



Economic Growth and Multidimensional Environmental Performance in Developing Countries: An EKC Perspective on Energy Efficiency and Clean Energy Transition

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Abstract

Economic growth in developing countries remains closely tied to fossil fuel dependence, generating persistent tension between development and environmental sustainability. This conceptual paper revisits the Environmental Kuznets Curve (EKC) framework to conceptualises how economic growth affects environmental performance, disaggregated into three dimensions of the Environmental Performance Index (EPI): Environmental Health (HLT), Ecosystem Vitality (ECO), and Climate Change Mitigation (PCC). Unlike literature treating environmental quality as a single composite measure, this paper conceptualises that growth's effects vary across these dimensions. It further theorises energy efficiency and clean energy transition as moderators capable of reshaping the EKC's trajectory and turning point. Synthesising energy economics and sustainability literature, the paper develops a conceptual model linking growth, energy efficiency, and clean energy transition to environmental performance, offering policy-relevant insights aligned with SDGs 7, 8, and 13 in developing economies.

Keywords: Economic Growth, Energy Efficiency, Clean Energy Transition, EKC, EPI, Developing Economies

Introduction

This conceptual paper delves into the advantages of economic growth in developing countries and gives a quick summary of how the countries are categorised by the World Bank according to income to kick off the conversation. It also conceptualises the multidimensional impact of economic growth on environmental quality in a broader sense by taking into account the Environmental Performance Index (EPI) and each of its individual components, such as Environmental Health (HLT), which measures environmental threats to human health; Ecosystem Vitality (ECO), which measures natural resources and ecosystem services; and Climate Change Mitigation (PCC), which measures a country's projected greenhouse gas emissions. Moreover, it theorises energy efficiency and the clean energy transition as moderators towards more sustainable energy sources.

The intricate interplay between economic growth and environmental quality underscores a pivotal challenge facing the modern world. Historically intertwined with fossil fuel consumption, economic growth has come at the cost of environmental degradation, as fossil fuel combustion releases pollutants and greenhouse gases. Fossil fuels (FFs), such as coal and oil, were primarily used to meet production system requirements and enhance economic growth (GDP) in various countries, which resulted in massive emissions of greenhouse gases (GHG) and exacerbated climate change. Fossil fuels have enabled a rapid expansion of agriculture, transportation, and industrial processes (Hudson, 2011).

The empiricist was driven to determine the growth-environment link in the context of developing countries because of the divergent perspectives on this relationship, i.e., positive, negative, neutral, or non-linear on both sides of the spectrum. Comprehending the structural mechanisms behind pollution patterns throughout economic expansion is crucial for several reasons in each nation.

The environment is harmed by economic activity in the form of greenhouse gas emissions, biodiversity loss, air and water pollution, and resource extraction. The Greenhouse Gas (GHG) problem, which contributes to environmental issues including global warming and climate change, continues to be the most significant environmental concern for the worldwide community (Alola, 2019; Bekun et al., 2019).

Over 90% of the world's GHG emissions are produced by five fundamental systems: energy, cities, transport, manufacturing, and agriculture, food, water, and land use. To combat climate change, build a sustainable future with minimal carbon emissions, and protect biodiversity and natural capital, these systems must be altered (World Bank, 2021).

Energy consumption and economic growth are strongly correlated since nations with higher energy consumption also tend to have more developed economies. The main cause of CO₂ emissions is the combustion of fossil fuels. Since fossil fuels have supplied about 90% of the commercial energy used in developing economies, the more commercial energy used, the more CO₂ emissions there will be (Karki et al., 2005). Over 75% of all emissions on the planet are caused by energy (IEA, 2020). While consuming less energy can reduce greenhouse gas emissions, it may also have a detrimental effect on economic growth. In this setting, rising energy (fossil fuel) demand continues to be the primary driver of greenhouse gas emissions (Alola, 2019; Hamit-Hagggar, 2012). For this reason, most poor nations are reluctant to adhere to the Kyoto Protocol.

The most recent Sustainable Development Goals (SDG) progress report (United Nations, 2022) demonstrates the incapacity of developing countries to address the issue of rising emission levels. These countries are straying from achieving SDG 7 and 13, i.e., clean energy and climate action respectively, because of their energy-driven growth trajectory. The economic growth patterns of developing countries may not prove to be sustainable, which may present a challenge to achieving SDG 8's goals of decent work and economic growth (United Nations, 2022). The developing countries have come under fire in the 2019 SDG progress report for directing investments towards boosting the production of energy based on fossil fuels while ignoring environmental initiatives (United Nations, 2020).

Energy efficiency and clean energy transition are the twin pillars of the sustainable energy scenario (IEA, 2022a). Energy efficiency relates to the economic value of fuel consumption and offers a cost-effective and efficient energy source for creating goods and services (Hussaini, 2018; Lan et al., 2021). Energy efficiency is the single largest measure to avoid energy demand in the Net Zero Emissions by 2050 Scenario (IEA, 2022b). Energy efficiency has been suggested as a potential policy tool for changing developing countries into low-carbon countries by the United Nations Environmental Programme (UNEP). According to the International Energy Agency (IEA), greater energy efficiency in manufacturing, transportation, and construction could reduce global energy consumption by 30% by 2050 while also assisting in the reduction of greenhouse gas emissions (IEA, 2022b).

In expanding clean energy systems, like hydropower, infrastructure must be developed with consideration for climate resilience, water-related shocks, and the various uses of reservoirs. The ability of alternative energy sources to reduce greenhouse gas emissions, which contribute significantly to climate change, is one of their main advantages (World Bank, 2022). The International Energy Agency estimates that by 2050, global CO₂ emissions could be reduced by up to 70% using renewable energy sources (IEA, 2022a). The highest potential for investments in Renewable Energy Technology (RET) in developing countries is identified by sustainable development scenarios prepared by the IEA. The most cost-effective way to reduce emissions in terms of climate action is in developing countries since the average investment cost is roughly half that of affluent countries (IEA, 2017, 2020). Investments in low-carbon baseload capacity, especially renewable energy and energy-efficient technologies, are essential for lower-income countries to ensure that everyone has access to energy.

The following research questions are posed in light of the topics covered in this study: (1) How do economic growth, energy efficiency and clean energy transition affect environmental health under the EKC framework in developing countries? (2) How do economic growth, energy efficiency and clean energy transition affect ecosystem vitality within the EKC framework in developing countries? (3) How do economic growth, energy efficiency and the clean energy transition affect climate change under the EKC framework in developing countries? (4) How do energy efficiency and clean energy transition moderate the relationship between economic growth and environmental performance, shaping the Environmental Kuznets Curve in developing countries? By investigating these questions, this study extends the literature on energy efficiency and clean energy transition to examine the impact of economic growth on environmental performance in the context of developing countries.

Review Approach

This paper is designed as a conceptual and structured literature review. Its purpose is to synthesise existing evidence on the links among economic growth, energy efficiency, clean energy transition, and environmental performance in developing countries, and to develop propositions for future empirical testing. Literature was identified through Scopus and Google Scholar using keywords such as "Environmental Kuznets Curve," "economic growth," "energy efficiency," "clean energy transition," "environmental performance index," and "developing countries." The review focuses mainly on studies published between 2019 and 2023, with foundational works and a small number of more recent studies added through reference

tracing. Studies were selected for their relevance to the focal constructs and their contribution to theory or evidence, with preference for peer-reviewed articles and authoritative institutional reports. The propositions developed in this study therefore represent theoretically and empirically informed expectations derived from the reviewed literature rather than statistically tested hypotheses.

Literature Review and Proposition Development

Economic Progression – Environmental Depletion Nexus

In recent decades, global economies have grappled with the dual challenge of attaining greater economic growth while curbing environmental degradation (Destek & Sarkodie, 2019; Khan et al., 2017; Wang et al., 2020; Wang et al., 2017; Yang et al., 2020; Zheng et al., 2020). The potential inverted U-shaped relationship between environmental pollutants and economic growth was primarily explained theoretically by Grossman and Krueger (1991), known as the EKC hypothesis. The EKC hypothesis outlines the timeline for environmental deterioration that a nation would experience as its economy grows.

Economists assert that economic growth is the most effective solution to address global environmental issues. In the modern era, global warming and climate change have sparked debate as a major threat to the broader ecosystem and the environment (Eren et al., 2019; Lee et al., 2016; Wang & Chen, 2014). Global economies strive for higher economic growth, but often at the cost of environmental degradation, including resource exploitation and harmful emissions causing global warming (Chakravarty & Mandal, 2020; Panayotou, 1993). The debate on environmental convergence between developed and developing nations lacks a conclusive consensus in empirical studies (Sarkodie, 2021; Badunenko et al., 2023). This implies that various studies have used different measurements to capture key indicators in the growth-environment nexus. In the current era, numerous indicators have been used to assess environmental quality, such as CO₂ emissions, ecological footprint (EFP), environmental efficiency (EE), eco-innovation (EINV), environmental sustainability (EVS), and greenhouse gas emissions (GHG), etc.

The intricate relationship between CO₂ emissions, economic development, and the environment is at the forefront of global discussions and challenges. Economic development is typically associated with increased industrialisation, urbanisation, and greater energy consumption, often leading to higher CO₂ emissions. Global warming and a host of other negative environmental effects are exacerbated by increased CO₂ levels, which are mostly caused by human activities such as the burning of fossil fuels and deforestation. The latest literature investigates the relationship between CO₂ emissions and economic development, highlighting a nonlinear connection between GDP and CO₂ emissions (Agozie et al., 2022; Badunenko et al., 2023; Kon et al., 2023; Sikder et al., 2022; Bakry et al., 2023; Djellouli et al., 2022; Mujtaba et al., 2022; Pata & Samour, 2022; Raihan et al., 2022; Raihan & Tuspekova, 2022; Wang et al., 2023; Xue et al., 2022; Yu et al., 2022).

The EFP measures how species use the world's natural capacity for recreation, including resource production and consumption. Ecological footprint (EFP) was established by Wackernagel and Rees (1996) and composed of six components: fishing grounds, cropland, grazing land, forest land, carbon footprint, and built-up land (Lin et al., 2018). Environmental deterioration is indicated by the positive correlation between economic growth and

ecological footprint. A rising economy is associated with a larger ecological footprint, indicating environmental degradation (Adebayo et al., 2023a; Rafique et al., 2022; Bashir et al., 2023a; Fakher et al., 2023; Mujtaba et al., 2022).

Regarding the economic ramifications of climate change, a rise in greenhouse gas emissions forecasts calamity for both the environment and humankind owing to the adverse consequences it has on the climate. Greenhouse gas emissions encompass six primary greenhouse gases: carbon dioxide (CO₂), methane, sulphur hexafluoride, nitrous oxide, hydrofluorocarbons, and perfluorocarbons. A positive relationship between GDP and GHG is evident by the (Mohsin et al., 2021; Mortezaazadeh et al., 2023; He et al., 2022; Sarkodie & Strezov, 2019; Yusuf et al., 2020; Qing et al., 2023).

The Environmental Performance Index (EPI), which assesses the environmental performance of nations in the areas of human health (HLT), ecosystem vitality (ECO) and climate change mitigation (PCC), is one of these crucial indicators (Mortezaazadeh et al., 2023). By identifying issues and objectives, pursuing trends, determining the most effective policy practices to maximise environmental efficiency, and supporting efforts to attain the United Nations Sustainable Development Goals, this index offers countries practical guidance on how to advance (Mortezaazadeh et al., 2023). Empirical literature that sought to examine the relationship between economic activity, using GDP as a proxy, and EPI for environmental performance reveals a significant positive relationship among the variables (Adeel-Farooq et al., 2023; Fu et al., 2020; Mortezaazadeh et al., 2023; Raza et al., 2021; Wang et al., 2021; Wendling et al., 2022).

P1: Economic growth is conceptually expected to exhibit a nonlinear relationship with environmental performance in developing countries, consistent with the Environmental Kuznets Curve (EKC) framework, but the shape and turning point are expected to differ across the three EPI dimensions (HLT, ECO, PCC).

Growth-Energy-Environment Nexus

Economic growth needs to be strongly supported by energy (Ahmad & Muslija 2021). There are several ways to produce energy, including nuclear power, fossil fuels (coal, oil, and natural gas), and renewable energy sources (solar, wind, hydro, and geothermal) (Chen et al., 2023; Song et al., 2023). The environment is significantly impacted by the production, distribution, and consumption of energy, and environmental factors also have an impact on energy systems (Shahbaz et al., 2013). Environmental contamination is mostly caused by conventional energy sources, which are essential for economic activity (Chien et al., 2021a). Energy-related CO₂ emissions rebounded to 36.6 Gt in 2021, marking the highest annual increase in emissions (IEA, 2022c).

Economic Growth, Energy Efficiency and Environmental Performance

A cheap and safe energy source that is needed for production activities is crucial for economic expansion (IEA, 2022c). Energy efficiency has the potential to indirectly improve environmental quality of life and lower pollution-related mortality by supporting environmentally friendly practices and innovations (IPCC, 2021). The reduction of greenhouse gas emissions, achieved through the adoption of energy-efficient technologies and practices, is essential for curbing global warming and preserving the delicate balance of our ecosystems.

Embracing energy efficiency is not just an environmental imperative; it is a pathway to a more resilient, responsible, and sustainable future for our planet (IRENA, 2020; United Nations, 2021; World Economic Forum, 2021). According to the International Energy Agency (IEA), more than one-third of the cumulative reductions in greenhouse gas (GHG) emissions required to stabilise climate change could be achieved through energy efficiency enhancements (IEA, 2018).

P2: Energy efficiency is expected to contribute positively to environmental performance in developing countries.

Economic Growth and Clean Energy Transition and Environmental Performance

Developing economies rely on two primary types of energy: renewable and non-renewable. The utilisation of renewable energy has an adverse impact on CO₂ emissions, whereas the consumption of fossil fuel energy is associated with environmental pollution in these economies (Chien et al., 2021a). The vibrant use of renewable energy serves as a positive indicator for boosting economic growth, mitigating carbon dioxide emissions, supporting environmental conservation, and fostering both short-term and long-term economic progress (Shahbaz et al. (2018); Sugiawan & Managi (2016). To elucidate the relationship, Balcilar et al. (2023) in 34 African countries, Azam et al. (2021) in top ten CO₂ emitting countries, Chien et al. (2021) in Pakistan, Abbasi et al. (2022) in China, Bakry et al. (2023) in 76 DCs, Yu et al. (2022) in 25 DCs, Mujtaba et al. (2022) in OECD countries, have investigated a negative correlation between carbon emissions and renewable energy.

Adebayo et al. (2023a) verified the positive influence of renewable energy use on environmental quality for the MINT economies. The findings of the research were consistent with (Ahmed et al., 2022; Bashir et al., 2023b; Danish et al., 2020; Destek & Sinha, 2020; Dingru et al., 2021; Fakher et al., 2023; Wang et al., 2022; Mujtaba et al., 2022; Usman et al., 2020) supporting the positive relationship between economic growth and ecological footprint, as well as increased renewable energy consumption diminishes ecological footprint. Global climate goals are concurrently aligned with lowering GHG emissions through the adoption of renewable energy evident by the empirical work of He et al. (2022) and Qing et al. (2023).

P3: Clean energy transition is expected to exhibit a positively association with environmental performance in developing countries.

The Function of Moderators in the Growth-Environment Nexus

More recent research in the literature is paying keener attention to the impact of moderators in the growth-environment nexus. As economic growth accelerates, the moderators act as buffers or amplifiers that shape the environmental consequences. A comprehensive understanding of the growth-environment nexus is enhanced by the investigation of moderators, which provides crucial information for well-informed decision-making and policy formulation aimed at striking a harmonious balance between environmental stewardship and economic advancement.

For instance, studies have explored the moderating role of technological innovation (TI) by Jahangir et al. (2022) foreign direct investment (FDI) by Uddin et al. (2024), corruption (COR)

by Wang et al. (2018), urbanisation by Nathaniel, (2021) and financial development (FD) by Rjoub et al. (2021). Both energy consumption and GDP and energy consumption and CO₂ emissions, are directly correlated. The empirical work of Ehigiamusoe et al. (2020) unfolds strong evidence of a moderate impact of energy consumption on the income-carbon emissions nexus in middle-income nations. Similarly, in the energy-income nexus, energy consumption moderates the impact of GDP on CO₂ emissions. Conclusively, the previous studies have not been able to grasp how energy efficiency and the clean energy transition can contribute to the problem's resolution since there hasn't been much of an effort to understand the moderation of these two concepts. If energy efficiency and clean energy transition act as moderators, developing economies should implement energy-efficient or conservation policies to lessen the detrimental impact of energy consumption on environmental performance.

P4: Energy efficiency and clean energy transition are theorised to moderate the relationship between economic growth and environmental performance, potentially altering the shape or turning point of the EKC.

Theoretical Framework

The main concern about the connection between environmental deterioration and economic growth is the EKC hypothesis. The economic perspective suggests that environmental degradation increases with economic growth and development, then decouples from it, and eventually decreases with a certain income level. Panayotou originally dubbed this inverted U-shaped link between environmental deterioration and economic growth as the Environmental Kuznets Curve (EKC) (Panayotou Theodore, 1993).

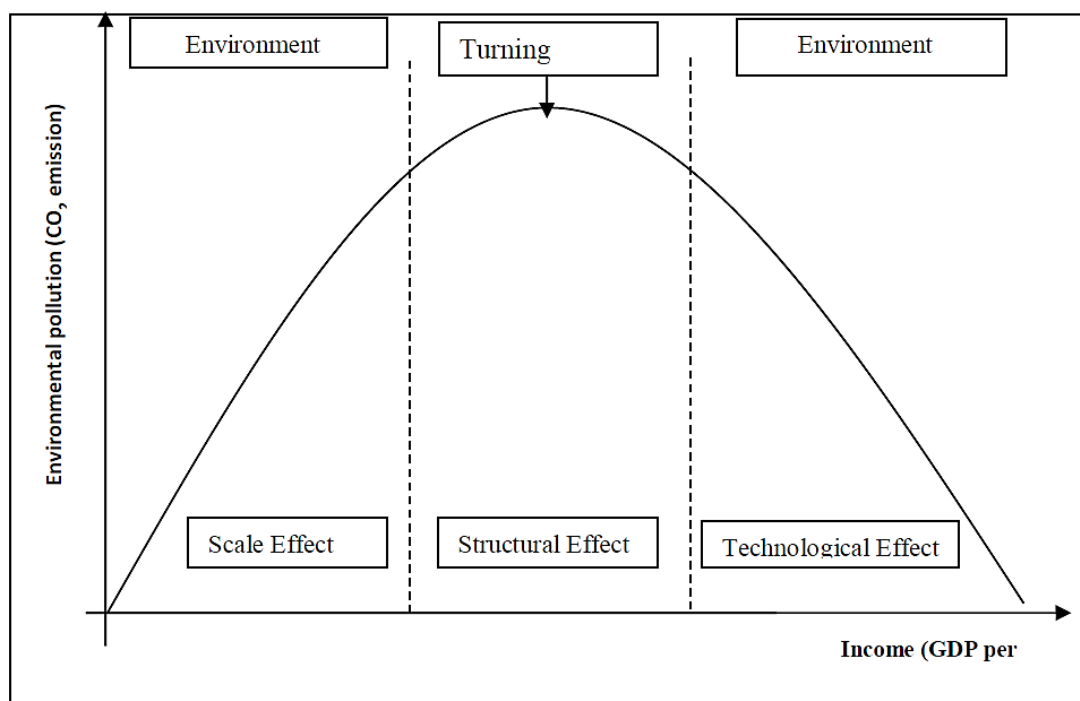


Figure 1: Conceptual framework of the Environmental Kuznets Curve (EKC), illustrating the scale, composition, and technique effects conceptualised by Grossman and Krueger (1991) and first visualised by Panayotou (1993).

Source: Adapted from Grossman and Krueger (1991); Panayotou (1993).

Numerous academics have investigated the EKC concept in the wake of the three ground-breaking investigations that followed: Grossman and Krueger, (1991); Panayotou Theodore, (1993); and Shafik and Bandyopadhyay, (1992). They all attempted to evaluate the changes in environmental quality over time and to respond to the question of whether economic expansion causes or alleviates environmental concerns (Kijima et al., 2010). The Grossman and Krueger (1991), divided the environmental effects of economic growth into three categories: scale effect, composition effect and technique effect.

The scale effect suggests that economic growth can cause environmental damage, as higher output requires more energy and resources. Growing economies will lead to higher production and consequent environmental deterioration. The composition effect refers to favourable or unfavourable impact on the ecosystem. An economy's production structure shifts from agriculture to heavy industries in the early phases of economic development. This is how the environment is negatively impacted by economic growth. An advantageous effect of economic growth on the environment is that it will cause the economy to restructure itself in favour of clean manufacturing and service sectors.

The technique effect indicates that economic expansion benefits the environment. This shows that as the economy grows, newer, cleaner technologies replace outdated, dirty ones, improving the environment. The EKC states that during the early phases of economic growth, the scale effect exacerbates environmental degradation; subsequently, positive effects from composition and technique effects will predominate, lowering the emission level (Stern, 2004).

The literature on energy consumption, environmental pollutants, and economic growth is authored by three research groups. The first group primarily focuses on the environmental pollutants and output nexus. They specifically investigate the Environmental Kuznets Curve (EKC) hypothesis which suggests an inverse U-shaped relationship between environmental quality and economic growth.

An analysis of the connection between energy consumption and economic growth is presented in the second group of literature. Economic growth is thought to be highly dependent on energy consumption. The correlation between increased energy consumption and economic growth is widely acknowledged. Energy consumption and economic growth are therefore closely related. This group focuses on the question of whether energy consumption elevates economic growth or the other way around.

The third group finally surfaced recently. Literature in this category integrated the previous two methods to look at the dynamic relationship in a unified framework between energy consumption, environmental pollutants, and economic growth.

Discussion

The conceptual paper proposes a detailed framework of economic growth, energy efficiency, clean energy transition and environmental performance in developing countries and also theorises the moderating role of energy efficiency and clean energy transition as an important

contribution to the literature of sustainable development. The practical implications of this study are supposed to explore the heterogeneous impact of growth on the environment among developing countries which is beneficial for policymakers to design context-specific solutions suitable for regions of the developing world. The discussion below interprets the reviewed literature and the propositions it supports

First, most of the earlier researches focused on demonstrating the negative correlation between economic growth and environmental performance without considering the elements that reduce environmental degradation while promoting economic growth in developing countries. The proposed framework addresses this gap by positioning energy efficiency and clean energy transition as mechanisms that may weaken the adverse environmental effects of growth.

Second, the reviewed literature points that energy efficiency consistently emerges as the most powerful and structurally stable driver of environmental improvement across the developing economies. This suggests that developing countries should systematically shift energy consumption away from fossil fuels toward energy-efficient and green technologies for both industrial production and domestic use to decouple economic growth from carbon-intensive energy consumption. These economies should invest in smart grid infrastructure, building energy codes, and technology upgrading programmes that systematically reduce energy intensity across manufacturing, transport, and services sectors.

Third, the literature indicates that *future sustainable economic growth and societal well-being depend on renewable energy sources*. The switch to clean energy is acknowledged as a business opportunity for governments in developing countries to concurrently overcome their energy difficulties by diversifying away from imported fossil fuel sources (Alessandro et al., 2010; Khan et al., 2021). Investing in renewable energy can expand the economy and provide jobs. The renewable energy industry employed around 11.5 million people worldwide in 2019, up 6% from the year before (IRENA, 2020). In addition, generating this clean energy is less expensive than extracting coal or natural gas, making it more accessible to the public.

Forth, previous studies have focused on understanding the problem of how economic growth degrades the environment but there has been little attempt to understand the moderation of energy efficiency and clean energy transition which is useful for the solution. Evidence linking energy efficiency and clean energy transition directly to EPI outcomes remains limited, so this relationship is best treated as a proposition for future empirical testing. Additionally, it gives policymakers a better understanding of how to create more effective policies by considering the moderators of energy efficiency and the transition to clean energy for emerging countries and individual regions.

Finally, the framework suggests that the growth-environment relationship may differ across income groups (upper-middle, lower-middle, and low-income economies), because countries differ in energy structure, institutional capacity, and stage of development. Much of the reviewed literature does not distinguish between income groups, so context-specific policy design is a valuable direction for future research. If future empirical work confirms these differences, policymakers could design policies tailored to the needs of each group rather than relying on a single general approach. This proposition remains to be tested.

Conclusion

This conceptual paper conceptualises the multidimensional impact of growth on the environment, thus providing more detailed insight into the growth-environment nexus. The goal of this paper is to conceptualise the impact of economic growth on environmental quality in a broader sense by taking into account the environmental performance index (EPI) and each of its individual components, such as Environmental Health (HLT), Ecosystem Vitality (ECO), and Climate Change Mitigation (PCC). To conceptualise environmental sustainability in developing countries, this paper discusses whether the growth-environment relationship is consistent with the Environmental Kuznets Curve (EKC). Furthermore, it breaks down the developing countries into sub-samples based on the World Bank's income classification UMIE, LMIE, and LIE.

This review paper makes conceptual contributions to the environmental economics literature. It discusses how economic expansion deteriorate environmental performance in all dimensions. It theorises energy efficiency and clean energy transition solutions as moderators to help reduce the negative effects of growth on the environment. This paper suggests the heterogeneous impact of growth on the environment among developing countries which is beneficial for policymakers to design context-specific policies suitable for regions of the developing world. The paper complements existing literature, much of which relies on single indicators such as CO₂ emissions, ecological footprint, or GHG emissions and on a single income category.

This paper has some limitations. First, as a narrative review, it does not claim exhaustive coverage. The literature was drawn mainly from Scopus and Google Scholar for 2019-2023, with foundational works added. Second, the propositions are theory-based and have not been empirically tested. Third, much of the reviewed evidence relies on indicators such as CO₂ emissions and ecological footprint rather than the Environmental Performance Index (EPI) and its components, which limits how directly it supports the propositions. Finally, the discussion of income-group differences draws on limited literature and remains a conceptual expectation.

This paper opens several productive avenues for future research through systematic reviews, meta-analyses, and empirical testing. Empirically testing the proposed framework, including at the level of disaggregated EPI indicators, would reveal whether the moderating effects of energy efficiency and clean energy transition operate through different environmental channels. Future studies should incorporate a broader set of variables spanning cultural dimensions, technological advancements, specific policy interventions, and socioeconomic considerations absent from the present framework.

The primary focus of this work is on developing countries, followed by an examination of the various income brackets and an attempt to determine how growth is affecting those income-specific groups. Furthermore, it gives policymakers the detailed insight they need to create policies that address the unique characteristics of those income groups rather than just a general policy. Because each country's growth has a unique impact on environmental performance, the universal approach is not practically viable. Understanding how growth affects those countries is crucial, and policies should be developed to address the issue.

Declarations

Ethical Approval and Consent to Participate

This declaration is not applicable

Consent for Publication

This declaration is not applicable

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References

- Abbasi, K. R., Shahbaz, M., Zhang, J., Irfan, M., & Alvarado, R. (2022). Analyze the environmental sustainability factors of China: The role of fossil fuel energy and renewable energy. *Renewable Energy*, 187, 390–402. <https://doi.org/10.1016/j.renene.2022.01.066>
- Adebayo, T. S., Kartal, M. T., Ağa, M., & Al-Faryan, M. A. S. (2023). Role of country risks and renewable energy consumption on environmental quality: Evidence from MINT countries. *Journal of Environmental Management*, 327. <https://doi.org/10.1016/j.jenvman.2022.116884>
- Adeel-Farooq, R. M., Raji, J. O., & Qamri, G. M. (2023). Does financial development influence the overall natural environment? An environmental performance index (EPI) based insight from the ASEAN countries. *Environment, Development and Sustainability*, 25(6), 5123–5139. <https://doi.org/10.1007/s10668-022-02258-x>
- Agozie, D. Q., Akwasi Gyamfi, B., Victor Bekun, F., Ozturk, I., & Taha, A. (2022). Environmental Kuznets Curve hypothesis from lens of economic complexity index for BRICS: Evidence from second generation panel analysis. *Sustainable Energy Technologies and Assessments*, 53. <https://doi.org/10.1016/j.seta.2022.102597>
- Ahmad, M., Muslija, A., & Satrovic, E. (2021). Does economic prosperity lead to environmental sustainability in developing economies? Environmental Kuznets curve theory. *Environmental Science and Pollution Research* (2021) 28:22588–22601. <https://doi.org/10.1007/s11356-020-12276-9/Published>
- Ahmed, Z., Caglar, A. E., & Murshed, M. (2022). A path towards environmental sustainability: The role of clean energy and democracy in ecological footprint of Pakistan. *Journal of Cleaner Production*, 358. <https://doi.org/10.1016/j.jclepro.2022.132007>
- Azam, A., Rafiq, M., Shafique, M., Zhang, H., & Yuan, J. (2021). Analyzing the effect of natural gas, nuclear energy and renewable energy on GDP and carbon emissions: A multi-variate panel data analysis. *Energy*, 219. <https://doi.org/10.1016/j.energy.2020.119592>
- Badunenko, O., Galeotti, M., & Hunt, L. C. (2023). Better to grow or better to improve? Measuring environmental efficiency in OECD countries with a stochastic environmental Kuznets frontier (SEKF). *Energy Economics*, 121. <https://doi.org/10.1016/j.eneco.2023.106644>
- Bakry, W., Mallik, G., Nghiem, X. H., Sinha, A., & Vo, X. V. (2023b). Is green finance really “green”? Examining the long-run relationship between green finance, renewable energy

- and environmental performance in developing countries. *Renewable Energy*, 208, 341–355. <https://doi.org/10.1016/j.renene.2023.03.020>
- Balcilar, M., Usman, O., & Ike, G. N. (2023). Operational behaviours of multinational corporations, renewable energy transition, and environmental sustainability in Africa: Does the level of natural resource rents matter? *Resources Policy*, 81. <https://doi.org/10.1016/j.resourpol.2023.103344>
- Bashir, M. F., Pan, Y., Shahbaz, M., & Ghosh, S. (2023a). How energy transition and environmental innovation ensure environmental sustainability? Contextual evidence from Top-10 manufacturing countries. *Renewable Energy*, 204, 697–709. <https://doi.org/10.1016/j.renene.2023.01.049>
- Bekun, F. V., Alola, A. A., & Sarkodie, S. A. (2019). Toward a sustainable environment: Nexus between CO₂ emissions, resource rent, renewable and nonrenewable energy in 16-EU countries. *Science of The Total Environment*, 657, 1023–1029. <https://doi.org/10.1016/j.scitotenv.2018.12.104>
- Chakravarty, D., & Mandal, S. K. (2020a). Is economic growth a cause or cure for environmental degradation? Empirical evidences from selected developing economies. *Environmental and Sustainability Indicators*, 7. <https://doi.org/10.1016/j.indic.2020.100045>
- Chen, W., Alharthi, M., Zhang, J., & Khan, I. (2023). The need for energy efficiency and economic prosperity in a sustainable environment. *Gondwana Research*. <https://doi.org/10.1016/j.gr.2023.03.025>
- Chien, F., Ajaz, T., Andlib, Z., Chau, K. Y., Ahmad, P., & Sharif, A. (2021a). The role of technology innovation, renewable energy and globalization in reducing environmental degradation in Pakistan: A step towards sustainable environment. *Renewable Energy*, 177, 308–317. <https://doi.org/10.1016/j.renene.2021.05.101>
- D'Alessandro, S., Luzzati, T., & Morroni, M. (2010). Energy transition towards economic and environmental sustainability: feasible paths and policy implications. *Journal of Cleaner Production*, 18(6), 532–539. <https://doi.org/10.1016/j.jclepro.2010.02.022>
- Danish, Ulucak, R., & Khan, S. U. D. (2020). Determinants of the ecological footprint: Role of renewable energy, natural resources, and urbanization. *Sustainable Cities and Society*, 54. <https://doi.org/10.1016/j.scs.2019.101996>
- Destek, M. A., & Sarkodie, S. A. (2019). Investigation of environmental Kuznets curve for ecological footprint: The role of energy and financial development. *Science of The Total Environment*, 650, 2483–2489. <https://doi.org/10.1016/J.SCITOTENV.2018.10.017>
- Destek, M. A., & Sinha, A. (2020). Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: Evidence from organisation for economic Co-operation and development countries. *Journal of Cleaner Production*, 242. <https://doi.org/10.1016/j.jclepro.2019.118537>
- Dingru, L., Ramzan, M., Irfan, M., Gülmez, Ö., Isik, H., Adebayo, T. S., & Husam, R. (2021). The Role of Renewable Energy Consumption Towards Carbon Neutrality in BRICS Nations: Does Globalization Matter? *Frontiers in Environmental Science*, 9. <https://doi.org/10.3389/fenvs.2021.796083>
- Djellouli, N., Abdelli, L., Elheddad, M., Ahmed, R., & Mahmood, H. (2022). The effects of non-renewable energy, renewable energy, economic growth, and foreign direct investment on the sustainability of African countries. *Renewable Energy*, 183, 676–686. <https://doi.org/10.1016/j.renene.2021.10.066>

- Dogan, E., & Inglesi-Lotz, R. (2020). The impact of economic structure to the environmental Kuznets curve (EKC) hypothesis: evidence from European countries. *Environmental Science and Pollution Research*, 27(11), 12717–12724. <https://doi.org/10.1007/s11356-020-07878-2>
- Ehigiamusoe, K. U., Lean, H. H., & Smyth, R. (2020). The moderating role of energy consumption in the carbon emissions-income nexus in middle-income countries. *Applied Energy*, 261. <https://doi.org/10.1016/j.apenergy.2019.114215>
- Eren, B. M., Taspinar, N., & Gokmenoglu, K. K. (2019). The impact of financial development and economic growth on renewable energy consumption: Empirical analysis of India. *Science of The Total Environment*, 663, 189–197. <https://doi.org/10.1016/J.SCITOTENV.2019.01.323>
- Fakher, H. A., Ahmed, Z., Acheampong, A. O., & Nathaniel, S. P. (2023). Renewable energy, non-renewable energy, and environmental quality nexus: An investigation of the N-shaped Environmental Kuznets Curve based on six environmental indicators. *Energy*, 263. <https://doi.org/10.1016/j.energy.2022.125660>
- Fatai Adedoyin, F., Agboola, P. O., Ozturk, I., Bekun, F. V., & Agboola, M. O. (2021). Environmental consequences of economic complexities in the EU amidst a booming tourism industry: Accounting for the role of brexit and other crisis events. *Journal of Cleaner Production*, 305. <https://doi.org/10.1016/j.jclepro.2021.127117>
- Fu, Q., Chen, Y. E., Jang, C. L., & Chang, C. P. (2020). The impact of international sanctions on environmental performance. *Science of the Total Environment*, 745. <https://doi.org/10.1016/j.scitotenv.2020.141007>
- Grossman, G. M., & Krueger, A. B. (1991). Environmental Impacts of a North American Free Trade Agreement. <https://doi.org/10.3386/W3914>
- Hamit-Haggar, M. (2012). Greenhouse gas emissions, energy consumption and economic growth: A panel cointegration analysis from Canadian industrial sector perspective. *Energy Economics*, 34(1), 358–364. <https://doi.org/https://doi.org/10.1016/j.eneco.2011.06.005>
- Hao, L. N., Umar, M., Khan, Z., & Ali, W. (2021). Green growth and low carbon emission in G7 countries: How critical the network of environmental taxes, renewable energy and human capital is? *Science of the Total Environment*, 752. <https://doi.org/10.1016/j.scitotenv.2020.141853>
- Hasanov, F. J., Khan, Z., Hussain, M., & Tufail, M. (2021). Theoretical Framework for the Carbon Emissions Effects of Technological Progress and Renewable Energy Consumption. *Sustainable Development*, 29(5), 810–822. <https://doi.org/10.1002/sd.2175>
- He, Y., Li, X., Huang, P., & Wang, J. (2022). Exploring the Road toward Environmental Sustainability: Natural Resources, Renewable Energy Consumption, Economic Growth, and Greenhouse Gas Emissions. *Sustainability (Switzerland)*, 14(3). <https://doi.org/10.3390/su14031579>
- Hussaini, I. U. (2018). Households' energy efficiency practices in a bereft power supply economy of Nigeria. In *Energy-Efficient Approaches in Industrial Applications*. IntechOpen.
- IEA. (2017). *World Energy Outlook*.
- IEA. (2018). *The Role of Energy Efficiency*, IEA, Paris.
- IEA. (2020). *World Energy Outlook 2020*. www.iea.org/weo
- IEA. (2022a). *Clean Energy Transitions Programme*, IEA Annual Report 2022.

- IEA. (2022b). The value of urgent action on energy efficiency.
- IEA. (2022c). World Energy Outlook 2022. www.iea.org/t&c/
- IPCC. (2021). IPCC — Intergovernmental Panel on Climate Change. <https://www.ipcc.ch/>
- IRENA. (2020). Renewable Energy and Jobs Annual Review 2020.
- Jahanger, A., Usman, M., Murshed, M., Mahmood, H., & Balsalobre-Lorente, D. (2022). The linkages between natural resources, human capital, globalization, economic growth, financial development, and ecological footprint: The moderating role of technological innovations. *Resources Policy*, 76. <https://doi.org/10.1016/j.resourpol.2022.102569>
- Jammazi, R., & Aloui, C. (2015). RETRACTED: On the interplay between energy consumption, economic growth and CO₂ emission nexus in the GCC countries: A comparative analysis through wavelet approaches. *Renewable and Sustainable Energy Reviews*, 51, 1737–1751. <https://doi.org/https://doi.org/10.1016/j.rser.2015.07.073>
- Karki, S. K., Mann, M. D., & Salehfar, H. (2005). Energy and environment in the ASEAN: challenges and opportunities. *Energy Policy*, 33(4), 499–509. <https://doi.org/https://doi.org/10.1016/j.enpol.2003.08.014>
- Khan, I., Hou, F., Zakari, A., & Tawiah, V. K. (2021). The dynamic links among energy transitions, energy consumption, and sustainable economic growth: A novel framework for IEA countries. *Energy*, 222, 119935. <https://doi.org/https://doi.org/10.1016/j.energy.2021.119935>
- Khan, M. T. I., Yaseen, M. R., & Ali, Q. (2017). Dynamic relationship between financial development, energy consumption, trade and greenhouse gas: Comparison of upper middle income countries from Asia, Europe, Africa and America. *Journal of Cleaner Production*, 161, 567–580. <https://doi.org/10.1016/J.JCLEPRO.2017.05.129>
- Kijima, M., Nishide, K., & Ohyama, A. (2010). Economic models for the environmental Kuznets curve: A survey. *Journal of Economic Dynamics and Control*, 34(7), 1187–1201. <https://ideas.repec.org/a/eee/dyncon/v34y2010i7p1187-1201.html>
- Kon, Y. Q., Chin, M. Y., & Ong, S. L. (2023). The Threshold Level of Economic Growth in BRI and Non-BRI Developing Countries for Better Environmental Quality. *Institutions and Economies*, 15(1), 1–25. <https://doi.org/10.22452/IJIE.vol15no1.1>
- Le, H. P., & Sarkodie, S. A. (2020). Dynamic linkage between renewable and conventional energy use, environmental quality and economic growth: Evidence from Emerging Market and Developing Economies. *Energy Reports*, 6, 965–973. <https://doi.org/10.1016/j.egyr.2020.04.020>
- Lee, B. X., Kjaerulf, F., Turner, S., Cohen, L., Donnelly, P. D., Muggah, R., Davis, R., Realini, A., Kieselbach, B., & MacGregor, L. S. (2016). Transforming our world: implementing the 2030 agenda through sustainable development goal indicators. *Journal of Public Health Policy*, 37, 13–31.
- Li, R., Wang, X., & Wang, Q. (2022). Does renewable energy reduce ecological footprint at the expense of economic growth? An empirical analysis of 120 countries. *Journal of Cleaner Production*, 346. <https://doi.org/10.1016/j.jclepro.2022.131207>
- Mohsin, M., Kamran, H. W., Atif Nawaz, M., Sajjad Hussain, M., & Dahri, A. S. (2021). Assessing the impact of transition from nonrenewable to renewable energy consumption on economic growth-environmental nexus from developing Asian economies. *Journal of Environmental Management*, 284. <https://doi.org/10.1016/j.jenvman.2021.111999>
- Mortezazadeh, F., Amiri-Hosseini, S., & Gholami-Borujeni, F. (2023). Comparison of EPI in the field of climate changes indexes in Iran and other countries in 2020 and the relationship

- between GDP and EPI. *Environmental Health Engineering and Management*, 10(1), 23–31. <https://doi.org/10.34172/EHEM.2023.03>
- Mujtaba, A., Jena, P. K., Bekun, F. V., & Sahu, P. K. (2022). Symmetric and asymmetric impact of economic growth, capital formation, renewable and non-renewable energy consumption on environment in OECD countries. *Renewable and Sustainable Energy Reviews*, 160. <https://doi.org/10.1016/j.rser.2022.112300>
- Panayotou Theodore. (1993). Empirical tests and policy analysis of environmental degradation at different stages of economic development. - International Labour Organization. https://ilo.primo.exlibrisgroup.com/discovery/fulldisplay/alma992927783402676/41ILO_INST:41ILO_V2
- Pata, U. K., & Samour, A. (2022). Do renewable and nuclear energy enhance environmental quality in France? A new EKC approach with the load capacity factor. *Progress in Nuclear Energy*, 149. <https://doi.org/10.1016/j.pnucene.2022.104249>
- Qing, L., Alwahed Dagestani, A., Shinwari, R., & Chun, D. (2023). Novel research methods to evaluate renewable energy and energy-related greenhouse gases: evidence from BRICS economies. *Economic Research-Ekonomska Istrazivanja*, 36(1), 960–976. <https://doi.org/10.1080/1331677X.2022.2080746>
- Rafindadi, A. A., & Usman, O. (2019). Globalization, energy use, and environmental degradation in South Africa: Startling empirical evidence from the Maki-cointegration test. *Journal of Environmental Management*, 244, 265–275. <https://doi.org/10.1016/j.jenvman.2019.05.048>
- Raihan, A., Muhtasim, D. A., Khan, M. N. A., Pavel, M. I., & Faruk, O. (2022). Nexus between carbon emissions, economic growth, renewable energy use, and technological innovation towards achieving environmental sustainability in Bangladesh. *Cleaner Energy Systems*, 3, 100032. <https://doi.org/10.1016/j.cles.2022.100032>
- Raihan, A., & Tuspekova, A. (2022a). Role of economic growth, renewable energy, and technological innovation to achieve environmental sustainability in Kazakhstan. *Current Research in Environmental Sustainability*, 4. <https://doi.org/10.1016/j.crsust.2022.100165>
- Raihan, A., & Tuspekova, A. (2022b). Toward a sustainable environment: Nexus between economic growth, renewable energy use, forested area, and carbon emissions in Malaysia. *Resources, Conservation and Recycling Advances*, 15. <https://doi.org/10.1016/j.rcradv.2022.200096>
- Raza, A., Sui, H., Jermisittiparsert, K., Zukiewicz-Sobczak, W., & Sobczak, P. (2021). Trade liberalization and environmental performance index: Mediation role of climate change performance and greenfield investment. *Sustainability (Switzerland)*, 13(17). <https://doi.org/10.3390/su13179734>
- Rjoub, H., Odugbesan, J. A., Adebayo, T. S., & Wong, W. K. (2021). Sustainability of the Moderating Role of Financial Development in the Determinants of Environmental Degradation: Evidence from Turkey. *Sustainability 2021*, Vol. 13, Page 1844, 13(4), 1844. <https://doi.org/10.3390/SU13041844>
- Sarkodie, S. A. (2021). Environmental performance, biocapacity, carbon & ecological footprint of nations: Drivers, trends and mitigation options. *Science of the Total Environment*, 751. <https://doi.org/10.1016/j.scitotenv.2020.141912>
- Sarkodie, S. A., & Strezov, V. (2019). Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing

- countries. *Science of the Total Environment*, 646, 862–871.
<https://doi.org/10.1016/j.scitotenv.2018.07.365>
- Shafik, N., & Bandyopadhyay, S. (1992). Economic growth and environmental quality : time series and cross-country evidence. Policy Research Working Paper Series.
<https://ideas.repec.org/p/wbk/wbrwps/904.html>
- Shahbaz, M., Solarin, S. A., Mahmood, H., & Arouri, M. (2013). Does financial development reduce CO₂ emissions in Malaysian economy? A time series analysis. *Economic Modelling*, 35, 145–152.
<https://doi.org/https://doi.org/10.1016/j.econmod.2013.06.037>
- Shahbaz, M., Zakaria, M., Shahzad, S. J. H., & Mahalik, M. K. (2018). The energy consumption and economic growth nexus in top ten energy-consuming countries: Fresh evidence from using the quantile-on-quantile approach. *Energy Economics*, 71, 282–301.
<https://doi.org/10.1016/J.ENERCO.2018.02.023>
- Sikder, M., Wang, C., Yao, X., Huai, X., Wu, L., KwameYeboah, F., Wood, J., Zhao, Y., & Dou, X. (2022). The integrated impact of GDP growth, industrialization, energy use, and urbanization on CO₂ emissions in developing countries: Evidence from the panel ARDL approach. *Science of the Total Environment*, 837.
<https://doi.org/10.1016/j.scitotenv.2022.155795>
- Stern, D. I. (2004). Diffusion of emissions abating technology.
- Sugiawan, Y., & Managi, S. (2016). The environmental Kuznets curve in Indonesia: Exploring the potential of renewable energy. *Energy Policy*, 98, 187–198.
<https://doi.org/https://doi.org/10.1016/j.enpol.2016.08.029>
- Szymczyk, K., Şahin, D., Bağcı, H., & Kaygın, C. Y. (2021). The effect of energy usage, economic growth, and financial development on co2 emission management: An analysis of oecd countries with a high environmental performance index. *Energies*, 14(15).
<https://doi.org/10.3390/en14154671>
- Uddin, M. M. M., Sharif, T., Islam, A. R. M., & Abedin, M. Z. (2024). Moderating impact of FDI on the growth-environment nexus in the pre-COVID-19 eras. *Research in International Business and Finance*, 67. <https://doi.org/10.1016/j.ribaf.2023.102114>
- Ulucak, Z. S., & Yucel, A. G. (2021). Can renewable energy be used as an effective tool in the decarbonization of the Mediterranean region: fresh evidence under cross-sectional dependence. *Environmental Science and Pollution Research*, 28(37), 52082–52092.
<https://doi.org/10.1007/s11356-021-14350-2>
- United Nations. (2020). The Sustainable Development Goals Report.
- United Nations. (2021). Stakeholders Thematic E-Consultation for the United Nations High-Level Dialogue on Energy Summary Report.
- United Nations. (2022). The Sustainable Development Goals Report.
- Usman, O., Alola, A. A., & Sarkodie, S. A. (2020). Assessment of the role of renewable energy consumption and trade policy on environmental degradation using innovation accounting: Evidence from the US. *Renewable Energy*, 150, 266–277.
<https://doi.org/10.1016/j.renene.2019.12.151>
- Wang, H., & Chen, Q. (2014). Impact of climate change heating and cooling energy use in buildings in the United States. *Energy and Buildings*, 82, 428–436.
<https://doi.org/10.1016/J.ENBUILD.2014.07.034>
- Wang, Q. J., Geng, Y., & Xia, X. Q. (2021). Revisited globalization’s impact on total environment: Evidence based on overall environmental performance index.

- International Journal of Environmental Research and Public Health, 18(21).
<https://doi.org/10.3390/ijerph182111419>
- Wang, Q., Yang, T., & Li, R. (2023). Does income inequality reshape the environmental Kuznets curve (EKC) hypothesis? A nonlinear panel data analysis. *Environmental Research*, 216.
<https://doi.org/10.1016/j.envres.2022.114575>
- Wang, R., Mirza, N., Vasbieva, D. G., Abbas, Q., & Xiong, D. (2020). The nexus of carbon emissions, financial development, renewable energy consumption, and technological innovation: What should be the priorities in light of COP 21 Agreements? *Journal of Environmental Management*, 271, 111027.
<https://doi.org/10.1016/J.JENVMAN.2020.111027>
- Wang, Z., Danish, Zhang, B., & Wang, B. (2018). The moderating role of corruption between economic growth and CO₂ emissions: Evidence from BRICS economies. *Energy*, 148, 506–513. <https://doi.org/10.1016/j.energy.2018.01.167>
- Wendling, Z. A., Jacob, M., Esty, D. C., & Emerson, J. W. (2022). Explaining environmental performance: Insights for progress on sustainability. *Environmental Development*, 44.
<https://doi.org/10.1016/j.envdev.2022.100741>
- World Bank. (2021). *Climate Change Action Plan*, World Bank Group.
- World Bank. (2022). *Helping Countries Adapt to a Changing World*.
- World Economic Forum. (2021). *World Economic Forum: Annual Report 2021-2022* | World Economic Forum. <https://www.weforum.org/publications/annual-report-2021-2022/>
- Xue, C., Shahbaz, M., Ahmed, Z., Ahmad, M., & Sinha, A. (2022). Clean energy consumption, economic growth, and environmental sustainability: What is the role of economic policy uncertainty? *Renewable Energy*, 184, 899–907.
<https://doi.org/10.1016/j.renene.2021.12.006>
- Yu, Z., Khan, S. A. R., Ponce, P., Lopes de Sousa Jabbour, A. B., & Chiappetta Jabbour, C. J. (2022). Factors affecting carbon emissions in emerging economies in the context of a green recovery: Implications for sustainable development goals. *Technological Forecasting and Social Change*, 176. <https://doi.org/10.1016/j.techfore.2021.121417>
- Zhu, H., Duan, L., Guo, Y., & Yu, K. (2016). The effects of FDI, economic growth and energy consumption on carbon emissions in ASEAN-5: Evidence from panel quantile regression. *Economic Modelling*, 58, 237–248.
<https://doi.org/https://doi.org/10.1016/j.econmod.2016.05.003>