Is economic growth sustainable in the long run? The answer might not be obvious

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Abstract

Natural resources provide ecosystem services to humans and society. Economic sectors use natural resources for economic benefits. Intense and uncontrolled economic activities and human intervention create adverse effects on the balance between all pillars of sustainability, namely the economy, environment, and society. In this context, researchers investigate potential causalities to provide inputs and insights into relevant decision-making processes and structure effective, applicable, and long-lasting plans and policies. These policies highlight the role of energy efficiency by accelerating the replacement of fossil fuels with renewables and minimizing greenhouse and carbon dioxide emissions. The Environmental Kuznets Curve (EKC) hypothesis and the energy growth nexus discussion offer research fields to determine whether growth creates environmental degradation or whether energy drives economic growth. Both approaches can be used under different methodological approaches using various indicators, groups of countries, and thematic fields. Research findings should accompany relevant practical implications for the business world and everyday life. These implications are expected to advance responsible consumptive behavior, the use of technological advancement, and a sustainability culture concerning households, organizations, and consumers. The key target is to bring a better future closer to our reality.

Keywords: environment, energy, economy, sustainability

1. Introduction

The natural environment accommodates all economic and human activities, whereas the good ecological status of natural resources should always be at the top of the agenda. Energy keeps the global economy running. Its fundamental role in achieving many of the Sustainable Development Goals (SDGs) as determined by the United Nations (UN) has been outlined in the literature under different methodological schemes, models, and theoretical backgrounds (e.g., energy poverty, climate action, responsible consumption and production, decent work and economic growth, sustainable cities and communities). The present paper constitutes a means of better understanding the interdependencies and interactions between natural and socioeconomic systems. In this framework, the authors of this discussion paper present their work on previously published articles to continue the discussion within academia on relevant subjects and gain feedback for further research and research collaboration on high-impact thematic fields.

In this effort, we present our work on published papers regarding how energy and environmental quality levels and improvements interrelate with economic growth and development in the context of the Environmental Kuznets Curve (ECK) hypothesis. Furthermore, to strengthen our approach, we refer to how dominant economic sectors in a nation's economy (e.g., tourism) affect relevant environmental performance. Moreover, the energy growth nexus discussion always has a pivotal role in detecting pathways toward sustainability.

It is well acknowledged that every economic sector uses natural resources to produce products and offer services to meet consumption and satisfy consumers. By nature, this supply and demand interaction constitutes a dynamic system that might differ in time and space as new trends and developments arise. Consequently, various determinants can be adopted and test their predictive power on energy and environment related variables. This approach mirrors the interdisciplinary nature and the relevant multifaceted scientific aspects between the economy and the natural environment. In this context, special attention is required regarding the received environmental benefits from ecosystem goods and services that nature provides us (e.g., supporting, regulating, provisioning and cultural services). It is fundamental to continuously test the quality status of these offered ecosystem goods and services and potential impacts from economic activities that extensively use natural resources (e.g., air, land, sea).

One of the most crucial issues our modern world faces is the CO_2 emission and reduction levels to achieve met zero economies and effectively confront global warming phenomena and greenhouse effects. Economies should become more inclusive and sustainable at the interface of economic pursuits, benefits, and goals to ensure viability and decent work positions in the long run. Economies should stress the importance of giving an anthropogenic character in the business process and highlight the dominant role of energy and a clean and safe environment when practicing business. This is highly important if the target is to experience sustainable development and viable economies with a long-term perspective.

These issues are extensively highlighted in academia by scientists of different fields, who align their expertise and adjust their research findings into applicable policies and energy and environmental management plans toward a more sustainable future.

2. Energy and economy: A dynamic relationship

No one would deny the significance of experiencing a safe and healthy environment in which the natural environment, the economy, and humans interact to make a system, the performance rates of which extensively impact the living status and viability (Halkos & Ekonomou, 2023; Ekonomou & Halkos, 2023; Halkos and Bousinakis, 2017). Vital to these efforts are the cause-and-effect relationships and how energy affects the course or process of growth, considering also the environmental quality. The scientific argument behind this approach is that causalities and impactful relationships between the environment, the energy sector, and the economy are dominant in literature debates with a view of planning and applying management plans focused on natural resources and environmental economics. For instance, in the last decades, considerable effort has been put into practice to effectively manage plans and efficiently treat resources (e.g., natural, human, financial, technical). These efforts emphasize the need to ease, lessen, adapt, and mitigate climate change impacts and restore natural damages and negative externalities from intense and frequently uncontrolled and unstructured economic activities worldwide. This approach needs more than ever multidisciplinary teams to see these aspects systematically and holistically and integrate research results into relevant decision-making processes.

The EKC specifies that environmental deterioration levels rise in the first phases of a nation's economic growth process (Halkos, 2003; Halkos, 2013). After a specific (turning) point in this growth process, environmental degradation levels decrease, meaning that the environment does not continue suffering from damages attributed to the economy (Halkos, 2003; Halkos, 2013).Graphically, this process is defined by an inverted U-shaped curve and implies that after this certain point, the economy is sustainable in environmental terms, and environmental quality improvements might be present. It should be noted that researchers have justified the N-shaped curve in literature (Balsalobre-Lorente et al., 2022; Numan et al., 2022). Interestingly, as claimed by Balsalobre-Lorente and Alvarez-Herranz (2016) as well as Alvarez-Herranz et al. (2017), the N-shaped curve practically implies that the environmental degradation levels will increase again after a specific point in the process of economic growth. Initially, the curve has a medium-run U-shaped curve. Then, this evidenced U-shaped curve acquires an N-shaped curve in the long run (Balsalobre-Lorente et al., 2022).

The Energy Growth Nexus discussion determines how economic growth interrelates to energy under four well-defined hypotheses. These hypotheses help to understand how energy conservation measures impact a nation's economic growth (Menegaki & Tugcu, 2017; Menegaki & Tugcu, 2018): (i) the Growth hypothesis, which implies that an increase (decrease) in energy consumption will increase (decrease) economic growth; (ii) the Conservation hypothesis which suggests the potential energy conservation measures will not restrict growth rates; (iii) the Feedback hypothesis that highlights complementarities betweenenergy and economic growth patterns; (iv) the Neutrality hypothesis which highlights the independence between energy consumption and economic growth.

Interestingly, the Growth hypothesis evidences a unidirectional causality relationship between energy consumption and energy-related variables. These economies seem to be energy-dependent to a considerable extent. The Conventional hypothesis also indicates a unidirectional hypothesis but with a different direction. This hypothesis indicates a causality running from economic growth to energy consumption, meaning that the economy of reference is less energy dependent, whereas economic growth might be attributed to other dynamics. The Feedback hypothesis is based on a bi-directional causality between the tested variables. This means that an increase (decrease) in energy consumption patterns will increase (decrease) economic growth rates and vice versa. In the Neutrality hypothesis, no causality relationship is identified. This means that economic growth is based on factors other than energy.

In this perspective, the authors' review paper, *Exploring the Impact of Economic Growth on the Environment: An Overview of Trends and Developments*, was put into the process to determine key issues in the relevant literature for the EKC hypothesis and the energy growth nexus discussion. This paper was structured based on an integrative review process. The authors used well-structured and accredited publications within the scientific community, namely papers and research studies that appeared in Scopus and Science Direct data basis. The root cause for this research derives from the necessity to detect unobserved or less visible or overlooked dynamics and parameters that affect environmental quality issues and energy demand. This attempt also justifies the need for a responsible character when exploiting the environment, considering future energy needs and linkages with the economic system.

In particular, a paper of the authors of the present paper titled *Can Business and Leisure Tourism Spending Lead to Lower Environmental Degradation Levels? Research on the Eurozone Economic Space* enriches the current literature. This paper considers how two major and discrete market segments in the tourism market affect environmental quality levels in the context of the tourism-induced EKC hypothesis. The authors adopt an untested set of tourism proxies in the relevant literature in this study. They use business andleisure tourism spending as growth variables to evidence the EKC hypothesis. Furthermore, the authors consider the predictive power of capital investment spending in the travel and tourism sector instead of the conventional tourism proxy of foreign direct investment. Last, the authors holistically examine the role of energy on environmental degradation, by including in the relevant econometric models the primary and final energy consumption. These issues should be more visible in the specific field of EKC. Hence, it is significant to examine the EKC hypothesis based on a wide-ranging tourism analysis that advances the sector’s productivity potential, considering green growth patterns within quality and sustainability (Adedoyin, 2022). Interestingly, given this core role of tourism, a research field appeared to investigate if tourism, widely known as the “smokeless industry,” leads to environmental degradation(Destek & Aydin, 2022). Having identified the fundamental role of tourism in the economic system globally, potential environmental pressures should be evidenced.

As is the case in many multivariate research efforts, differentiations in results and outcomes occur. Variations in results when testing the EKC or elaborating on the energy growth nexus discussion might be attributable to the methodological approaches used or the econometric models processed by researchers. For instance, researchers use time series or, panel analysis, or other regression models. Moreover, the growth variables used to evidence the research hypotheses are highly important, whereas the time range of the analysis, group of countries, and data availability differentiate the research findings.

Appendix A presents selected publications regarding the energy growth nexus discussion, whereas Appendix B presents selected studies concerning the EKC hypothesis (Ekonomou & Halkos, 2023a). Appendix C concerns the relationships among growth variables, renewables, and the environment focused on the case of China (Ekonomou & Menegaki, 2023). We refer to China, given its fundamental role in the global economic system and relevant transitions into low-carbon economies.

4. What the results indicate

Multiple indicators have been used to conceptualize economic growth and contextualize energy and environmental-related variables. Researchers have widely used the conventional Gross Domestic Product (GDP) as a growth variable, whereas energy is mostly proxied to primary and final consumption. In the case of the EKC hypothesis, environmental degradation proxies (e.g., pollutant indicators) widely consider carbon dioxide emissions and greenhouse gas releases directly related to air quality. For instance, researchers can use the Index of Sustainable Economic Welfare (ISEW)when searching for causalities between energy consumption and growth patterns.

Results in the bibliography indicate the need to test the predictive power of additional growth variables in the case of the EKC hypothesis and the energy growth nexus discussion. These additional growth variables can concern dominant and high-leverage sectors in a country's GDP. This approach can provide further inputs in structuring effective sectoral policies. In this way, policymakers can define which specific sectors are responsible for environmental degradation in the case of the EKC hypothesis or are energy-dependent in the case of the energy growth nexus discussion.

In this framework, if we take as an example the travel and tourism sector, four hypotheses should be examined (Tugcu, 2014): the Tourism-Led Growth Hypothesis (TLGH), the Economy Driven Tourism Growth hypothesis (EDTGH), the Feedback hypothesis, and the Neutrality hypothesis. First, the TLGH suggests a one-way causality running from tourism to economic growth. This relationship mirrors that ineffective tourism-focused plans or external shocks will restrict a country's economic perspective. Second, the EDTGH implies an evidenced unidirectional causality. The direction of this relationship is from economic growth to tourism. This causality means that such an economy is less tourism-dependent. Consequently, other economic sectors or forces generate growth for this economy. Third, the Feedback suggests that a two-way (bi-directional) causality is present. The direction of this reciprocal relationship runs from economic growth to tourism and vice versa. This relationship indicates that complementarities exist at the interface of tourism and economy. Last, the Neutrality hypothesis reveals no causalities between tourism and the economy. This type of relationship suggests that other driving forces and economic sectors create growth.

In the case of the EKC, as noted above, the T-EKC hypothesis has gained the researchers' interest. At this point, it should be noted that in their valuable research efforts, many researchers have used tourism arrivals or receipts to contextualize tourism development, expansion, or growth in relevant regression models. In this context, one interesting approach is to adopt specific market segments to test the EKC hypothesis or the tourism-led growth hypothesis. Specifically, business tourism spending and leisure tourism spending offer research opportunities to test how spending for these two popular, major, and profitable market segments affects environmental degradation levels or drives a country's growth. In this cases spending does not represent a purely numerical figure in shaping the tourism's GDP in a region or nation. On the contrary, it can be linked to a responsible consumptive character that promotes sustainability in destinations. It can be matched with eco-friendly practices to buy products or use services in tourist attractions and areas with increased visitation rates. Consequently, useful and exploitable conclusions can be obtained by relevant empirical research in these fields.

In Appendix C, empirical research for China is presented. This is vital because of the debate in literature for countries with ecological impact and noticeable economic presence at a global level. In the case of China, the country should speed up the integration of renewable sources in the energy mix. Hence, China should increase energy efficiency patterns in consumption behavior and achieve high investment rates with the help of research and development inputs. The key contribution of renewables in advancing eco-friendly economic processes is promoting social benefits and strengthening social values in the long run. From industry to households, renewables constitute a dependable way to lower green house and carbon dioxide emissions to live a better life.

5. Discussion and Conclusions

Intense economic activities and unregulated policies (e.g., poor energy and environmental management and extensive use of fossil fuels) enhanced by traditional management methods made natural ecosystems vulnerable to our modern world. Natural systems are in jeopardy due to unmanaged human interventions, ineffective sectoral policies, biodiversity loss, and resource overconsumption.

The concept of energy efficiency features largely when managing the environment. It constitutes a valuable and advantageous means of processing business practices regarding sustainability without losing much from business pursuits. Technological advancements and cutting-edge technologies always remain a dependable way to integrate responsible consumptive behavior. This is a key point in reducing the devastating air emissions and replacing fossil fuels with renewables and clean energy.

In this perspective, it has been observed that hesitations to change consumptive behavior, limited information, and lack of openness to new visions, developments, and trends control (e.g., restrict) investments or question potential gains from European-funded projects. This situation reflects the so-called 'energy efficiency gap' (between actual and optimal energy use) that appeared long ago (Jaffe & Stavins, 1994)or the 'energy paradox'.

Researchers should use indicators and proxies to capture social issues that need further elaboration. The content of sustainability is diverse and concerns many domains. As a result, it should be useful to increase social-related variables in econometric models that depict social cohesion, bonds, social infrastructure, and social justice. This approach can advance relevant research efforts by offering a complete picture of how society develops at the interface of the economy and the natural systems. For instance, the concept of Corporate Social Responsibility can offer insights that help adapt to sustainability challenges (Szczuka, 2015). The economic pillar of sustainability has gained much attention. However, the social dimension of sustainability should not be overlooked. This social dimension highlights the role of firms' impact on societal aspects such as social support, community relations, and charities (Kim, 2018).

Authors should disseminate the research results and how they can be translated into applicable plans and policies. Collective action is demanded from all key stakeholders worldwide. All sectors that form a nation's economy should adapt their business endeavor under environmentally friendly practices. Then, initiatives toward quality results and sustainability will appear. Also, high-leverage contributions to form integrated environmental and energy policies are needed. For instance, this approach can widely help to achieve equilibrium between supply and demand, production and consumption, exports and imports, energy type, source, and form used to practice business. These attempts should also be mutually agreed upon and consistent with goals set in the long run. SDGs show the way to follow if we wish to bring closer to our reality a sustainable future.

Notwithstanding the promising and well-justified character of such attempts, there are difficulties in managing natural resources and maintaining a good ecological status. Even with the long-term character of this endeavor, effective energy management still has challenges to confront. These challenges include limited economic resources, lack of financial support, funding, and business reluctance to proceed with ‘green’ investments potentially due to economic uncertainty.

Research attempts should emphasize the use of specific and measurable targets as well as relevant monitoring and controlling processes toward SDGs. Moreover, these goals are strong enough to remove difficulties, overcome problems, and avoid delays toward green growth patterns. In these attempts, the issue of environmental ethics and respect for all living (biotic) and non-living things (abiotic) environment is crucial, namely biodiversity and geodiversity. Biodiversity and geodiversity extensively provide valuable ecosystem services, namely the benefits that nature provides to humans and society.

In this effort, great attention is attached to empirical studies. Based on research outcomes and tests, such efforts add extra value to the whole endeavor regarding multiple stakeholders concerning natural and socioeconomic systems. The main target is to increase the use of renewables, and this issue deeply concerns the business world without putting aside the role of households. Notably, carbon dioxide emissions must be limited to zero releases by 2050.

The causalities and cointegrating relationships between the use of natural resources (quality and quantity), energy, and the economy still constitute an issue that attracts scientific interest and demands further research over the years. This existing situation offers new research opportunities to gain feedback and draw conclusions, match them with current reality, and make projections regarding future perspectives. Last but not least, if our culture and mindset toward these challenges fail to wisely use the natural environment and exploit the received ecosystem goods and services efficiently, then failures to meet SDGs will occur with questionable results on our well-being status.

Appendix A. Investigating Energy and Economy (Energy Growth Nexus Discussion) (Ekonomou & Halkos, 2023a).

Authors	Period	Country	Variables	Methodology	Causality
You & Ku (2009)	1995–2005	Six countries:Argentina, France, Germany, Korea, Pakistan, and Switzerland	GDP nuclear energy consumption	Grangercausality test	Switzerland: feedback hypothesis France and Pakistan: conventional hypothesis Korea: growth hypothesis Argentina and Germany: neutrality hypothesis
Apergis& Payne (2011)	1980–2006	Six Central American countries	GDP renewable energy consumption, real gross fixed capital formation, labor	FMOLS Engle–Granger two-step procedure	Feedback hypothesis for GDP and energy consumption (short and long run)
Ozcan& Ari (2015)	1980–2012	Fifteen OECD countries	GDP nuclear energy consumption, fixed capital formation, labor force	Bootstrap causality test developed by Hacker and Hatemi-J (2006) Toda Yamamoto (1995) causality test	Neutrality hypothesis 10 out of 15 OECD countries based on bootstrap-corrected causality test Neutrality hypothesis is supported for 8 OECD countries BASD ON Toda Yamamoto (1995)

					causality test
Fang& Chang (2016)	1970–2011	Sixteen Asian Pacific countries	GDP, energy consumption, physical capital, labor, human capita	Continuously updated fully modified estimation Bootstrap panel Granger causality test	Conventional hypothesis from GDP to energy use, Results vary for individual countries
Raza et al. (2016)	1980–2010	Four Asian countries	GDP, electricity consumption, labor, capital	Random effects modeling	Growth hypothesis from electricity consumption to economic growth
Saidi & Mbarek (2016)	1990–2013	Nine developed countries	GDP pc, nuclear energy consumption, CO_2 emissions, renewable energy, capital, labor	Panel causality test	Growth hypothesis for renewable energy consumption for all panels at the short run Neutrality hypothesis for nuclear energy and GDP pc
Menegaki & Tugcu (2017)	1995–2013	G7 countries	ISEW pc, BISEW pc, GDP pc, total energy consumption	Panel ARDL model PMG estimator	Feedback hypothesis for ISEW pc and energy Growth hypothesis from energy to the BISEW pc Conventional hypothesis

			pc, fixed capital formation, total labor force, research and development, expenditures per capita		from ISEW pc BISEW pc GDP pc energy consumption
Menegaki & Tugcu (2018)	1990–2015	Eighteen selected Asian countries	ISEW pc, BISEW pc, GDP pc, non-renewable energy consumption (NREN), renewable energy consumption (REN), trade, rents, financial development, inflation	Panel analysis Westerlund (2007) cointegration tests Dumitrescu and Hurlin (2012) Granger noncausality tests	Feedback hypothesis for ISEW pc Feedback hypothesis for BISEW pc Feedback hypothesis for GDP pc
Marques et al. (2020)	1965–2015	Global level	Real global GDP	VAR methodology	Feedback hypothesis
Nguyen& Ngoc (2020)	1980–1994 1995–2016 (structural break in 1995)	Vietnam	GDP pc, energy consumption, total global aggregate primary energy consumption	ARDL Toda and Yamamoto (1995) Granger causality test	Feedback hypothesis from GHDP to energy consumption

Khan et al. (2021)	1971–2014,	Malaysia	GDP pc, energy consumption pc, capital, labor, and urbanization	ARDL bound test Granger causality results	Mixed results in the short run and the long run.
Rahman et al. (2021)	1990–2017	BRICS and ASEAN countries	GDP pc, energy use pc, international trade pc and Foreign Direct Investment pc (FDI), capital stock pc, labor pc	Fixed effects panel quantile regression Granger noncausality test	Feedback hypothesis was confirmed
Fachrurrozi et al. (2022)	1984–2013	Eleven countries	GDP, energy consumption, index for globalization	Panel causality test based on Seemingly Unrelated Regressions (SUR) system	Feedback hypothesis for Egypt, Indonesia, Iran, South Korea, Nigeria, and Turkey
Simionescu (2023)	2002–2021	Ten nuclear energy-consuming countries from the European Union	GDP, nuclear energy consumption, renewable energy consumption,		Feedback hypothesis for nuclear energy Growth hypothesis for renewable energy

			gross fixed capital formation, labor		

Appendix B. Investigating the EKC Hypothesis (Ekonomou & Halkos, 2023a).

Authors	Period	Country	Variables	Methodology	EKC Hypothesis
Halkos (2003)	1960–1990	Seventy-three OECD and non-OECD countries	GDP pc, sulfur emissions	First-time random coefficients and Arellano–Bond Generalized Method of Moments (A–B GMM) econometric methods	EKC confirmed for A–B GMM EKC not confirmed for first-time random coefficients
Halkos (2013)	1950–2003	Ninety-sevenEuropean and non-European countries	GDP pc, sulfur emissions	Westerlund ECM panel cointegration tests Fixed effects with Driscoll–Kraay standard errors	EKC confirmed
Apergis et al (2017)	1960–2010	Forty-eight US States	Real personal income pc, CO_2 pc	Common Correlated Effects (CCE) estimation	EKC confirmed for 10 states
Halkos& Tzeremes (2009)	1980–2002	Seventeen OECD countries	GDP pc, constructed environmental efficiency ratio	Data envelopment (DEA) window analysis generalized method of moments (GMM)	EKC not confirmed
Olale et al. (2018)	1990–2014	Canadian	Greenhouse gas	Pooled regression fixed-	EKC confirmed at

		and provincial/territorial levels	emissions	effects regression	the Canadian level EKC confirmed for five out of ten provincial/territorial levels (under pooled regression) EKC confirmed for all provincial/territorial levels (under fixed-effects regression) EKC confirmed at the Canadian level, and in all provinces and territories
Sarkodie&Strezov (2018)	1971–2013	Australia, China, Ghana, and the USA	GDP, CO_2	PMG estimator	EKC confirmed (China)
Mesagan et al. (2019)	1992–2014	BRICS countries	GDP pc, CO_2 pc	Panel cointegration methods (DOLS)	EKC confirmed
Wang& He (2019)	1995–2013	Thirty Chinaprovinces	GDP, $CO_{2,}$	Spatial regression Cubic models	N-shape curve
Arnaut&Lidman (2021)	1970–2018	Greenland(Arctic region)	real GDP pc $CO_{2,}$ total electricity	Autoregressive distributed lag (ARDL)	EKC not confirmed

			production, urban population		
Józwik et al. (2021)	1995–2016	Central European countries	CO_2 pc, real GDP pc, energy use pc, trade openness,	Autoregressive distributed lag bound testing	EKC confirmed only in Poland
Ekonomou& Halkos (2023b)	1996–2019	Eurozone countries	GDP pc Direct contribution of tourism to GDP pc (dcgdppc), greenhouse gas emissions pc	Fixed effects with Driscoll– Kraay standard errors	EKC confirmed for GDP pc EKC confirmed for dcgdppc
Halkos & Ekonomou (2023)	1996–2019	Eurozone countries	Business tourism spending pc (btspc), leisure tourism spending (ltspc), greenhouse gas emissions pc	Fixed effects with Driscoll–Kraay standard errors	EKC confirmed for btspc EKC confirmed for ltspc
Voumik et al. (2023)	1982–2021	South Asian Association for Regional Cooperation (SAARC)	GDP, GHGs emissions, fossil fuels,	Second-generation unit root test, cointegration test, AMG technique	EKC not confirmed in SAARC countries

renewable energy,

nuclear energy

Appendix C. Research onRenewables, Growth, and the Environment in China(Ekonomou & Menegaki, 2023a).

Authors	Period	Country/Provinces	Variables	Methodology	Outcome
Wang et al. (2005)	1977–2005	China	Energy-induced CO_2 emission, total energy consumption carbon content of fuel	Logarithmic mean divisia index (LMDI) method	Renewable energy penetration also exhibits positive effect to the CO_2 decrease
Fang (2011)	1978–2008	China	Real GDP, GDP pc, per capita annual income of rural and urban households renewable energy consumption (REC), share of renewable energy consumption, number of employees, annual R&D expenditure per employee	Cobb–Douglas type production functions, multivariate OLS	Increases in REC increases: real GDP, GDP per capita, per capita annual income of rural households, per capita annual income of urban households
Yalta & Cakar (2012)	1971–2007	People's Republic of China	Real GDP, five different aggregated and disaggregated energy consumption measures	Meboot DGP based VAR estimation framework based on Yalta (2021)	Neutrality hypothesis confirmed in 53 out of 60 model estimations
Lin& Moubarak (2014)	1977–2011	China	GDP, renewable energy consumption, CO_2 emissions, labor	Johansen cointegration test, autoregressive distributed lag approach (ARDL), Granger causality test	Bi-directional long-term causality between renewable energy consumption and economic growth
Bloch et al. (2015)	1977–2013 (supply side) 1965–2011 (demand	China	Aggregate output coal, oil and renewable energy consumption, flow of services provided by the existing	Autoregressive distributed lag (ARDL) and vector error correction modeling (VECM)	Renewable energy consumption reduces emissions

	side)		capital stock, labor employed in production, level of technology, energy measure for combined coal, oil and renewable energy consumption		
Long et al. (2015)	1952–2012	China	real GDP, labor, capital stock, coal, oil and gas consumption, electricity generated by wind, hydro, and nuclear	Johansen cointegration test Granger causality test	Bi-directional causality confirmed for GDP and CO_2, coal, gas, and electricity consumption
Chen et al. (2018)	1996–2013	30 provinces in China	Per capita real GDP, CO_2 emissions, foreign trade, urbanization, renewable energy consumption	Dynamic system-GMM panel model	Explanatory variables impact renewable energy consumption
Dong et al. 2018)	1993–2016	China	Pc GDP, pc CO_2 emissions, pc fossil fuel consumption, pc nuclear energy consumption, pc renewable energy consumption	Series of econometric techniques allowing for structural break is utilized	EKC confirmed for CO_2 emissions, Renewable energy plays important roles in mitigating CO_2 emissions
Solarin et al. (2019)	1970–2014	China	Real GDP, hydroelectricity consumption, fossil fuels, capital stock, labor force	VECM Granger causality test	Feedback hypothesis confirmed between economic growth and hydroelectricity consumption
Fan& Hao (2020)	2000–2015	31 Chinese provinces	GDP pc, foreign direct investment pc, renewable energy consumption pc	VECM, impulse response function analysis, Granger causality test	Long-term and stable equilibrium relationship among GDP pc, foreign direct investment pc, and renewable energy

					consumption pc
Sarkodie et al. (2020)	1961–2016	China	GDP per capita/income level, human capital index, CO_2 emissions renewable energy consumption, fossil fuel energy consumption, ecological footprint, biocapacity	Neural network, SIMPLS, U test, dynamic ARDL simulations, Prais–Winsten transformed regression with robust standard errors	EKC hypothesis Confirmed
Wang et al. (2020)	2008–2014	29 Chinese provinces	Economic foundation, institutions, technological development potential, energy security and environmental protection, current status of the renewable energy sector	Dynamic principal component analysis technique	Large variations in RE development across provinces in China
Cheng& Yao (2021)	2000–2015	30 Chinese provinces	Carbon intensity, Renewable energy technology innovation		Renewable energy technology innovation does not affect carbon intensity in the short term; renewable energy technology innovation negatively and significantly affects carbon intensity in the long-term
Sun et al. (2021)	2012–2017	30 Chinese provinces	Wind power efficiency	Data envelopment analysis (DEA) method	Differences in the spatial distribution of wind power efficiency in China
Wang et al. (2021)	1997–2017 (national and regional levels)	China, 31 autonomous regions and municipalities	GDP, financial added value, renewable energy consumption (total electricity generation by renewable energy including hydropower, solar power, wind power, and nuclear power)	ARDL-PMG model, Granger causality test	Unidirectional causality from financial development to renewable energy consumption for China as a whole and eastern China, economic growth unidirectionally causes renewable energy consumption in China as a whole, and eastern and western China

He & Huang (2022)	1990–2020	China	Renewable energy consumption, annual percentage growth rate of GDP, gross capital formation, labor force, trade openness, R&D expenditures, foreign direct investment	Mediation model, Granger causality test	Bidirectional causality between renewable energy consumption and economic growth
Lian et al. (2022)	2011–2019	30 Chinese provinces	Dimensions of renewable energy (RE) development	AHP-EM integrated evaluation model	The comprehensive development level of RE in each province is relatively low, and the relatively high-level areas gradually move eastward in terms of spatial distribution
Shahbaz et al. (2022)	1971–2018	China	Real GDP, energy usage, fossil fuels, renewable energy, net enrollment in primary, secondary, and tertiary education, net energy imports, R&D expenditures	ARDL bounds testing approach	Feedback effect between economic growth, dirty energy usage, and clean energy usage
Ding & Liu (2023)	2008–2020	China	Renewable energy, green finance investment, GDP, renewable energy, public support policy	GMM model	Renewable energy and green economic growth (GDP) are critical determinants for sustainable development

References

Adedoyin, F.F. Tourism-induced Environmental Kuznets Curve. In Encyclopedia of Tourism Management and Marketing; Buhalis, D.,Ed.; Edward Elgar Publishing: Cheltenham, UK, **2022**.

Alvarez-Herranz, A., Balsalobre-Lorente, D., Shahbaz, M., Cantos, J.M. Energy innovation and renewable energy consumption in the correction of air pollution levels. Energy Policy **2017**, 386–397.

Apergis, N.; Payne, J.E. The renewable energy consumption–growth nexus in Central America. Appl. Energy. **2011**, 88, 343–347.

Apergis, N.; Christou, C.; Gupta, R. Are there Environmental Kuznets Curves for US state-level CO2 emissions? Renew. Sustain. Energy Rev. **2017**, 69, 551–558.

Arnaut, J.; Lidman, J. Environmental Sustainability and Economic Growth in Greenland: Testing the Environmental Kuznets Curve. Sustainability **2021**, 13, 1228.

Balsalobre-Lorente, D., Alvarez-Herranz, A., Economic growth and energy regulation in the environmental Kuznets curve. Environ. Sci. Pollut. Res. **2016**, 23, 16478–16494.

Balsalobre-Lorente, D.; Ibáñez-Luzón, L.; Usman, M.; Shahbaz, M. The environmental Kuznets curve, based on the economic complexity, and the pollution haven hypothesis in PIIGS countries. Renew. Energy **2022**, 185, 1441–1455.

Bloch, H.; Rafiq, S.; Salim, R. Economic growth with coal, oil and renewable energy consumption in China: Prospects for fuel substitution. Econ. Model. **2015**, 44, 104–115.

Chen, Y. Factors influencing renewable energy consumption in China: An empirical analysis based on provincial panel data. J. Clean. Prod. **2018**, 174, 605–615.

Cheng, Y.; Yao, X. Carbon intensity reduction assessment of renewable energy technology innovation in China: A panel data model with cross-section dependence and slope heterogeneity. Renew. Sustain. Energy Rev. **2021**, 135, 110157.

Destek, M.A.; Aydın, S. An empirical note on tourism and sustainable development nexus. Environ. Sci. Pollut. Res. **2022**, 29,34515–34527.

Ding, X.; Liu, X. Renewable energy development and transportation infrastructure matters for green economic growth? Empirical evidence from China. Econ. Anal. Policy **2023**, 79, 634–646.

Dong, K.; Sun, R.; Jiang, H.; Zeng, X. CO2 Emissions, Economic Growth, and the Environmental Kuznets Curve in China: What Roles Can Nuclear Energy and Renewable Energy Play? J. Clean. Prod. **2018**, 196, 51–63.

Ekonomou, G.; Halkos, G. Exploring the Impact of Economic Growth on the Environment: An Overview of Trends and Developments. Energies **2023a**, 16, 4497.

Ekonomou, G.; Halkos, G. Is tourism growth a power of environmental 'de -degradation'? An empirical analysis for Eurozone economic space. Econ. Anal. Policy **2023b**, 77, 1016–1029.

Fachrurrozi, K.; Masbar, R.; Seftarita, C. Energy-growth-globalization (EGG) nexus in N-11 countries. Heliyon **2022**, 8, e10522.

Fan, Y.; Hao, Y. An empirical research on the relationship amongst renewable energy consumption, economic growth and foreign direct investment in China. Renew. Energy **2020**, 146, 598–609.

Fang, Y. Economic welfare impacts from renewable energy consumption: The China experience. Renew. Sustain. Energy Rev. **2011**,15, 5120–5128.

Fang, Z.; Chang, Y. Energy, human capital and economic growth in Asia Pacific countries—Evidence from a panel cointegration and causality analysis. Energy Econ. **2016**, 56, 177–184.

Halkos, G.E. Environmental Kuznets Curve for sulfur: Evidence using GMM estimation and random coefficient panel data models. Environ. Dev. Econ. **2003**, 8, 581–601.

Halkos, G.E.; Tzeremes, N.G. Exploring the existence of Kuznets curve in countries' environmental efficiency using DEA window analysis. Ecol. Econ. **2009**, 68, 2168–2176.

Halkos, G. Exploring the economy–environment relationship in the case of sulfur emissions. J. Environ. Plan. Manag. **2013**, 56, 159–177.

Halkos, G.; Paizanos, E.A. Environmental Macroeconomics: Economic Growth, Fiscal Spending and Environmental Quality. Int. Rev. Environ. Resour. Econ. **2016**, 9, 321–362.

Halkos, G.; Bousinakis, D. The effect of stress and dissatisfaction on employees during crisis Economic Analysis and Policy **2017,** 55, 25-34

Halkos, G.; Ekonomou, G. Can Business and Leisure Tourism Spending Lead to Lower Environmental Degradation Levels? Research on the Eurozone Economic Space. Sustainability **2023**, 15, 6063.

He, Y.; Huang, P. Exploring the Forms of the Economic Effects of Renewable Energy Consumption: Evidence from China. Sustainability **2022**, 14, 8212.

Józwik, B.; Gavryshkiv, A.-V.; Kyophilavong, P.; Gruszecki, L.E. Revisiting the Environmental Kuznets Curve Hypothesis: A Case of Central Europe. Energies **2021**, 14, 3415.

Khan, H.N.; Alrasheedi, M.; Shahzada, G. A dynamic multivariate causality analysis of energy–growth nexus using ARDL approach: A Malaysian energy policy perspective. Front. Energy Res. **2021**, 9, 735729.

Kim, J. Social dimension of sustainability: From community to social capital. J. Glob. Sch. Mark. Sci. **2018**, 28, 175–181.

Lian, W.; Wang, B.; Gao, T.; Sun, X.; Zhang, Y.; Duan, H. Coordinated Development of Renewable Energy: Empirical Evidence from China. Sustainability **2022**, 14, 11122.

Lin, B.; Moubarak, M. Renewable energy consumption—Economic growth nexus for China Renew. Sustain. Energy Rev. **2014**, 40, 111–117.

Long, X.; Naminse, E.Y.; Du, J.; Zhuang, J. Nonrenewable energy, renewable energy, carbon dioxide emissions and economic growth in China from 1952 to 2012. Renew. Sustain. Energy Rev. **2015**, 52, 680–688.

Marques, L.M.; Fuinhas, J.A.; Marques, A.C. On the restricted form of energy-growth nexus: A global level VECM approach and the historical structural breaks. Int. J. Energy Sect. Manag. **2020**, 14, 1205–1220.

Menegaki, A.N.; Tugcu, C.A. Energy consumption and Sustainable Economic Welfare in G7 countries; A comparison with the conventional nexus. Renew. Sust. Energ. Rev. **2017**, 69, 892–901.

Menegaki, A.N.; Tugcu, C.A. Two versions of the Index of Sustainable Economic Welfare (ISEW) in the energy-growth nexus for selected Asian countries. Sustain. Prod. Consum. **2018**, 14, 21–35.

Mesagan, E.P.; Isola,W.A.; Ajide, K.B. The capital investment channel of environmental improvement: Evidence from BRICS. Environ. Dev. Sustain. **2019**, 21, 1561–1582.

Nguyen, H.M.; Ngoc, B.H. Energy Consumption—Economic Growth Nexus in Vietnam: An ARDL Approach with a Structural Break. J. Asian Financ. Econ. Bus. **2020**, 7, 101–110.

Numan, U.; Ma, B.; Saeed Meo, M.; Dino Bedru, H. Revisiting the N-shaped environmental kuznets curve for economic complexity and ecological footprint. J. Clean. Prod. **2022**, 365, 132642.

Olale, E.; Ochuodho, T.O.; Lantz, V.; El Armali, J. The environmental Kuznets curve model for greenhouse gas emissions in Canada. J. Clean. Prod. **2018**, 184, 859–868.

Ozcan, B.; Ari, A. Nuclear Energy Consumption-Economic Growth Nexus in OECD: A Bootstrap Causality Test. Procedia Econ. Financ. **2015**, 30, 586–597.

Rahman, M.M. The dynamic nexus of energy consumption, international trade and economic growth in BRICS and ASEAN countries: A panel causality test. Energy **2021**, 229, 120679.

Raza, S.A.; Jawaid, S.T.; Siddiqui, M.H. Electricity consumption and economic growth in South Asia. S. Asia Econ. J. **2016**, 17, 200–215.

Saidi, K.; Mbarek, M.B. Nuclear energy, renewable energy, CO2 emissions, and economic growth for nine developed countries: Evidence from panel Granger causality tests. Prog. Nucl. Energy **2016**, 88, 364–374.

Sarkodie, S.A.; Strezov, V. Empirical study of the environmental Kuznets curve and environmental sustainability curve hypothesis for Australia, China, Ghana and USA. J. Clean. Prod. **2018**, 201, 98–110.

Sarkodie, S.A.; Adams, S.; Owusu, P.A.; Leirvik, T.; Ozturk, I. Mitigating degradation and emissions in China: The role of environmental sustainability, human capital and renewable energy. Sci. Total Environ. **2020**, 719, 137530.

Shahbaz, M.; Song, M.; Ahmad, M.; Vinh Vo, X. Does economic growth stimulate energy consumption? The role of human capital and R&D expenditures in China. Energy Econ. **2022**, 105, 105662.

Simionescu, M. The renewable and nuclear energy-economic growth nexus in the context of quality of governance. Prog. Nucl. Energy **2023**, 157, 104590. [

Sun, X.; Lian, W.; Duan, H.; Wang, A. Factors affecting wind power efficiency: Evidence from provincial-level data in China. Sustainability **2021**, 13, 12759.

Szczuka, M. Social dimension of sustainability in CSR standards. 6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015. Procedia Manuf. **2015**, 3, 4800–4807.

Tugcu, C. T. Tourism and economic growth nexus revisited: A panel causality analysis for the case of the Mediterranean region. Tour. Manag.,2014, *42,* 207–212.

Voumik, L.C.; Hossain, M.I.; Rahman, M.H.; Sultana, R.; Dey, R.; Esquivias, M.A. Impact of Renewable and Non-Renewable Energy on EKC in SAARC Countries: Augmented Mean Group Approach. Energies **2023**, 16, 2789.

Wang, C.; Chen, J.; Zou, J. Decomposition of energy-related CO2 emission in China: 1957–2000. Energy **2005**, 30, 73–83.

Wang, Y.; He, X. Spatial economic dependency in the Environmental Kuznets Curve of carbon dioxide: The case of China. J. Clean. Prod. **2019**, 218, 498–510.

Wang, Y.; Zhang, D.; Ji, Q.; Shi, X. Regional renewable energy development in China: A multidimensional assessment. Renew. Sustain. Energy Rev. **2020**, 124, 109797.

Wang, J.; Zhang, S.; Zhang, Q. The relationship of renewable energy consumption to financial development and economic growth in China. Renew. Energy **2021**, 170, 897–904.

Yalta, A.T.; Cakar, H. Energy consumption and economic growth in China: A reconciliation. Energy Policy **2012**, 41, 666–675.

Yoo, S.H.; Ku, S.J. Causal relationship between nuclear energy consumption and economic growth: A multi-country analysis. Energy Policy **2009**, 37, 1905–1913.