques et al., 2006).

Nonetheless, the push toward net-zero emissions with a just transition is paramount from a social and environmental perspective. Achieving net-zero targets requires a comprehensive overhaul of energy systems, prioritizing low-carbon technologies and green infrastructure, such as carbon capture and storage (CCS) (Reiner, 2016). This transition must be inclusive, ensuring that vulnerable populations and small businesses are not left behind. A just transition must emphasize equity, inclusivity, and resilient energy systems (McCauley & Heffron, 2018) from both local and global perspectives. It should aim to reduce social inequalities and ensure fair access to affordable energy, thereby contributing to Sustainable Development Goal 7 (SDG 7): affordable and clean energy for all. In addition, just transition

would also create new job opportunities, particularly in the green energy sector, helping to contribute to the Sustainable Development Goal 8 (SDG8): decent work and economic growth.

This book contains 16 chapters, curated in an edited volume, on the energy and economic sustainability challenges that developing and emerging economies face under the net-zero agenda. While the world pursues low carbon emissions and the adoption of renewable energy technologies and negative emission technologies, developing economies, in particular, are vulnerable to the aftermath of external shocks and structural changes in the global economy. These include high energy prices and cost volatility, high dependence on imported energy, and a lack of sustainable financial support, technologies, and skilled labor.

Emerging economies must follow the global dedication to decarbonization, but many require financial or technological support from developed nations. Furthermore, developing economies must find effective ways to manage energy resources and institutions while striving for green development and a just transition. The development and implementation of clean energy-saving technologies and environmental protection are significant concerns globally, not only in the developing and emerging countries. Still, they are increasingly a primary global concern (Lean & Lee, 2022).

Hence, it is paramount to generate ideas and solutions to spot opportunities for emerging economies to fit into the global arena in the context of the global sustainable pursuit. This book addresses the aforementioned challenges from economics, finance, and management perspectives in the energy sector, in line with international efforts to attain the Sustainable Development Goals. Specifically, it addresses Goal 7: affordable and clean energy and Goal 13: climate action.

This book investigates the underlying factors affecting carbon dioxide, explores the potential sustainable energy, and examines the impacts of energy transition from management and financial perspectives, identifying investment opportunities. These chapters are divided into three parts.

Part 1—Energy economics in developing and emerging economies

A total of seven chapters in Part 1 address topics related to energy economics, such as energy security, energy efficiency, energy and the environment, energy and development, energy and uncertainty, energy pricing, and social capital.

Dzul Hadzwan Husaini and Hooi Hooi Lean wrote Chapter 1, The Energy–Growth Nexus in Malaysia: Does Energy Security Matter? The authors investigate the role of energy security in driving economic growth in Malaysia. The results show that energy security has a positive relationship with economic growth. This chapter recommends establishing an advanced renewable energy system with a larger generation scale and widespread transmission and distribution. This will improve energy security by reducing the dependence on imported and unsustainable energy sources.

The ASEAN region has experienced rapid growth and a significant increase in energy consumption over the last 2 decades. Chapter 2: Energy Transition, Energy Efficiency, and Green Finance in the ASEAN Region was authored by Mita Bhattacharya and Eric Yan. The authors identify some policy measures initiated by ASEAN governments to improve

the energy efficiency and sustainability of the energy sector. This chapter proposes that an improvement in energy efficiency or energy transition can be fostered by either an effective fiscal policy or sound financial institutions for green finance.

Chapter 3: Economic Policy Uncertainties and Energy Generation Dynamics in Emerging Economies: A Panel Data Analysis was contributed by Shreya Pal and Mantu Kumar Mahalik. They examine the complex relationship between economic policy uncertainties and renewable and nonrenewable energy generation, focusing on 20 emerging economies. The findings highlight the adverse effects of uncertainty on energy sector investments. The study signals systemic flaws in institutional frameworks across emerging economies. As economic growth accelerates, there is a notable increase in nonrenewable energy consumption, emphasizing the imperative for sustainable energy transitions. Globalization emerges as a key factor shaping energy consumption patterns, with increased global economic integration fostering a more significant demand for renewable energy. This chapter offers policy implications for emerging economies, advocating for transparency in economic policymaking, promoting technological advancements in renewables, strengthening institutional quality, the sustainable management of economic growth, and leveraging globalization for sustainable energy transitions.

Chapter 4: Income Growth and Green Financing in Renewable Energy: Mitigating Environmental Degradation among Emerging Asian Countries was written by Tze-Haw Chan, Abdul Saqib, and Agustin Isnaini Nuzula. This chapter explores the environmental Kuznets curve hypothesis in 10 emerging East and South Asian countries, examining the impact of green finance, financial development, and their interaction with carbon emissions. It is revealed that green finance and financial development significantly reduce carbon emissions, and their combined effect is even more pronounced, suggesting that the growing green finance sector, supported by a sound financial system, can significantly enhance environmental sustainability. Furthermore, the expansion of the green finance sector facilitates the transition to a sustainable economy through enhanced financial development.

Chapter 5: Macroeconomic Analysis of Fuel Subsidy Reforms in ASEAN countries was contributed by Nam Foo, Hooi Hooi Lean, and Ruhul Salim. This chapter shows that removing fuel subsidies affects the overall household consumption, GDP, and oil prices in both the short- and long-run of these countries. Thus, abolishing fuel subsidies in ASEAN countries may significantly alter citizens' living standards. Hence, the policy recommendations for ASEAN countries include adopting a nonprice energy policy in the energy sector, such as autonomous energy efficiency improvement and green energy technologies. Doing so will promote the development of a clean and diversified energy economy and maintain the growth trajectories of ASEAN countries.

Chapter 6: Moderating the Role of Global Value Chains between Countries' Ability to Adopt and Adapt the Frontier Technology and Renewable Energy Innovations: Evidence from Selected Developing Economies was written by Qaiser Munir, Shamrez Ali, and Kasim Mansur. The authors explore the impact of 13 developing countries' ability to adopt and adapt frontier technology on renewable energy innovations. The results reveal a positive relationship between the countries' frontier readiness and renewable energy innovation. This relationship is further strengthened when considering the moderating role of global value chains, indicating that the presence of global value chains enhances the positive impact of the countries' frontier technology on renewable energy innovations.

Chapter 7: Social Capital and Its Spatial Spillover on Energy-Based Carbon Emissions in Indonesia was authored by Windia Urfa Hani, Djoni Hartono, and Putu Angga Widyastaman. This chapter examines the spatial effects of carbon emissions and social capital using provincial panel data from Indonesia from 2010 to 2018. The results reveal the adverse effects of social capital on carbon emissions. Furthermore, the estimated carbon emissions are lower when considering the spatiotemporal effects of carbon emissions. This chapter suggests that reinforcing social capital through several channels may foster green practices and innovation diffusion to lower carbon emissions.

Part 2—Energy finance in developing and emerging economies

Part 2 has four chapters that address various topics in energy finance: energy stock performance, risk analysis, the dynamics of energy commodities, and the corporate governance of energy companies in emerging economies.

Chapter 8: Beyond Profit: An In-Depth Analysis of ESG Factors and Financial Performance in the Chinese New Energy Sector was written by Irene Wei Kiong Ting, Qian Long Kweh, Ren Chunya, and Jawad Asif. This chapter examines the influence of environmental, social, and governance (ESG) factors on financial performance and the differential effects of the proportion of shareholdings of the top 10 controlling shareholders on the relationship between ESG and the financial performance of 20 Chinese listed new energy companies during 2018–2022. This study finds that the financial performance of the sample companies is significantly and positively affected by ESG. The positive association between ESG and financial performance is particularly evident in the sample with a high level of the top 10 controlling shareholdings.

Chapter 9: How Carbon Emission Efficiency Affects Stock Price Crash Risk—Evidence from Listed Firms in Taiwan was written by Yuan Chang. Based on the data of 1658 Taiwanese listed nonfinancial firms covering the period of 2013~2022, this chapter examines how carbon emission, carbon reduction, carbon productivity, and carbon profitability affect a firm's stock price crash risk. This study shows that firms with higher levels of carbon disclosure tend to have lower stock price crash risks, and firms with greater carbon productivity and profitability but lower carbon reduction rates tend to have a smaller stock price crash risk.

Chapter 10: Asymmetric Relationships among the Crude Oil Price, Palm Oil Price, and Exchange Rate: The Case of Malaysia was written by Sook-Rei Tan and Xiu-Wei Yeap. Commodity prices have experienced significant volatility in the recent years, mainly due to the impact of the pandemic and geopolitical tensions. They utilize the nonlinear autoregressive distributed lag (NARDL) model to analyze the short-run and long-run asymmetric relationships among crude oil price, palm oil price, and Malaysia's exchange rate. This chapter provides valuable insights for investors and policymakers, enabling them to make informed decisions and develop effective strategies in response to market fluctuations and economic challenges.

Chapter 11: Asymmetric Causality Relationship between the Global Energy Market and ASEAN Stock Markets was contributed by Jianxu Liu, Yansong Li, Xuefei Kang, Jiande Cui, and Woraphon Yamaka. This chapter explores the asymmetric causal relationship

between the global energy market, specifically crude oil and natural gas prices, and the stock markets of three ASEAN countries: Singapore, Malaysia, and Thailand. The findings reveal that the Singapore stock market exhibits a stronger unidirectional causal relationship with the energy market than that of the other two countries, suggesting its higher sensitivity to global energy price fluctuations. Moreover, the study highlights asymmetric causal relationships between ASEAN stock markets and energy prices, with negative shocks having a more pronounced impact than the positive ones.

Part 3—Energy policies and management in developing and emerging economies

There are five chapters in Part 3, addressing energy management and policy topics, including a just transition, challenges in technology innovation and diffusion, policy innovation and big data, and innovation systems and R&D. Part 3 begins with Chapter 12, which analyses the perspective of a global multilateral energy institution on low-carbon transition in energy systems in emerging economies. Then, Chapter 13 offers a specific review of the energy sector in developing countries and its socioeconomic role, discussing the challenges in demand management and energy efficiency management. Chapter 14 and Chapter 15 dive into the case studies of two types of technology adoption in developing and emerging economies.

Chapter 12: International Energy Agency's Approaches to Low-Carbon Energy Transitions and Just Transitions in Emerging Economies was written by Chung-Han Yang. This chapter examines the International Energy Agency (IEA)'s role in promoting the transition to clean energy and enhancing energy efficiency in developing regions. Acknowledging that the IEA plays a broader role in modern global energy governance, Yang evaluates the IEA's landmark reports and recent documents to identify the unique characteristics of the IEA's operational frameworks. Aiming to achieve the UN Sustainable Development Goals and 2030 climate targets, the IEA adopts a framework promoting a fair, "people-centered" clean energy transition. "Just transition" principles are essential aspects of these frameworks, which help governments create equitable strategies focusing on skills development, decent jobs, worker protection, and social inclusion, ensuring that the transitions are both sustainable and just. This chapter concludes by synthesizing the key findings and discussing their implications for future research and potential policy reforms.

Chapter 13: Energy Efficiency and Energy Management in Developing Countries: A Way Forward was written by Qaiser Munir, Shamrez Ali, and Kasim Mansur. They investigate the critical role of energy in the socioeconomic development of nations, with a particular focus on demand issues in developing countries. This chapter highlights the importance of energy efficiency for optimizing energy use in developing economies while cautioning against the potential rebound effects. This study also identified the financial, legal, and organizational challenges as critical barriers to energy efficiency, in addition to more well-established factors, such as consumer preferences and poorly designed policies. Conversely, the literature identifies several drivers in improving energy efficiency, such as increased investments in energy infrastructure, advancements in Information and Communication Technology (ICT) innovation and adoption in the energy sector, and the adoption of

energy-efficient technologies in infrastructure and transportation. This chapter calls for a holistic approach to integrating energy efficiency, economic growth, and environmental sustainability.

Chapter 14: Prospects for Hydrogen Energy and its Production in India, was written by William J. Nuttall, Bernaurdshaw Neppolian, Madhu Madhavi, and Aswathy Rajan. The authors take a future perspective to examine the potential of Indian hydrogen energy development on three timescales: near-present, 2050, and 2070. This chapter assesses the current state of the hydrogen industry in India, including assessing hydrogen manufacture, uses, and the role of industrial clusters in hydrogen technology development. This chapter emphasizes the role of innovation, the importance and promise of active Indian research into low-carbon hydrogen production. This chapter suggests that India could have its specific development pathway and synergies compared to other advanced economies, particularly considering India's extended timeline and economic and social realities. These should permit the consideration of other industrial approaches, including fossil fuel–related options, along the transition journey. The analysis recommends that a hydrogen economy is attractive to India, which can play a world-leading role in developing essential hydrogen technologies.

Chapter 15: Enhancing Sustainable Urban Mobility: A Customer-Centered Comparative Analysis of Service Providers in Seat-Based E-Scooter Sharing was written by Sirirat Sae Lim and Han-Wei Chiang. The authors focus on analyzing specific technological adoption and diffusion (i.e., e-scooters in Taiwan). E-scooter-sharing services have been adopted rapidly and have emerged as a promising solution in many densely populated urban areas in Asia. This chapter presents a study analyzing user-perceived satisfaction and engagement in e-scooter adoption. Through a comprehensive literature review, the authors identify four key aspects and sixteen criteria pivotal for the development of e-scooter-sharing services. The authors conducted a survey and collected 166 useful questionnaires to assess customer attitudes toward e-scooter-sharing services. This chapter proposes a novel development pathway, delineating specific aspects and criteria for the services. The authors offer practitioners a customer-centric analysis model to support strategy formulation that enhances the usage and satisfaction of e-motorbike services within their respective communities.

The last chapter, Chapter 16: Optimal Green Energy Policy Supports for Rural Water Facility Operation in Nigeria, was written by Saheed Bello. This chapter takes a developmental perspective to investigate the needs and challenges of adopting new clean technology in Africa. Examining the installation of water supply facilities in Nigeria, the author identifies the lack of electricity access in the most rural communities and the unreliable supply of grid-connected areas as the key factors hindering modern water facilities' effective and efficient operations. This chapter also explores the optimal strategies that can be implemented to support the water facility operation in rural communities, particularly in using the potential renewable energy resources. Nonetheless, stakeholder interviews reveal other financial and management challenges typically encountered in new technology adoptions in developing countries. The author suggests that mitigating the high upfront costs of solar-powered water facilities and providing know-how training to the local youth would strengthen the sustainability of new infrastructure installations.

Conclusions

This book disseminates invaluable knowledge to policymakers on environmental degradation mitigation strategies and energy policies. It also provides insights to financial institutions and investors, particularly about investment opportunities in renewables and energy price risks during the global energy transition. The last five chapters provide insights into institutions and governance, energy efficiency and demand management, new technology development and management, and issues pertaining to energy technology adoptions in developing and emerging economies. This book offers key considerations for the energy sector in its (just) transition to low-carbon. Finally, this book benefits researchers and students by filling the research gap and inspiring them about the potential future research areas.

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CHAPTER

1

The energy-growth nexus in Malaysia: Does energy security matter?

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1.1 Introduction

Energy should be readily available to all users and consumers in the economy across the world in the modern era. However, energy availability is not secured everywhere or at all times. Energy security affects the economy in principle. For example, production may suffer from cost disadvantages and a decline in customer welfare as a result of an unreliable energy supply. It ultimately has a negative effect on a country's ability to expand its economy.

In the current energy economics literature, the energy variable is commonly proxied by the total usage or per capita energy consumption, or by energy production, electricity consumption, and (or) electricity production (Lean and Smyth, 2010a, 2010b; Yoo & Kim, 2006; Zeshan, 2013). Some studies have examined these issues at the disaggregated level, which can be investigated in terms of perspective energy usage by economic sector and energy by source. Husaini and Lean (2015) and Lean and Smyth (2014) looked at issues from the sectorial level. Rehman et al. (2020), Atems and Hotaling (2018), Ito (2017), and Lean and Smyth (2014) inspected these factors by considering different fuel types. These studies have reached a varied mix of conclusions. Inconsistencies in findings have occurred even in studies that have investigated these issues within the same countries (Chandran et al., 2010; Etokakpan et al., 2020; Tang & Tan, 2013).

Some studies have offered possible answers and explanations for these inconsistencies. For example, Sarwar et al. (2017) argued the occurrence of such inconsistency is due to the nature of an economy, either as a net oil exporter or a net oil importer. Sarwar et al. (2017) and Asafu-Adjaye et al. (2016) claimed that its occurrence is due to the economic structure of the sample country with differing classes of society and status of income. The

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status of a county's energy security is another important factor that leads to this inconsistency. Unfortunately, the issue of energy security has not been given enough focus in the current literature. However, Le and Nguyen (2019) and Shah et al. (2019) argued that energy security plays a significant role in influencing the trend in energy consumption and production, which is frequently used as a substitute for energy in the current literature, to affect a change in a particular economic indicator. For instance, research has uncovered that energy production or consumption has a detrimental impact on economic growth, which runs counter to accepted theories about the matter (Carfora et al., 2020; Mukhtarov 2017; Lu et al., 2016). It is noteworthy that one measure of the energy security index is the component proportion of energy imports within overall energy output or consumption (Le & Nguyen, 2019). This peculiar reversal of events might be caused by the economy's net higher share of energy imports; the more energy the economy consumes, the greater its dependence on energy imports, making it more susceptible to unfavorable shocks and global events, particularly when those events lead to increases in oil prices.

The Asia Pacific Energy Research Center (APERC, 2007) describes energy security as the capacity of an economy to ensure the availability of energy resources in a sustainable and timely manner, with energy prices at levels which do not adversely affect the economic performance of the economy. Thus, the focus of discussion of energy security should be the "physical availability of supply sources," "economic affordability," and "environmental sustainability" (Le & Nguyen, 2019). Energy security is thus a multifaceted concept, with each dimension having its own scale and characteristics (Global Energy Institute, 2020). This makes it extremely difficult to sum up the complex topic of energy security into a single number.

Malaysia, as a small and open emerging economy, faces multifaceted challenges, with energy insecurities suffered at both the demand and supply aspects (Malaysia Energy Information Hub, 2020). On the demand side, the final energy product consumption for the past 10 years (2009–18) grew at an average of 3.26%, which is higher than the growth rate of total energy production (2.8%). On the supply side, Malaysia is heavily dependent on imported final energy products (Malaysia Energy Information Hub, 2020). At the primary level, 63.2% of the crude oil input is locally sourced (Malaysia Energy Information Hub, 2020); however, final energy products in forms such as petroleum products, natural gas, and coal are mainly imported (Malaysia Energy Information Hub, 2020; The Institute of Energy Economics Japan, 2020). This statistic indicates a real and potential vulnerability and a large source of high strain on Malaysia's foreign exchange reserves. In addition, it is important to note that the energy mix in Malaysia is primarily dominated by fossil fuels, accounting for nearly 80% (Husaini et al., 2023, 2024). Hence, it is imperative to reduce the dependence on imported final energy products especially the fossil fuel products to secure the supply of adequate ecofriendly alternatives and improve the energy infrastructure to provide quality, affordable, and reliable energy services to end users.

In this modern era, energy should be easily accessible to any consumer or user in any economy across the world. However, energy supply is not always secure at all times in all places. The issue of energy security has been unfortunately given less focus in the current literature and in Malaysia. Therefore, it is important and fundamental to investigate the role of energy security in promoting economic growth.

The economy is affected by reduced energy security in a number of ways. First, collective production experiences cost disadvantages and a decline in customer welfare due to an unreliable energy supply. It ultimately has a negative effect on a country's ability to expand its economy. Second, too much reliance on fossil fuel energy leads the economy to be exposed to oil price fluctuation risks and foreign currency reserve pressure. It ultimately leads the economy especially the production very vulnerable to any external shock. Third, even though energy subsidies secure the economy from oil price shocks, the cost to continuously finance this program is expensive and inefficient. It not just involves the explicit direct subsidy cost but also an implicit hidden cost such as the opportunity cost to invest in the renewable energy sector, education programs, health programs, and expanding the social safety net program for the needier segments of Malaysian society as all such worthy programs which will probably be sacrificed in favor of providing oil and petroleum subsidies, missing the opportunity to generate more economic growth.

Fourth, Malaysia is expected to create more wealth via exporting the energy commodities abroad. However, the tradeoff in exporting the energy commodities is the corresponding loss of energy security for the producing country. The volume of energy exports can alternatively be used in domestic operations to improve national energy security. Hence, to choose to centralize on exporting more energy should be further considered, as it is one of the significant components that drive economic growth.

For that reason, it is crucial to determine how Malaysia's economic growth is affected by energy security. By doing so, the policymaker will receive pertinent information and carefully thought out simulation models, enabling them to make informed decisions on energy policy that are intended to increase energy security. This is because Malaysia's energy security will be at risk if effective planning and strategic energy policy development are not done. Therefore, in addition to addressing concerns about environmental preservation, this study aims to explore the role of energy security to drive more economic growth in Malaysia.

This study contributes several insights. First, it explores a novel energy-growth nexus insight using the energy security index as a proxy for energy. As far as we are aware, these issues have not been thoroughly examined in the empirical literature, especially in the context of Malaysia. Lean and Smyth (2010a, 2010b), (2014), and Husaini and Lean (2015) limited the use of the common energy proxy, such as energy consumption (inducing energy consumption disaggregation) and energy production (including energy production disaggregation) in this context. Although Husaini and Lean (2015) examine the sectoral level in Malaysia, the exploration of the energy-growth nexus is seriously underused by these proxies. Compared with the other typical energy proxy, the energy security indicator will provide a wider coverage of the characteristics of energy itself. This study will develop a new energy security index for Malaysia.

Second, we examine energy security's contributions to economic growth in terms of its dimensions. Each dimension has its own unique quality and character. We thus expect that the eventual result will vary across all dimensions at the disaggregated level. In the end, our research offers policymakers with rich statistical evidence that helps them comprehend the energy security dilemma.

Third, this work goes beyond the work by Li and Nguyen (2019) using time series analysis. Li and Nguyen (2019) failed to account for country-specific effects in their investigation using panel data analysis. As a result, they were unable to draw a firm conclusion about how energy security specifically in Malaysia promotes economic growth. This issue can be solved by time series analysis because it only records the statistical evidence from country-specific effects (Badeeb et al., 2016). This knowledge is crucial for assisting policymakers in comprehending the role that energy security plays in promoting economic growth in Malaysia.

Fourth, we chose Malaysia because of its unique characteristics. Southeast Asian countries that produce an extensive amount of oil include Malaysia. In contrast to other oil-producing countries in Southeast Asia such as Thailand, Malaysia remains a net oil exporter (Husaini & Lean, 2021). The value of the net oil export, however, is just a tiny fraction of the total energy use (Husaini & Lean, 2021). In accordance with an environmental perspective, nonrenewable energy makes up about 90% of Malaysia's energy mix (Husaini & Lean, 2022a, 2022b, 2022c). This trait makes it unclear how energy security may support sustained economic growth, necessitating a careful examination of the literature. Other countries might gain insight from knowing this study's findings.

This paper is structured as follows. The next section will demonstrate the model specifications, data, and methodology. Section 1.3 will discuss the empirical results. Section 1.4 will discuss the empirical results. Section 1.5 will relate the conclusions and policy implications.

1.2 Model, methodology, and data

Energy is a key source of economic growth because energy is a basic input in production (Husaini & Lean, 2015). Generally, the use of energy drives economic productivity and industrial growth, and is central to the operation of any modern economy. There are numerous energy proxies in the literature.

For example, Ivanovski et al. (2021) and Dogan (2020) used energy consumption as a proxy of energy while Hdom and Fuinhas (2020) and Rehman et al. (2020) used energy production as a proxy of energy. Lean and Smyth (2010a) used electricity consumption as a proxy of energy. Lean and Smyth (2010b) used electricity production as a proxy of energy. Lean and Smyth (2014b) used energy disaggregation data as a proxy of energy.

This study improves the framework using energy security index as a proxy of energy in the model, rather than energy consumption or production. We develop the energy security index (ES), and the value for energy security index is in the range 1–100. A higher value indicates better energy security, which gives a more comprehensive picture about the status of energy ecosystems, including infrastructure and supply in the economy. We start by developing a multidimensional framework for energy security using the baseline definition put forth by the Asia Pacific Energy Research Center (APERC, 2007) and Savacool et al. (2011), who contend that the discussion of energy security should center on the availability, acceptability, and affordability of energy, and the regulation and governance of the energy sector and energy efficiency. As a result, this study will use 13 energy security indicators to create five dimensions, which will be used to create the energy security index. The energy

security index is calculated by averaging the normalized value of each component dimension. The details of selected energy indicators are as follows[1]:

(1) Availability (**ESa**)
- **(a)** Security of supply (**ES1**)
  - **(i)** Total primary energy supply/Energy demand per capita
  - **(ii)** Total final energy supply/Energy demand per capita
- **(b)** Self-sufficiency (**ES2**)*
  - **(i)** Petroleum product demand (% of supply)
  - **(ii)** Gas demand (% of supply)
  - **(iii)** Coal demand (% of supply)
  - **(iv)** Electricity demand (% of supply)
- **(c)** Energy import dependency (**ES3**)*
  - **(i)** Crude oil import (% of supply)
  - **(ii)** Petroleum product import (% of supply)
  - **(iii)** Gas import (% of supply)
  - **(iv)** Coal import (% of supply)

(2) Acceptability (**ESb**)
- **(a)** Environmental quality (**ES4**)*
  - **(i)** CO_2 Emissions per capita
  - **(ii)** CO_2 Intensity—CO_2 emissions over GDP
- **(b)** Energy sustainability (**ES5**)
  - **(i)** Share of renewable energy in energy production
  - **(ii)** Share of renewable energy in electricity generation

(3) Affordability (**ESc**)
- **(a)** Petroleum price index (**ES6**)*
- **(b)** Gas price index (**ES7**)*
- **(c)** Coal price index (**ES8**)*
- **(d)** Electricity price index (**ES9**)*

(4) Regulation and governance (**ESd**)
- **(a)** Energy subsidies per capita (**ES10**)
- **(b)** Energy export (**ES11**)*
  - **(i)** Crude oil export (% supply)
  - **(ii)** Petroleum product export (% supply)
  - **(iii)** Natural gas export (% supply)
  - **(iv)** Coal export (% supply)

(5) Energy efficiency (**ESe**)
- **(a)** Energy intensity (**ES12**)*
- **(b)** Transmission and distribution losses (**ES13**)

Second, as suggested by Malik et al. (2020) and Amin et al. (2022), we use the min–max method to create the energy security index for Malaysia. We chose this method because it

[1] * means the indicator is in a nature of "the lower the better." The lower the value the higher the level of energy security.

effectively handles both monetary and nonmonetary units, combining all the different indicators into a single number. The index value ranges from 1 to 100. First, the maximum and the minimum values should be identified within each indicator. Some indicators are in the nature of "the higher, the better," and some are "the lower, the better." For example, in terms of energy subsidies, energy security is improved by the government providing bigger energy subsidies. In contrast, the more CO_2 emissions are reduced, the better this will be for energy security. The value for the energy security index will translate into language, as the higher the value, the higher the level of energy security, regardless of whether a particular indication is of the kind of "the higher, the better" or "the lower, the better."

For the indicator with "the higher, the better" (X'), the formula is as follows:

$$X' = 1 + \frac{X - \min_A}{\max_A - \min_A} .100 \tag{1.1}$$

where X' is the transform indicator; X is the untransformed indicator; A is the data range of X; Min A is the minimum value in A; Max A is the maximum value in A.

For the indicator with "the lower, the better" (X''), the formula is as follows:

$$X'' = 1 + \frac{X - \max_A}{\min_A - \max_A} . 100 \tag{1.2}$$

where X'' is the transform indicator; X is the untransformed indicator; A is the data range of X; min A is the minimum value in A; max A is the maximum value in A.

Energy is one of the main inputs in production. In this study, we use the energy security index as a proxy to energy. The security of energy leads the source of energy to become more competitive in economic production. Therefore, ensuring energy security has been the most critical goal for achieving sustainable development in the long run (Le & Nguyen, 2019). In addition, higher energy security also represents the reality that the energy supply is abundant and sufficient (Inglesi-Lotz & Ajmi, 2021). Hence, we expect the magnitude sign for energy security, which causes more economic growth to be positive.

Other important variables that could affect economic growth or output are the trade (TRADE) and financial development (FD) (Badeeb et al., 2016). In fact, numerous researchers have highlighted the roles of financial development in determining output (Badeeb et al., 2016; Le & Nguyen, 2019). Two main channels explain how financial development translates to output growth. First, the accumulative channel through its induced effects on capital and labor. Second, the allocative channel by its positive effects on the effectiveness of resource allocation (Le & Nguyen, 2019). Furthermore, the higher the level of financial sector development in an open economy encourages foreign direct investment (FDI) inflow, thus, technological transfers are catalyzed to occur (Osei & Kim, 2020).

In this study, domestic credit granted to the private sector constant in 2010 in Malaysian Ringgit (MYR) has been used as a proxy of financial development. In short, the expected sign for FD to cause economic growth is positive. The effect of trade on economic growth has been well studied and documented in the work by Badeeb and Lean (2017). It can be justified that the trade openness encourages economic growth by improving domestic productivity through innovation and technology development (Le & Nguyen, 2019). Trade also

creates economies of scale through specialization (Amable, 2000). Trade additionally creates and engenders tough competition; thus, it encourages innovation to achieve higher efficiency (Hadhek & Mrad, 2015). As a result, trade drives technological advancement and consequently increases the economic growth (Le & Nguyen, 2019). In short, the expected sign for TRADE to cause economic growth is also positive.

The value of TRADE is derived from the sum of export and import constant at 2010, RM. It should be noted that the value for export, import, and gross domestic product is constant at 2010, RM. In short, the expected sign for TRADE to cause economic growth is positive. Combining the factor of energy, therefore, the roles of trade and financial development are explicitly incorporated in the extended production function as follows:

$$Y_t = \alpha_0 + \beta\alpha_1 E_t + \alpha_2 K_t + \alpha_3 L_t + \alpha_4 \mathrm{TRADE}_t + \alpha_4 \mathrm{FD}_t + \varepsilon_t \tag{1.3}$$

where K is the capital, L is the labor, and E is an energy proxy.

This study also put into account the factor of capital (K) and labor (L) as another control variable. This approach is widely practiced in the current literature (Husaini & Lean, 2022a, 2022b, 2022c; Le & Nguyen, 2019).

To proximate the factor of capital, this study uses gross capital formation constant in 2010 in RM. Generally, capital is a factor of production that has been produced for use in the production of output. Hence, K is expected to have a positive sign in affecting economic growth. The level of employment is used to proximate L in this model. Meanwhile, labor is a human effort that can be applied to extend the production in the economy. Hence, L is expected to have a positive sign to cause economic growth.

The new suggested model is presented as follows:

$$Y_t = \beta_0 + \beta_{j,1} \mathrm{ES}_{j,t} + \beta_2 K_t + \beta_3 L_t + \beta_4 \mathrm{TRADE}_t + \beta_5 \mathrm{FD}_t + \varepsilon_t \tag{1.4}$$

where Y is the Gross Domestic Product (Constant at 2010, RM); $\mathrm{ES}_{j,t}$ is the energy proxy with j equals to energy security index (ES), energy availability (ESa), energy acceptability (ESb), energy affordability (ESc), government and governance related to energy (ESd), and energy efficiency (ESe); K is the Gross Capital Formation (constant at 2010, RM); L is the level of employment; TRADE is the sum of export and import (constant at 2010); and FD is the domestic credit to private sector (constant at 2010, RM).

We employ the ARDL model to figure out the magnitude impact of exogenous variable on FDI from the linear perspective. The ARDL model is expressed as follows:

$$\begin{aligned}\Delta Y_t = {} & \alpha_1 + \sum_{i=1}^{p} \delta_i \Delta Y_{t-i} + \sum_{j=0}^{q} \phi_i \Delta \mathrm{ES}_{t-j} + \sum_{k=0}^{r} \Omega_i K_{t-k} + \sum_{l=0}^{s} \gamma_i \Delta L_{t-l} + \sum_{m=0}^{u} \rho_i \Delta \mathrm{TRADE}_{t-m} \\ & + \sum_{n=0}^{v} \lambda_i \Delta \mathrm{FD}_{t-n} + \pi_1 Y_{t-1} + \pi_2 \mathrm{ES}_{t-1} + \pi_3 K_{t-1} + \pi_4 L_{t-1} + \pi_5 \mathrm{TRADE}_{t-1} + \pi_6 \mathrm{FD}_{t-1} + \varepsilon_t\end{aligned} \tag{1.5}$$

where $\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6$, and π_7 are the long-run parameters and ε_t is the error term. To capture the long-run relationship, the model was restricted by the lagged-level variables, Y_{t-1}, ES_{t-1} K_{t-1}, L_{t-1}, TRADE_{t-1}, and FD_{t-1} in Eq. (1.5). The F test was used to determine the