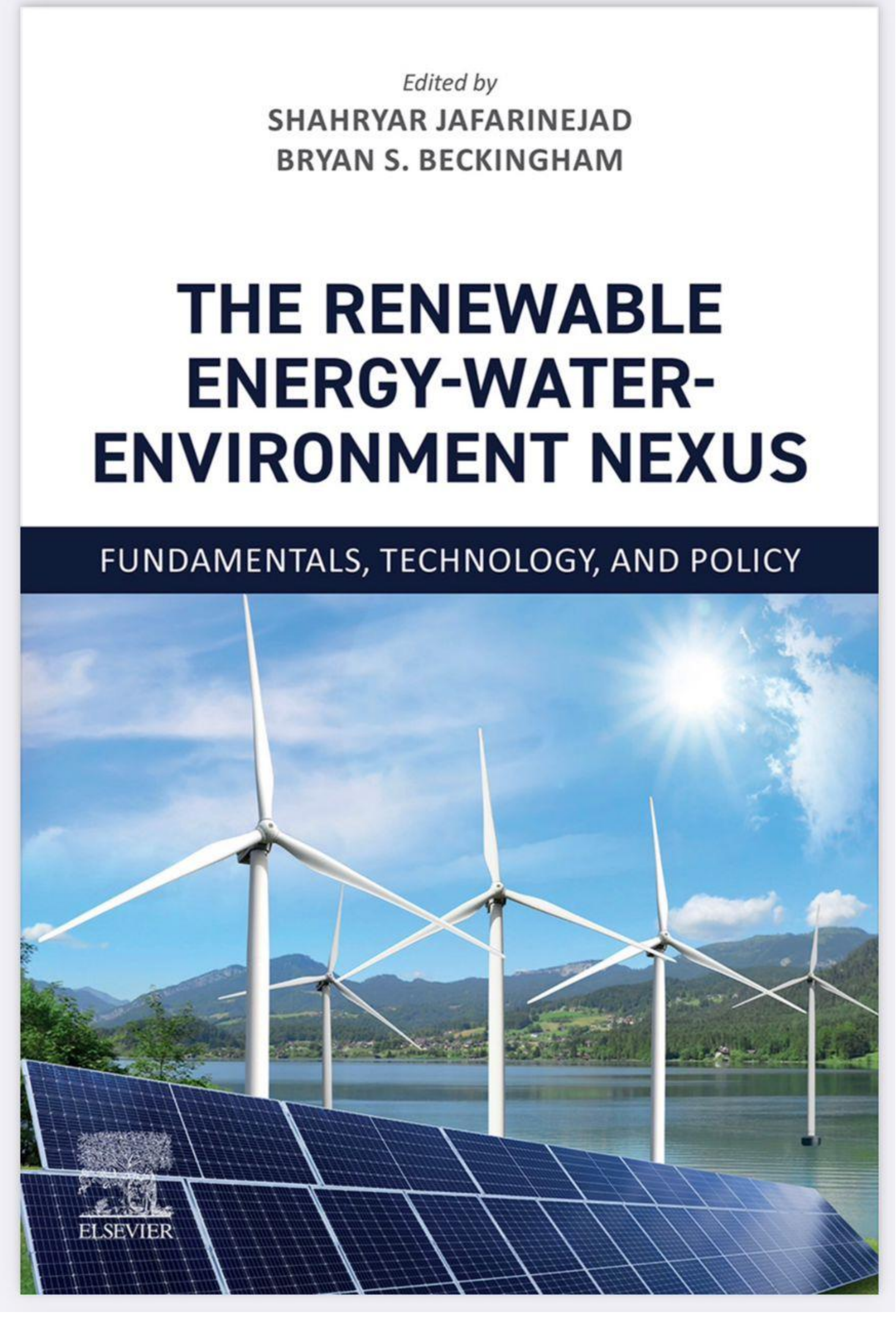

Edited by

SHAHRYAR JAFARINEJAD
BRYAN S. BECKINGHAM

THE RENEWABLE ENERGY-WATER-ENVIRONMENT NEXUS

FUNDAMENTALS, TECHNOLOGY, AND POLICY

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The Renewable Energy-Water-Environment Nexus

Fundamentals, Technology, and Policy

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The renewable energy–environment nexus

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7.1 Introduction

Environment has been granted the definition by the Organization for Economic Co-operation and Development (OECD, 2005) as the entirety of all the outside conditions that underlies the development of life and survival of all living organisms. In the context of mankind, the environment is the naturally produced physical surroundings in which human beings rely completely upon its functions and activities. Throughout history, human civilization has been built at the expense of the environment. As human civilization progresses, human society has carried out a series of unrestrained activities such as construction, deforestation, industrialization, and exploitation of natural resources. These human activities have had a serious environmental toll that is irreversible. Environmental issues including climate change, biodiversity loss, desertification, and undrinkable water source are indeed the repercussions of human civilization.

To a certain extent, science and technology advancement has facilitated the pace of environmental degeneration (Ezimah, 2021). Science and technology that shaped our society and economic structure today come with significant environmental costs. With the help of science and technology, mankind was able to initiate the first industrial revolution in the mid-18th century. It all started with the use of coal as the major power source that acted as a catalyst for the first industrial revolution. In fact, we can trace the use of coal to as early as the 13th century. It was only until the mid-18th century that coal was intensively utilized in key industries from electricity generation to manufacturing (Folk, 2021). During that time, the utmost priority of the world was exponential development. Science and technology were used exactly for that purpose, by expanding the industries, accelerating urbanization, and improving the living quality of the people, all at the cost of the environment. It was also science and technology that gave rise to weapons of mass destruction such as the nuclear weapon that were used after World War II. These weapons caused unprecedented damage to the environment and took the lives of many. After that, many countries took desperate measures for postwar rehabilitation, with no consideration over the environmental effects. This scenario worsens the environmental issues, and we are now in the face of retaliation from the nature.

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Environmental issues such as the devastations of ecosystems and habitat, pollutions of air, water, and soil, depletion of natural resources, desertification, and climate change are the manifestations of environmental degradation. The utmost priority of each country was economic and social development during the post-World War II. Environmental degradation was never a concern to the world until the organization of the United Nations Conference on the Human Environment in 1972, better known as the Stockholm Conference. It was the first worldwide conference that acknowledged environmental degradation as a global issue. This conference marked the beginning of global efforts in tackling environmental issues by introducing a series of principles and action plans. The United Nations Environment Programme was formed as a resultant of the conference. Thereafter, continuous global efforts have been directed to environmental preservation and protection. In 2015, 7 out of 17 Sustainable Development Goals (SDGs) introduced in the Agenda 2030 are directly related to the environment, including Goal 6 (Clean Water and Sanitation), Goal 7 (Affordable and Clean Energy), Goal 11 (Sustainable Cities and Communities), Goal 12 (Responsible Consumption and Production), Goal 13 (Climate Action), Goal 14 (Life Below Water), and Goal 15 (Life on Land) (United Nations, 2023a).

The exacerbation of environmental degradation is becoming increasingly more worrisome to the world as it affects multidimensional aspects of a nation in terms of economics, social, and environment. According to the World Health Organization (World Health Organization, 2022), environmental degradation accounted for 13.7 million deaths in 2016, which was about 24% of the global deaths. In the current era, people are much more vulnerable to noncommunicable diseases such as ischemia, chronic respiratory diseases, asthma, and cancer than never before because more than 90% of the unhealthy air that threatens our health is caused by fossil fuel consumption.

The heat-trapping greenhouse gases (GHGs) are the culprit of the environmental challenges. The emissions of GHG primarily cause climate change, air pollution, smog, and wildfires. The United States Environmental Protection Agency reported that the net emissions of GHG rose by 43% from 1990 to 2015 (United States Environmental Protection Agency, 2022). This increase leads to an atmospheric concentration of GHG that gives rise to a warming effect with an increment of 45% between 1990 and 2019. The biggest contributor to the GHGs is carbon dioxide (CO_2), which is accountable for three-fourths of the total GHG emissions (United States Environmental Protection Agency, 2022). While a portion of the CO_2 is emitted from nature, a substantial amount of CO_2 emissions comes from daily anthropogenic activities that are driven from the burning of fossil fuels and deforestation activities. A prediction has been conducted by Chen and Lei (2018) that CO_2 emissions would increase between 40% and 110% from 2017 to 2030.

In this chapter, the RE−environment nexus is discussed, and the interconnection between the RE consumption and environmental degradation from an economic perspective is probed. In reality, the environmental impacts of REs are briefly reviewed; the principles and theory pertaining the economic growth and the environmental degradation are summarized. Also, the past literature concerning the environmental Kuznets curve (EKC) hypothesis and the incorporation of RE as a major variable in the studies are reviewed. In terms of the literature, the role of RE in environmental sustainability from both the consumption and production sides is scrutinized. In addition, the existing RE policies in the world are discussed. Furthermore, a case study analysis on the RE−environment nexus is conducted by employing the EKC model to serve as an empirical example in this chapter. Finally, some policy recommendations and insights for the future research direction are presented.

7.2 The interconnection between renewable energy and the environment

In this section, the environmental impacts of the RE technologies are discussed.

7.2.1 Attributes of renewable energy

Contrary to the high-carbon energy, RE sources are sustainable due to its abundance in nature. They come from the sun, wind, water, wastes, and thermal heat from our planet Earth. The amount of these energy sources is indefinite as they are inexhaustible and emit little to no harmful gases into the atmosphere. According to the National Renewable Energy Laboratory (2013), RE sources release 20 times less than that of coal and nearly 10 times less than natural gas of CO_2 emissions for every kilowatt-hour of electricity over their life cycles. Generally, there are six types of REs: hydropower, bioenergy (biofuels, biogas, and biomass), wind energy, solar energy, geothermal energy, and marine (ocean) energy (salinity gradients, ocean thermal energy conversion, ocean currents, tidal currents, tidal range, and waves) (Ellabban, Abu-Rub, & Blaabjerg, 2014). It is noteworthy that tidal barrages are the only marine energy technology that is yet to undergo the commercialization stage.

RE began its rapid growth in 2011, and 10 years later, RE managed to generate about 29% of the global electricity (REN21, 2019). RE is never new to us as our ancestors had been accustomed to it since the age of the Paleolithic when mankind learned about making fire with wood for the first time, which produces energy in our modern term called biomass. Various RE types including solar, hydro, wind, biodiesel, and geothermal have been repeatedly experimented and used throughout history. Back then, REs were primarily used to generate heat, pump water, mill grain, and sail. It was not until the 19th century when people thought about using REs to generate electricity. Hydropower was the first renewable that was put into that specific use in 1878 when an English engineer and industrialist, William Armstrong, built the world's very first hydroelectric power station in Northumberland, England (Zafar, 2022).

Today, REs account for 26% of the global electricity production, while the remaining 10% and 64% are from nuclear power and fossil fuels, respectively

(World Economic Forum, 2022). Hydropower remains the most prevalent RE in electricity generation in the world which contributes to 83% of the global electricity generation from renewables, followed by wind energy (7%), biomass and biowaste energy (7%), geothermal energy (2%), and solar, tidal, and wave energy (1%) (Schleeter, 2022). Nevertheless, the favor of renewables for electricity production has been shifted toward sources other than hydropower lately. In accordance with the International Energy Agency (IEA, 2021), solar power was among the fastest-growing renewable sources for electricity generation, which was recorded at 23% of annual growth in 2020. This is mainly due to the consistency of the solar energy and the advancement in the solar technology. Other factors include the scalability of solar power from industrial to domestic scale and the capability to store excess solar electricity in batteries.

7.2.2 The environmental impacts of renewable energy technologies

The most abundant energy source on the planet is solar energy. The Earth is constantly blanketed by 173,000 TW of solar energy, which is 10,000 times greater than the total global energy consumption (United States Department of Energy, 2016). Solar energy is among the best substitutes for fossil fuels. The operations of solar power plants and its associated technologies are free from air pollution and GHG (United States Energy Information Administration, 2022c). In practice, solar energy brings along some environmental co-benefit opportunities including exploitation of degraded or unfertile lands, co-placement of photovoltaic (PV) with agricultural lands, floatovoltaics, hybrid power deployments, and integration of scalable PV with architecture to conserve water and land uses (Hernandez et al., 2014). While the solar power operation is environmentally harmless, solar energy brings some adverse environmental impacts indirectly depending on the technologies, mainly PV cells and concentrating solar thermal plants (CSPs). PV cells are associated with its byproduct during the manufacturing process, the solar e-waste which is regarded by the United Nations as one of the biggest potential contributors to the global e-waste (Hernandez, Jordaan, & Kaldunski, 2020). Chowdhury et al. (2020) estimated that the solar PV waste alone is likely to hit an accumulation of 78 million metric tons by 2050 given its speedy development in the present. The CSP requires wet-recirculating technology that can use up to 650 gallons of water for every megawatt hour of electricity generated, which can be a huge challenge to water conservation (Union of Concerned Scientists, 2013c). Based on the National Renewable Energy Laboratory, a CSP that is capable of accommodating a thousand homes would require 32 acres of land, which indicates that a vast natural landscape alteration of that size would have to be undertaken for the construction (Ong, Campbell, Denholm, Margolis, & Heath, 2013).

Similar to solar energy, wind energy is another modern RE source that is inexhaustible and releases neither air nor water pollution during operation. In precise, the electricity is generated by the kinetic energy of the wind, which is powered by the wind turbines. Technology pertaining the wind energy includes onshore and offshore wind turbines (Ellabban et al., 2014). Onshore wind turbines are usually grouped together to form wind farms, while offshore wind turbines are typically built on the sea surface. Similarly, wind energy also possesses some co-benefits to the environment in terms of land and ecosystem conservation. In the aspect of land conservation, onshore wind farms can be built besides productive agricultural and industrial lands (Union of Concerned Scientists, 2013d). Moreover, wind farms can also take advantage of abandoned or unproductive lands. With respect to ecosystem conservation, offshore wind farms can coexist with marine wildlife by acting as artificial reefs. However, wind energy has some disadvantages to the environment. Wind turbines induce noise pollution that leads to some potential adverse impacts on the natural acoustic environment such as disrupting the wildlife's crucial mechanisms for survival, reproductive and social processes, and continuity of habitat (Teff-Seker, Berger-Tal, Lehnardt, & Teschner, 2022). To be specific, noise pollution interrupts the natural acoustic environment by producing blaring broadband sound in the air which can be easily transmitted to wildlife (Dai, Bergot, Liang, Xiang, & Huang, 2015; Heffner & Heffner, 2007). Thaxter et al. (2017) reported that wind turbines are life-threatening to 362 bird and 31 bat species.

Hydropower is the most conventional and prevalent RE source. Hydropower technology branches into run-of-river (RoR), the traditional reservoir, and pumped storage hydropower (Ellabban et al., 2014). Apart from being one of the most reliant RE sources for electricity generation, hydropower is less harmful to the environment than fossil fuels. As a clean energy, hydropower is self-sustaining from the domestic water sources. The benefits of dammed reservoirs are beyond electricity generation by providing agricultural irrigation and flood control (Union of Concerned Scientists, 2013b). Nonetheless, hydropower is also among the most harmful renewable sources because a hydroelectric dam is often a large-scale construction project that can devastate the ecosystem and natural habitat of the area by flooding the land for reservoir. In light of that, Barbarossa et al. (2020) found that approximately 10,000 fish species are affected by the existing 40,000 and prospective 3700 hydroelectric dams. Furthermore, not only does the installation and deconstruction of large-scale hydroelectric facilities induce GHG emissions, but also during the operation of the facilities (Union of Concerned Scientists, 2013b). Specifically, the soil and vegetation in the flooded areas will decompose and emit both methane and carbon dioxide. The study found that the median life cycle GHG emissions of 480 hydroelectric facilities is estimated at 23 g CO_2-equivalents per kWh (Ubierna, Santos, & Mercier-Blais, 2022). These deleterious environmental impacts are relatively milder with RoR as it does not require a reservoir at all, or merely a small storage.

Biomass energy is another renewable and sustainable energy source that comes from energy crops, food-based residues, and domestic wastes. Biomass energy is versatile as it can produce both transportation fuels and electricity. Biomass energy comes with some significant environmental advantages. It avoids the expansion of footprint and saves ecological storage by making use of the unwanted byproducts from agriculture, household wastes, and construction debris (Union of Concerned

Scientists, 2012). At the same time, it should be noted that biomass energy technology involves thermochemical and combustion processes which can give rise to air pollution (Chai et al., 2022). Besides that, the use of pesticides and fertilizers on energy crops may also contribute to soil pollution.

Geothermal energy is sourced from rock, trapped stream, and water (Ellabban et al., 2014). Geothermal energy technology is different in terms of usage. Geothermal heat pump is for residential use, and geothermal power plant is for industrial purpose. According to the United States Energy Information Administration (2022a), geothermal facilities do not involve the combustion of fuels for electricity generation but release small amounts of sulfur dioxide (SO_2) and CO_2. Geothermal facilities usually adopt closed-loop system that reinjects the gases and water back into the Earth, thus reducing the emissions. On top of that, hydrogen sulfide released from the open-loop system can be mitigated using scrubbers. Since geothermal plants remove the underground stream and water, the land above it is susceptible to subsidence risk (Union of Concerned Scientists, 2013a). This risk is not eliminated even though water is reinjected into the Earth. Another environmental issue with geothermal energy is that the plants are usually situated in places which are prone to earthquakes. The extraction of underground resources may increase the risk and frequency of earthquakes.

Without a doubt, the environmental issues are rather alarming to the whole world, but they should not be overemphasized to the extent of impeding the growth of an economy. At the current stage where the RE technologies are still not matured yet, the development of an economy is very much dependent on the adoption of fossil fuels in various industries such as manufacturing, transportation, construction, and power generation, especially in the developing nations. It takes time to develop the RE sources in terms of coping with its environmental impacts and energy efficiency issues. Even if the RE technologies reach the maturity stage, the alternate energy sources are unlikely to fully substitute the conventional fossil fuels due to some constraints such as cost, stability, and inability to fulfill the drastic increase of energy demand due to the rapid population growth of the world. Hence, reaching an equipoise between economic advancement and environmental sustainability is of utmost importance. A question arises as to whether economic development is a tradeoff to the environmental sustainability. To answer that, the EKC has been developed in concern of the link between economic growth and environmental quality.

7.3 Literature review

This section reviews the literature from two aspects, the theoretical and empirical aspects. Subsection 7.3.1 explains the prominent theory of the growth−environment nexus. Subsections 7.3.2, 7.3.3, and 7.3.4 provide empirical reviews of the CO_2−RE consumption nexus, CO_2−RE production nexus, and CO_2−disaggregated RE sources nexus, respectively.

7.3.1 Theoretical review

Improving environmental sustainability while keeping undisturbed economic growth has always been a key challenge that has induced myriad of works around the world to seek the environmental effects of economic growth. The EKC hypothesis is the most prominent model that explains the environmental effects of economic growth. The EKC hypothesis is named after Simon Kuznets who developed a curve to explain the association between income inequality and economic development (Stern, 2018). According to Fig. 7.1, the graphical relationship between economic growth and environmental degradation is considered as a nonlinear or inverted U-shaped relationship. It reflects the shift of the relationship between the two variables from positive to negative after economic growth hits a certain turning point. Panayotou (1997) argued the traditional view of the tradeoff relationship between economic progression and environmental quality by claiming that the environmental quality will be gradually improved, resulting from a structural transformation in the information-intensive industries and services, increased environmental education and awareness, advanced environmental technologies, as well as better environmental regulations and enforcements at a higher level of economic development.

The nonlinear relation between economic growth and environment is affected by three underlying effects, which are scale, composition, and technique effects. Scale effect implies the scale of economic activities or scale of production that indicates the expansion of production (Stern, 2018). The composition effect refers to the change of economic structure from agrarian, industrial, to service base (Gill, Viswanathan, & Hassan, 2018). The technique effect is relevant to the technological advancement that gives rise to new techniques that are more efficient, productive,

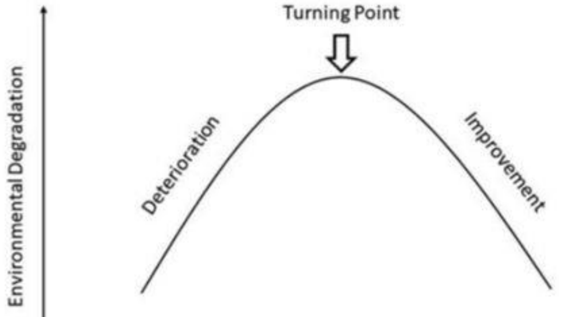

Figure 7.1 Environmental Kuznets curve (EKC) hypothesizes the inverted U-shaped relationship between economic growth and environmental degradation.
Modified from Gill, A. R., Viswanathan, K. K. & Hassan, S. (2018). A test of environmental Kuznets curve (EKC) for carbon emission and potential of renewable energy to reduce green house gases (GHG) in Malaysia. Environment, Development and Sustainability, 20(3), 1103–1114. https://doi.org/10.1007/s10668-017-9929-5.

and environmental-friendly. All these three effects are the demonstrations of economic progression that exert significant impacts on the environment. As the economy advances initially, the scale of production is relatively smaller, the economic structure is more inclined to agrarian-based, and techniques and tools used in the economic activities tend to be less developed and less harmful to the environment. The turning point occurs when the scale of production expands drastically alongside a structural change to industrial-based economy and the application of technologies that are highly productive but at the great expense of the environment. The environmental quality starts to improve when the scale of production is stabilized with the use of advanced technologies that are more environmental-friendly and the economic structure transitions into service-based.

Grossman and Krueger (1991) are the pioneers who started studying the growth−environment nexus by employing the EKC model. Thereafter, empirical work on the EKC hypothesis has been widely conducted across regions, countries, and periods. These empirical studies used different measures of environmental degradation such as carbon dioxide (CO_2) emissions (Omri & Saidi, 2022; Zou & Zhang, 2020), nitrogen dioxide (NO_2) emissions (Adebanjo & Shakiru, 2022; Cho, Chu, & Yang, 2014), and SO_2 emissions (Bakhsh, Akmal, Ahmad, & Abbas, 2022). However, the findings of the EKC hypothesis remain controversial until this day. While the EKC hypothesis has been verified in various studies such as (Cerdeira Bento & Moutinho, 2016), (Gill et al. 2018), (Balsalobre-Lorente, Ibáñez-Luzón, Usman, & Shahbaz, 2022), (Kilinc-Ata & Likhachev, 2022), and (Suki, Suki, Sharif, Afshan, & Jermsittiparsert, 2022), there is also another group of literature which presented opposing outcomes (Al-Mulali, Ozturk, & Lean, 2015; Djellouli, Abdelli, Elheddad, Ahmed, & Mahmood, 2022; Raihan & Tuspekova, 2022; Saudi, Sinaga, & Jabarullah, 2019; Zhang, Shah, & Yang, 2022). Osuntuyi and Lean (2022) revealed that the presence of the EKC differs across different income groups of 92 countries. They found that the EKC hypothesis only stands in high- and upper-middle-income countries, while lower-middle-income and low-income countries do not correspond with the hypothesis. This outcome is also in line with Iwata, Okada, and Samreth (2012) who found the presence of the EKC hypothesis in high-income nations including Finland, Japan, Korea, and Spain, albeit only Finland showed significant support.

7.3.2 Empirical studies of renewable energy consumption−environment nexus

Over the years, variables like foreign direct investment, technological innovation, trade, financial development, income inequality, deforestation, and tourism have been incorporated into the EKC model (Begum, Raihan, & Said, 2020; Djellouli et al., 2022; Javid & Sharif, 2016; Ota, 2017; Ozturk, Al-Mulali, & Saboori, 2016; Suki et al., 2022; Udeagha & Ngepah, 2022b). Lately, RE has gained progressively high attention among the most significant mitigating factors of environmental degradation. RE has been included in the EKC model as a major independent variable of CO_2 emissions in many empirical literature. The environmental effects of the RE are investigated from two different aspects, consumption and production. From the consumption side of RE, there are studies concluding that RE consumption alleviates the environmental deterioration in China, Japan, South Korea, Portugal, Italy, Ireland, Greece, Spain, Africa, the Association of Southeast Asian Nations (ASEAN), the Middle East and North Africa, and the Organization for Economic Co-operation and Development (OECD) countries (Ansari, 2022; Balsalobre-Lorente et al., 2022; Djellouli et al., 2022; Khan, Hassan, Kirikkaleli, Xiuqin, & Shukai, 2022; Omri & Saidi, 2022; Saidi & Omri, 2020; Suki et al., 2022). While the aforementioned studies supported the negative relationship between RE consumption and environmental degradation, Al-Mulali et al. (2015) drew an inference that RE consumption has no significant impact on the environmental quality in Vietnam.

7.3.3 Empirical studies of renewable energy production–environment nexus

In light of the RE production, Liddle and Sadorsky (2017) initiated a study on the correlation between nonfossil fuels (including nuclear and other renewables) electricity production and CO_2 emissions in 93 countries from 1971 to 2011. Their results implied that every 1% increase in the renewable electricity production will reduce CO_2 emissions by 0.82%. Another study to investigate the impact of the renewable electricity production has been undertaken in Italy from 1960 to 2011 by Cerdeira Bento and Moutinho (2016). Similarly, they deduced that per capita renewable electricity production will have a negative long- and short-run impact on CO_2 emissions per capita. The results of the study (Hdom, 2019) coincided with the aforesaid empirical findings. The study deployed the panel data approach in eight South American nations, consisting of Bolivia, Brazil, Chile, Colombia, Ecuador, Peru, Uruguay, and Venezuela between 1980 and 2010. The results of the study presented that renewable electricity generation diminishes CO_2 emissions over the sample period. In contrast, Kartal (2022) revealed a different outcome that RE production poses a positive short-run effect and a negative long-run effect on CO_2 emissions in the United States. Based on the literature, the majority of the RE production and consumption literature are able to reach a mutual conclusion that they both improve the environmental quality.

7.3.4 Empirical studies of disaggregated renewable energy–environment nexus

As the number of research studies on the RE–environmental nexus becomes abundant in the field, there is an emergence of criticism that questions the mutuality in the empirical findings and puts forward an argument that empirical studies employing aggregate RE sources are lacking comprehensiveness. The results obtained are incapable of conveying clear information about the specific significance of each RE source in curbing the environmental degradation. Some countries that have a higher inclination in utilizing certain RE source could produce a result that seems definite in the holistic RE−environment relationship. The results of such studies may not be instructive to the policymakers in deciding which RE source should be focused on given the respective environmental impacts of the RE sources and limited resources. Inappropriate and unplanned investment in certain RE sources can potentially put the environment at harm as each renewable source demonstrates distinctive characteristics (Wang, Mamkhezri, Khezri, Karimi, & Khan, 2022). Thus, there are advocates for disintegrating the RE sources and identifying the environmental impacts of each source.

At the disaggregate level, there is a mixed outcome on the environmental effect of hydroelectricity consumption. Sahoo and Sahoo (2020) discovered that the consumption of hydroelectricity can be detrimental to the environment, while the consumption of nuclear electricity is the otherwise in India. They attributed the harmful effect of the hydroelectricity consumption to the construction of the hydroelectric dams that can release large amount of CO_2 and methane gases, which can sometimes be greater than that of the fossil fuel power plants. On the contrary, Udeagha and Ngepah (2022a) obtained a conflicting result that hydroelectricity consumption is advantageous to the environment in South Africa, whereas the environmental impact of nuclear consumption is uncontradicted. In terms of the electricity consumption of biomass, Solarin, Al-Mulali, Gan, and Shahbaz (2018) exhibited their findings that it does not benefit the environmental quality in 80 developed and developing nations. On the other hand, Destek and Aslan (2020) claimed that not consumptions of all renewable sources improve the environment efficiently and demonstrated a more comprehensive conclusion in their study on the G-7 countries. They showed that hydroelectricity consumption has a mitigating effect in the United States, the United Kingdom, and Italy. On the other hand, the consumption of wind energy benefits all G-7 countries in environmental quality, but not Japan. Solar energy consumption decreases environmental degradation in the United States, the United Kingdom, Italy, and France, whereas the use of biomass energy improves the environmental quality in the United States, Japan, Italy, Germany, and France. In conclusion, they suggested that hydroelectricity is best in abating environmental degradation, while the effect of solar energy is insignificant on environmental degradation in the G-7 economies from a statistical perspective.

From the aspect of RE energy production, the environmental influences of the geothermal, nuclear, and hydroelectricity generations remain contentious. The positive environmental effect of hydroelectricity production is supported by the empirical works of Ehigiamusoe (2020) in 25 African countries, Luo et al. (2022) in China, and Jahanger et al. (2022) in Malaysia. Nuclear energy production has been found to benefit the environment in 11 OECD countries (Iwata et al. 2012). This is inconsistent with the outcome of Kartal (2022) which found nuclear energy generation increases CO_2 emissions in the United States. Zhang et al. (2022) investigated the effects of the disaggregated green energy generations in five emerging economies. The result acquired implied that geothermal and hydroelectricity generations are not environmentally friendly, meanwhile nuclear and wind power generations are beneficial to the environment. In the European region, Wang et al. (2022) uncovered that more advanced renewables production such as bioenergy, wind, and solar are either harmful or insignificant to the environment and pointed out that geothermal and hydroelectricity generations are more efficient in lowering CO_2 emissions, which opposes the finding of Zhang et al. (2022). This result is partially supported by Al-Mulali et al. (2015) but disputed the effect of bioenergy on environmental quality.

7.4 Existing policies of renewable energy in the world

On the national level, a country's dedication to improve the environmental quality is very much reflected by its corresponding policies. Initiatives to promote the adoption and development of RE have been observed in all parts of the world, with more than 100 cities worldwide pledged to hit 70% of RE consumption (Nunez, 2019). In fact, there have been 138 countries in the world that implemented policies on RE, clean cooking access, electricity access, and energy efficiency (World Bank, 2020). Common policies adopted in the world that encourage the growth of RE are carbon pricing, fuel economy standards, and efficiency standards in different economic sectors. These policies revolve around the synergy between renewables and energy efficiency. Parallel development, integration, and joint implementation of renewables and energy efficiency have formed the basis of RE policies at all levels of government (Sawin, 2013).

Interestingly, China as the world's largest CO_2 emitter is also concurrently having the most installations of PV and wind capacity (Hope, 2022). Besides that, it is also the major producer of solar PV module that contributes more than 70% of the global supply. In fact, the Central Government of China serves a crucial role in propelling the advancement of RE. The inclusion of RE adoption as a policy goal was first inaugurated in the 11th Five-Year Plan (FYP) that covers from 2006 to 2010 (Li & Clark, 2019). During that 5 years, National Energy Commissions (NEC), National Energy Bureau (NEB), and National Energy Administration (NEA) were established to formulate energy development plans, coordinate energy initiatives, and solve energy-related issues (National Academy of Engineering & National Research Council, 2010). Simultaneously, policy initiatives included feed-in tariffs (FITs) to mandate energy utilities to purchase all electricity produced by renewables at a fixed price, tendering contracts of RE supply by the government and RE technologies development. Since then, RE development and emissions reduction have been the key goals of every succeeding FYP of China. The ongoing 14th FYP (2021−25) of China is aiming for an additional 50% of electricity consumption to be generated by renewables, 50% increase in solar rooftop coverage for new public buildings, integrating 5 G technologies into solar and wind power plants, as well as expanding the solar and wind power facilities to the desert areas (Bhambhani, 2022).

In light of private investments, the Chinese government announced the Industry Catalogue Guiding Foreign Investment in 2017 that highlighted RE as a promoted area of foreign investment, while welcoming the overseas investors to set up wholly owned international companies in the nation (Chiu et al., 2017). Other than that, China also granted import purchase discounts for solar, wind, geothermal, and hydroelectric technologies to the domestic companies. These phenomena have earned China the second world's most attractive solar investment destination as ranked by Ernst & Young, scoring 2.6 more index points than the United States in 2022 (Santos, 2022).

In the United States, RE policies are designed separately at the federal, state, and local levels (National Academy of Engineering & National Research Council, 2010). At the federal level, RE policies are implemented with the complement of fiscal mechanisms such as the Modified Accelerated Cost Recovery System (MACRS), the Investment Tax Credit (ITC), and the Federal Production Tax Credit (PTC) to address the high upfront cost of RE installation. They incentivize the people by subsidizing the RE production price to be more cost competitive than conventional fossil fuels. These policy tools have been used in federal policies including electricity supply regulations, carbon pricing legislation, and renewable portfolio standards (RPSs). RPSs are policies that obligate the electricity companies to distribute a stated minimum portion of electricity generated by renewable sources. While the national RPSs have been proposed, there are no federal RPS policies implemented in the present.

In the United States, the implementations of RE policies are a lot more active and effective at the state level than the federal level because of the ease of stakeholders' participation in the design of RE policies. Rountree and Baldwin (2018) explained that electricity supply is mainly accounted for by utilities that are owned by private investors. These utilities are under the regulations of the Public Utilities Commission of respective states, thus tightly bound to any state-level enactments. Based on the United States Energy Information Administration (2022b), RPS programs have been enacted in 38 states and the District of Columbia to date, while 13 of them including the District of Columbia have set a goal to achieve 100% clean electricity latest by 2050. Apart from the RPS, the states have also introduced a few policies to promote the adoption and investment of RE technologies, such as the Property Assessed Clean Energy loan, FIT, net metering, interconnection standards, output-based environmental regulations, and public benefits funds for RE. The latest policy announced in the year 2022 is the Inflation Reduction Act, which employs the tax credit mechanism to promote the usage of clean energy among the households and invest in clean energy production (Smith, 2022).

Policy support for RE development in the European Union (EU) was initially planned, enforced, and monitored independently by individual member state, started by Denmark in 1979 (Kitzing, Mitchell, & Morthorst, 2012). It was not until 2009 when the member states adopted the Renewable Energy Directive (2009/28/EC), which established the obligatory RE targets by 2020. Nonetheless, each member state has the discretion to decide which support policies to put in place (Fruhmann & Tuerk, 2014). This legal framework set up an EU-wide target of 20% share of RE consumption by 2020, which was allocated differently as national targets among the member states, from 10% for Malta to 49% for Sweden. It also required each member country to present their respective National Renewable Energy Action Plans (NREAPs) to specify detailed strategies to achieve the said national targets in terms of transportation, heating, and cooling, as well as electricity sectors. After the legal approach has seen success in overperforming the original target by 2% in 2020, a few revisions have been made to increase the target to 45% by 2030 in the latest Communication on the REPowerEU plan (COM/2022/230 final). In striving to attain the EU-wide goal, a combination of policy tools has been used, which comprise the RE tender programs, tax allowance, investment subsidies, soft loans, loan guarantees, quota with tradable green certificates, feed-in premiums (FIPs), and FIT. The FIT, FIP, and tender programs are among the most favored policy in the EU due to their high capacities to improve cost-effectiveness and promote healthy competition in the market.

7.5 Case study

This section presents a case study analysis of the RE–environment nexus. In this analysis, Malaysia has been chosen as the subject. As an emerging economy, Malaysia's development is highly reliant on conventional fossil fuels. The CO_2 emissions in Malaysia are primarily constituted by electricity consumption, vehicles, and municipal solid wastes (Khoo, 2019). Although Malaysia only ranks fourth in terms of total CO_2 emissions in the ASEAN region, the country has disproportionately high CO_2 emissions per capita given its population amounting to merely about 33 million. In fact, Malaysia had the third largest CO_2 emissions per capita in 2019 after Brunei and Singapore (World Bank, 2023a). It is even more staggering to notice that Malaysia's CO_2 emissions per capita even surpassed that of China, the largest contributor of CO_2 emissions in the world, by 0.1 metric tons per capita in the same year.

Malaysia is blessed with abundant RE sources such as solar, hydro, palm oil biomass residues, municipal wastes, and landfill gas (Poh & Kong, 2002). This implies that Malaysia possesses lots of potential to develop its RE sources which could gradually decrease the overreliance on non-RE sources. Since Malaysia has pledged to achieve a reduction of 45% CO_2 emissions per gross domestic product (GDP) by 2030 in the Paris Agreement, it is of paramount importance for Malaysia to invest substantially in RE to transition from fossil fuels. Thus, this case study would like to determine whether RE consumption can improve the environmental degradation in Malaysia.

We employ CO_2 emissions as the indicator of environmental degradation which serves as the output variable, while the input variables are economic growth and RE consumption based on the EKC model. The model for this empirical analysis is presented below:

$$CO_{2t} = \beta_0 + \beta_1 GDP_t + \beta_2 GDP_t^2 + \beta_3 REC_t + \varepsilon_t \tag{1}$$

where CO_2 indicates the CO_2 emissions per capita (tons), *GDP* represents the GDP per capita (constant 2015 USD), GDP^2denotes the squared GDP per capita (constant 2015 USD), *REC* is referred to RE consumption per capita (megawatt hour), ε implies the residual, and subscript t is time. Additionally, β_0 is the intercept, whereas β_1, β_2, and β_3 signify the coefficients.

The data span from 1980 to 2019. CO_2 emissions, GDP per capita, and RE consumption were collected from Emissions Database for Global Atmospheric Research (2023), Crippa, Guizzardi, Banja, and Vignati (2022), Emissions Database for Global Atmospheric Research (2023), The World Bank (2023), and the United States Energy Information Administration (EIA) (U.S. Energy Information Administration, 2023).

First, the augmented Dickey−Fuller (ADF) unit root test is executed to identify if the variables are stationary or do not change with time. The ADF test was first introduced by Dickey and Fuller (1979) to check the stationarity of the time series variables. A stationary variable is free from trends and seasonality, on top of having constant mean and variance. This is to avoid spurious regression. The null hypothesis of the ADF test suggests that there is a unit root (nonstationary) in the variable. The null hypothesis is rejected if the test statistic value is greater than the critical value. Alternatively, the null hypothesis is rejected if the *P*-value is smaller than the significance level of 5%. Table 7.1 shows that all the variables are stationary at the first difference or having an order of integration of 1, I(1).

Next, the autoregressive distributed lag (ARDL) bounds test is employed to determine the long-run co-integration between RE consumption, economic growth, and CO_2 emissions. Proposed by Pesaran and Shin (1999), the ARDL approach is able to capture both long- and short-run effects of the independent variables on the dependent variable. It remedies the non-stationarity issue of the time series variables by taking into account different orders of integration, regardless of the variables being stationary at I(0), I(1), or a combination of both. This approach is a dynamic single model equation that includes unrestricted lag of the regressors in a regression.

Table 7.2 exhibits the findings of the ARDL bounds test. The null hypothesis is that there is no long-run co-integration in the model. The rejection rule states that

Table 7.1 The augmented Dickey−Fuller test results.

Variables	**Augmented Dickey−Fuller**			
	Level		**First difference**	
	Constant	**Trend**	**Constant**	**Trend**
CO_2	-1.374	-0.586	-5.208***	-5.388***
GDP	-0.485	-1.842	-5.216***	-5.146***
GDP^2	-0.219	-1.980	-5.303***	-5.230***
REC	-0.859	-1.521	-5.154***	-4.940***

Note: *** signifies significance level at 10%.

Table 7.2 The autoregressive distributed lag bounds test results.

Optimal lag length for ARDL model	**5,1,1,0**	
F-stat	5.722***	
Critical values	I(0) Bound	I(1) Bound
1%	3.65	4.66
5%	2.79	3.67
10%	2.37	3.20

Note: *** signifies significance level at 10%. The optimal lag length is selected by the Akaike info criterion (AIC).

Table 7.3 Long-run and short-run coefficients results based on the autoregressive distributed lag approach.

Variables	**Statistical results**
GDP	1.122***
GDP^2	-0.603***
REC	-0.132***
ECT	-0.251***
ΔGDP	-1.396***
ΔGDP^2	1.355***
Diagnostic test	
Breusch–Godfrey LM test	0.306 (0.739)
Jarque–Bera test	0.470 (0.791)
Ramsey RESET test	0.185 (0.855)
ARCH test	1.254 (0.271)

Note: *** signifies significance level at 10%. The Breusch–Godfrey LM test is to verify the serial correlation, the Jarque–Bera (J-B) test is to determine the normality of the residuals, the Ramsey RESET test is to verify the specification error, and the ARCH test is a heteroskedasticity test in time series.

there is enough statistical evidence to reject the null hypothesis when the F-statistic exceeds the upper critical bound. Based on the findings, the model is statistically co-integrated in the long run.

The outcomes of the short- and long-run coefficients are reported in Table 7.3. It can be seen that REC and GDP^2 are significant with a negative sign at 1% critical value, while GDP is significant with a positive sign at 1% critical value. According to the ceteris paribus assumption, the results can be interpreted as follows:

- A percentage increase in the GDP will increase CO_2 by 1.12%, while holding other variables constant.
- A percentage increase in the GDP^2 will reduce CO_2 by 0.60%, while holding other variables constant.
- A percentage increase in the REC will reduce CO_2 by 0.13%, while holding other variables constant.
- Overall, it is discovered that GDP has the biggest magnitude impact on the change in CO2. In comparison, GDP's magnitude impact is 8.6 times greater than that of REC.

The error correction term (ECT) is significant with a negative sign at 1% critical value, supporting the presence of long-run co-integration in the model. The coefficient of ECT (-0.251) informs that CO_2 emissions per capita will take about 3.01 months to adjust to the long-run equilibrium upon any occurrence of shocks. In terms of the short-run relationship, GDP per capita has negative and GDP^2 per capita has positive relationships with CO_2 emissions per capita. The findings of the diagnostic tests in Table 7.3 signify that the model is in good fit. Furthermore, Figs. 7.2 and 7.3 demonstrate the outcomes of the cumulative sum (CUSUM) and CUSUM of squares tests that stability is achieved in the model.

As an inference, the case study above validates the presence of the EKC hypothesis in Malaysia. It means that economic growth increases environmental degradation initially, but its impact gradually shifts and reduces environmental degradation

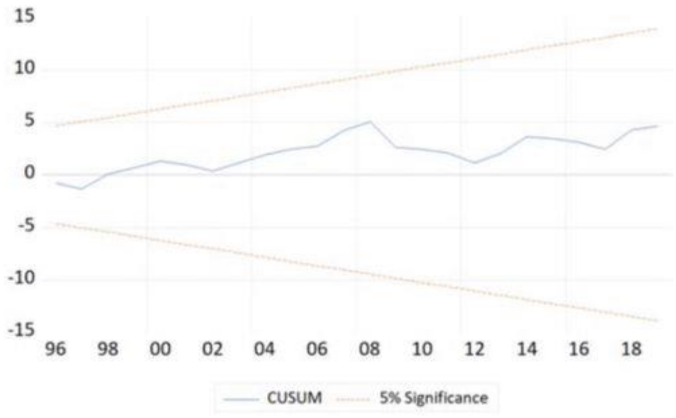

Figure 7.2 Cumulative sum test.

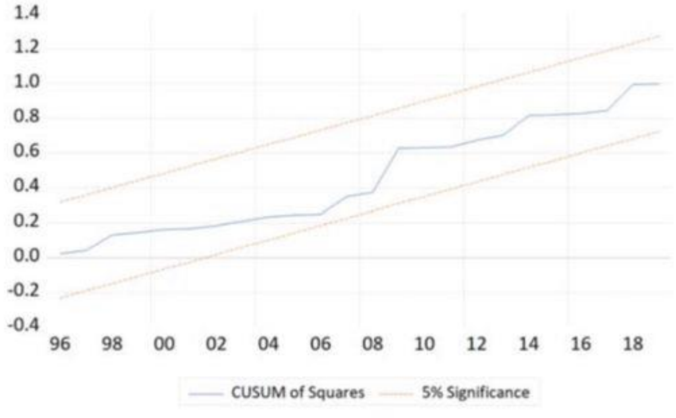

Figure 7.3 Cumulative sum of squares test.

over time. Another key result of this case study reflects the importance of RE consumption in the improvement of environmental sustainability in Malaysia. The results clearly show that the impact of RE consumption on the environmental degradation is not instantaneous, but rather takes time to show its effect. These findings reflect that Malaysia's economic structure and RE adoption initiatives are showing significant long-run effects on the environmental sustainability. The outcomes are in line with Balsalobre-Lorente et al. (2022) and Suki et al. (2022).

Chien et al. (2021) explained that RE consumption alleviates environmental degradation in two different ways. First, increased RE satisfies a proportion of the energy demand which could have been fulfilled by fossil fuels, in turn reducing harmful gases and air pollution. Second, diversification of energy consumption into RE implies that the demand for imported fuels decreases, thus improving environmental quality. Malaysia relies heavily on the imports of coal for power generation, and about 92% of its coal consumption came from the imported coal in 2018 (United States Energy Information Administration, 2021). In this context, promoting RE consumption will decrease the demand for imported coal and, hence, mitigate the environmental degradation issue.

7.6 Conclusions and future perspectives

The severity of environmental challenges must not be ignored. Environmental issues are endangering all living beings on the planet, regardless of species and geography. Pollutions, global warming, natural resources depletion, biodiversity loss, and climate change can be fatal to our survivability if left unattended. It is vital to comprehend the underlying factors in order to formulate the best possible ways to curtail the issue of environmental degradation. Unplanned economic development, excessive fossil fuels consumption since the first industrial revolution, and global military conflicts all put the environment at a major stake. These activities had been releasing significant amount of harmful GHG emissions to the atmosphere, which is a direct factor in environmental issues. To date, 75% of the GHG emissions and 90% of CO_2 emissions in the world come from gas, oil, and coal (United Nations, 2023b).

As an emphasis from the United Nations (2023b), energy is the key solution to global environmental challenges. Owing to the properties of the REs that are inexhaustible and substantially eco-friendlier than fossil fuels, they are excellent energy alternatives in the face of global environmental challenges. Hence, it is clear that the most effective way to sustain the environment while being able to support the continual development of civilizations is the deployment of REs. As environmentally friendly as the REs may seem in the long run, each RE source comes along with some detrimental influences to the environment that should not be ignored. Overall, the similar consequences on the environment that all RE sources share involve the alteration of landscapes, dislocation of natural habitats, and adverse wildlife interactions. The reduction of GHG emissions has prompted too much attention that little concern is given to the undesirable environmental impacts of the GHG reducing REs.

On top of that, RE sources are subject to two major challenges, intermittency and cost. Solutions have been found with respect to the intermittency issue with the help of technologies, such as battery storage and integration of two or more renewables to complement the consistent supply of energy. In terms of the cost issue, the costs of wind and solar power plants have plunged drastically in recent decades due to the increasing scale of renewable plants and governmental policies. The cost differential is particularly apparent during the Russia−Ukraine conflict when the costs of onshore wind and solar projects are 40% lower than the fossil fuel plants (Baker, 2022). The accentuation of RE as a vital role in ameliorating the environmental degradation has been extensively portrayed in the research area, as discussed in the literature review in Section 7.3.

From the theoretical perspective, environmental degradation is viewed as the cost of economic growth, but only during the early phase when a growing economy is reliant on the use of environmentally harmful technologies and prioritizes industrial development. Eventually, the environmental impact of economic growth will be reversed as a country becomes more developed with a shift in the economic structure and use of sophisticated technologies that are friendly to the environment. This relationship is described as the EKC hypothesis. Even though the EKC hypothesis has become fundamental in the growth−environment study, no unanimity has been reached, and findings remain conflicting depending on the scope of the study (Chen, Ma, Lin, Ma, & Li, 2022; Gill et al. 2018; Kilinc-Ata & Likhachev, 2022; Saudi et al. 2019).

Over the years as RE gains more significance with respect to environmental challenges, the EKC hypothesis has been extended to incorporate RE in the empirical literature. The literature on RE in the economic sphere is studied from consumption and production aspects (Ansari, 2022; Djellouli et al., 2022; Hdom, 2019; Kartal, 2022). Nevertheless, these studies were conducted by using aggregate RE which is inadequate to explain which particular RE source is best to cope with environmental degradation. Hence, Jahanger et al. (2022), Luo et al. (2022), Sahoo and Sahoo (2020), and Udeagha and Ngepah (2022a) initiated studies on the disaggregated RE−environment relationship. They revealed that the effect of each disaggregated RE source is different across nations. Overall, conventional renewable source such as hydropower is found to be effective to improve the environment in most countries, while newer renewable source such as solar power is less significant in mitigating environmental deterioration. This may be attributable to the maturity of the RE technology of each source. Long-established RE sources like hydropower have been around for more than a century, and they tend to be widely used in many countries on a larger scale. On the other hand, newer RE technology in solar power has only been started for a few decades, and it is not widely used in many countries yet because its limitations in intermittency and cost efficiency are relatively greater than the conventional renewable sources.

To better understand the RE consumption−environment nexus from an empirical point of view, this chapter provided a case study example. Malaysia was chosen to be the subject of the case study for two main reasons. First, Malaysia has the highest CO_2 emissions per capita among all ASEAN nations and even higher than that of China despite its relatively smaller population size. Second, Malaysia has abundant resources endowment including solar, hydro, and palm oil biomass residues; thus it possesses high potential for developing RE sources. According to Section 7.5, it was empirically proven that RE consumption is an effective remedy of environmental degradation, apart from substantiating the existence of the EKC hypothesis in Malaysia. The ARDL bounds test results suggested that RE consumption decreases environmental degradation in the long run. In reality, RE consumption does not manifest an instantaneous impact on the environmental degradation, especially when Malaysia's RE consumption only constituted 5.11% of the total energy consumption in 2019 (World Bank, 2023b). RE consumption is most likely to start exhibiting its effect on the environment in the long run when continuous utilization of RE is sufficient to have a cumulative improvement over the environment gradually.

The policy recommendation drawn from the case study is that policies center around the development of RE technology and adoption, while keeping the economy going is key to improve the environmental sustainability. First, it is suggested for the policymaker to incentivize both the businesses and households such as giving out tax cuts to the businesses that use RE and subsidizing the households in the RE cost. Second, the government should mediate the collaboration of foreign and domestic research and development initiatives on the RE technology. The form of collaboration can be commercial between the foreign and domestic companies or educational between foreign and domestic universities. By doing so, not only can the RE technology be effectively developed with the help of foreign countries having a more advanced technology but also increase the competitiveness of the local companies, promote foreign direct investments, and improve bilateral or multilateral relations, which overall stimulate economic growth. Third, the RE development policy should focus on the natural endowment of each country. For the case of Malaysia, it is suggested to concentrate on the development of solar, hydro, and biomass due to their abundance in the country. Apart from focusing on the endowment of energies, it is essential to design and implement systematic approaches for each specific RE source to address its corresponding negative environmental impacts, which leads to the last policy recommendation of this chapter. While many global RE frameworks focus primarily on the GHG emissions reduction (Anadón, Baker, & Bosetti, 2017), each government should be cautious with the potential environmental threats of each RE source and formulate a series of countermeasures before deploying them.

Although the RE—environment relationship studies are ample in the literature, none have considered the optimal mix of fossil fuels and RE sources that is environmentally sustainable. Due to the intermittency, cost, and incapacity to meet the rapid increase in energy demand, RE sources are unlikely to perfectly replace fossil fuels in various sectors. Unless the RE technology encounters a massive breakthrough that completely remedies its limitations, RE sources shall remain a complement to the high-carbon energies. As stated by Kooten (2021), a world without fossil fuels is more likely to exist upon unrealistic assumptions. Fundamentally, the most efficient energy source is most favored by the people. With the concern of environmental sustainability in mind, the use of fossil fuels as the most efficient energy sources has to be compromised. Simultaneously, this compromise should avoid undermining the long-term development of a nation. Hence, it is pivotal to determine the optimal mix of fossil fuels and RE that has the highest energy efficiency, while ensuring environmental sustainability. This could be a prospective topic for future environmental study.

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